

Towards a better understanding of information on the risk of extreme weather and climate change to Australia's threatened terrestrial and freshwater species

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We acknowledge the Traditional Owners of Country throughout Australia and their continuing connection to and stewardship of land, sea and community. We pay our respects to them and their cultures and to their Ancestors, Elders and future leaders. Our Indigenous research partnerships are a valued and respected component of National Environmental Science Program research.

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1. Executive summary

- There are currently more than 2100 species and ecological communities listed as threatened and >150 species listed as migratory (some of which are also listed as threatened) that are Matters of National Environmental Significance (MNES) under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act).
- The 2024 State of the Climate Report (State of Climate 2024) summarises the latest results on national and international climate research, monitoring, science and projections to describe changes and long-term trends in Australia's climate. The Department of Climate Change, Energy, the Environment and Water (DCCEEW) acknowledges the anticipated impact of climate change on natural systems in its recently released Australian National Climate Risk Assessment (Australian Climate Service 2025). Risks, including the risk of ecosystem transformation or collapse, are anticipated to be very high to severe by 2050. In the subsequent release of the National Adaptation Plan (Commonwealth of Australia 2025), existing and newly announced frameworks, policies and programs are presented that collectively aim to strengthen Australia's adaptation capacity and manage future disaster risk. The Adaptation Plan references targets and measures enshrined within 112 national policy instruments, including the flagship Threatened Species Action Plan (DCCEEW 2022) and Australia's Strategy for Nature (DCCEEW 2025a). These documents have informed this report.
- Nonetheless, this report finds that additional guidance is needed for non-specialists including: (1) DCCEEW officers, to inform the preparation of advice in conservation planning documents on the impacts of climate change on threatened terrestrial and freshwater species and ecological communities; and (2) proponents, assessors and decision makers on how to avoid, mitigate and adapt to the impacts of extreme weather and climate on protected species and ecological communities in development proposals.
- This report summarises the results from two expert workshops conducted in 2024 to guide DCCEEW on how to interpret and translate existing and emerging information on climate change and extreme weather events on threatened terrestrial and freshwater species.
- Topic experts provided advice and information (including URLs and relevant literature) on the databases available for:
 - climate projections and modelling
 - biological taxa (plants, invertebrates, vertebrates), and
 - adaptation options

The experts also advised on the accessibility of these materials for non-specialists.

- For each of these topics, the major gaps relevant to biodiversity conservation and adaptation planning were identified.
- DCCEEW's needs, including the products that might be of assistance in addressing those needs, were identified as outlined in this report, as well as outstanding issues and opportunities to support DCCEEW through future collaborations or partnerships.
- The number of relevant databases featuring climate information is increasing and existing databases are updated frequently. Users should check the key resources cited in this report and refer to the dedicated [Adapt Land&Sea knowledge platform](#) that is specifically designed for biodiversity managers involved in climate adaptation planning. In addition, the NESP [Climate Systems Hub platform](#) features explainers and webinars that outline the differences

between climate data products and related emissions scenarios, as well as providing applied examples of use for conservation outcomes.

- Many adaptation actions are logged in a dedicated site developed by the NESP Climate Systems Hub, which represents a searchable platform for Australia's first user-generated national adaptation stocktake known as [Australian Adaptation Database](#). The data collection component of the stocktake concludes in December 2025.
- A technical report investigating the current and future impacts of climate change on Australia's [Terrestrial Natural Ecosystems](#) was published by the Australian Climate Services in 2025. The report uses three approaches to present and rank climate risk. The approaches incorporate the latest biodiversity modelling techniques to provide a quantitative assessment of ecosystem resilience by ecosystem group and regions. Results inform the basis of the second-pass risk assessment and subsequent DCCEEW policy making.
- DCCEEW has recently released a consultation document (DCCEEW 2025b) for proponents and agency staff selecting climate scenarios, pathways and timeframes, which features decision trees and checklists for consideration. When finalised, DCCEEW staff should refer to this document for decision support in the first instance when undertaking a risk assessment.
- This report does not include advice from Indigenous experts. This gap should ideally be addressed as part of DCCEEW's program of Indigenous engagement.

2. Introduction and rationale

There are currently more than 2100 species and ecological communities listed as threatened and >150 species listed as migratory (some of which are also listed as threatened) that are Matters of National Environmental Significance (MNES) under the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act). Information on the impacts of climate change on these nationally protected species and ecological communities will be crucial to ensure their conservation into the future, as the adverse impacts of climate change and extreme weather events on biodiversity accelerate and increase the risk of extinction. The Australian Government has a role in the protection of these species through the development of conservation advices and recovery plans for species listed as threatened; wildlife conservation plans for species listed as migratory; threat abatement plans and advices; and the assessment of the environmental impact of projects.

The number of references to climate adaptation targets and progress measures is increasing in DCCEEW plans and policies, specifically to address climate risk to natural systems, water scarcity and Aboriginal and Torres Strait Islander people. For example, Target 7 of the Threatened Species Action Plan (2022-32) (DCCEEW 2022) states that ‘the impacts of climate change on priority species and places are identified and the following actions are being implemented to strengthen resilience and adaptive capacity.’ The following actions support Target 7:

- Support relevant research to improve understanding of how climate change will impact priority species and places and how it may alter risk from other threats (2022–2027).
- For susceptible species, update conservation plans to include adaptation measures to actively mitigate climate change risk (2022–2027).
- Identify and undertake management activities to build resilience and/or improve adaptive capacity of priority species and places vulnerable to climate change (2022–2027).

In Australia’s Strategy for Nature 2024–2039 (DCCEEW 2025), Targets 5, 7 and 10 reference climate progress targets for DCCEEW, relating to:

- 5D [The] Number of protected areas that include explicit consideration of future climate scenarios and adaptation responses in their planning and management
- 7 (F, G) [To] Minimise the impact of climate change on biodiversity
- 10B [The] Extent to which the likely impacts of climate change on terrestrial, aquatic and marine ecosystems and species are understood, and effective methods to promote adaptation and resilience are implemented.

The 2025 National Adaptation Plan (Commonwealth of Australia 2025) points to existing and newly released provisions for projects currently working with Traditional Custodians. The provisions support the development of a culturally relevant framework for climate adaptation and resilient landscapes (NESP 2024). They support Indigenous ranger and river programs; and expand Indigenous Land and Sea Corporations Savannah Management Programs to implement fire management practices to protect Country and cultural heritage while reducing global greenhouse gases. Further provisions are made for new Indigenous Protected Areas and safe havens for threatened species, including the Saving Koalas Fund, Saving Native Species Program and Ramsar Wetland Climate Change Vulnerability Assessment and Adaptation Planning project. Reference is also made to improving on-ground monitoring systems such as the [Ecological Monitoring System Australia](#) (EMSA), aimed at managing and storing monitoring data. A \$250 million investment for Saving Australia’s

Bushland Program will be made over the next 5 years to support conservation and contribute to the national target to protect and conserve 30% of Australia's landmass by 2030.

While these plans acknowledge the challenge of adaptation planning and monitoring, the selection and implementation of adaptation measures are often not prescribed and are therefore left to the discretion of biodiversity and conservation managers. Better guidance is needed for proponents, assessors and decision makers working on or assessing development proposals to determine how to avoid, mitigate and adapt to the impacts of extreme weather and climate on protected species and ecological communities. A report commissioned by the Australian Conservation Foundation and prepared by the Australian National University's GreenLaw project argued that there is a significant 'climate gap' in the management of Australia's threatened species (Reynolds et al. 2021). Their analysis concluded that when climate change was mentioned in relevant statutory planning documents, the information 'tended to be brief and generalised' and the recommended actions to mitigate the threat inadequate (Reynolds et al. 2021).

In workshops associated with the NESP Resilient Landscape Hub project *1.7 Cross-cutting initiative research: threatened and migratory species and threatened ecological communities* (Marsh and Carwardine 2023), Department of Climate Change, Energy, the Environment and Water (DCCEEW) environment assessment officers confirmed this problem and identified their need for information on:

- likely range shifts attributable to climate change
- parts of the range of protected species and ecological communities likely to be lost due to climate change
- populations and habitats likely to be particularly important for species and ecological communities in the face of climate change
- future core habitats and likely climate refugia
- possible climate mitigation and adaptation measures.

Guidance is also required to support the preparation of conservation planning documents, especially recovery plans and conservation advice. This would enable these documents to explain how the direct impacts of all dimensions of climate change and extreme weather events on terrestrial, aquatic and marine protected species and ecological communities should be addressed in development proposals, including options for avoidance, mitigation and adaptation. Guidance should extend to how to consider the interaction of climate change and extreme weather events with other threats.

2.1 Approach

The overall objectives of the workshops on which this report is based were to identify the status and sources of information required to inform the preparation of advice in (1) conservation planning documents on the impacts of climate change on threatened terrestrial and freshwater species and ecological communities, and (2) the development and approvals process.

The first workshop, held online on 11 April 2024, was to ensure participants had a common understanding of DCCEEW's needs and the research undertaken to date on the challenges of forecasting climate impacts on plants and animals (see Agenda at section 13.1.1).

A second workshop (see Agenda at section 13.1.2) was held face-to-face at CSIRO Black Mountain, Canberra on 6 September 2024. The objective of the second workshop was to provide the foundations for guidance to DCCEEW on how to interpret and translate existing and emerging information on climate change and extreme weather events on threatened terrestrial and

freshwater species, using the exposure-sensitivity-adaptative capacity framework¹, by eliciting and discussing:

- 1) the information available in a format accessible to proponents and relevant DCCEEW officers, who are unlikely to be climate change specialists
- 2) how these officers can evaluate the quality and relevance of the information available to them
- 3) whether additional, accessible information is required for species of frequent regulatory scrutiny.

These questions were individually addressed by topic experts to consider in the context of:

- climate projections and modelling (section 4)
- biological taxa (plants, invertebrates, vertebrates) (sections 5-7)
- adaptation options (section 8).

The workshop was introduced with a presentation from DCCEEW outlining the context of decision-making and the need for information sources to support better understanding of climate change impacts and management responses (section 3). The report was updated to reflect recent policy changes (i.e. Climate Adaptation Plan) and the release of Coupled Model Intercomparison Project Phase 6 (CMIP6) climate information (via the Australian National Climate Risk Assessment (Australian Climate Service 2025a) and DCCEEW's [Australian Climate Service information web portal](#) and data explorer.

This report does not include advice from Indigenous experts. This gap should ideally be addressed as part of DCCEEW's program of Indigenous engagement.

¹ Exposure is the degree to which a listed entity could be affected by climate change and/or extreme weather; sensitivity is the degree to which the entity could be harmed by that exposure; and adaptive capacity is the degree to which the entity can reduce the potential for harm e.g. behavioural changes.

3. DCCEEW's role and relevant needs

3.1 Biodiversity Division (Protected Species and Communities Branch and Office of the Threatened Species Commissioner)

The Threatened Species Commissioner raises community awareness and support for threatened species. The Commissioner's responsibilities include leading the implementation of the Threatened Species Action Plan 2022-2032 (DCCEEW 2022) and biodiversity threat abatement.

The Protected Species and Communities Branch of the Biodiversity Division of DCCEEW is responsible for the preparation of conservation planning documents for threatened species and ecological communities. The content of these documents has changed over time, but the current intent is to include:

The content of these documents has changed over time, but the intent as of 2025 is to include:

- 1) a description of the listed entity, its biological and ecological characteristics and requirements, including its habitat
- 2) a threat statement, identifying the relevant threats and key threatening processes impacting the listed species or ecological community
- 3) a listing rationale, outlining its eligibility for inclusion on the relevant list
- 4) a conservation objective, outlining what needs to be achieved to protect or recover the listed species or ecological community to allow it to be removed from the list
- 5) a list of conservation and recovery actions, providing (as appropriate) guidance to:
 - i. support regulatory decision making, such as identification or description of habitat critical to the survival of the species and important populations
 - ii. the priority proactive activities needed to recover the listed species or ecological community
 - iii. requirements for additional information including survey and monitoring priorities and other information and research priorities.

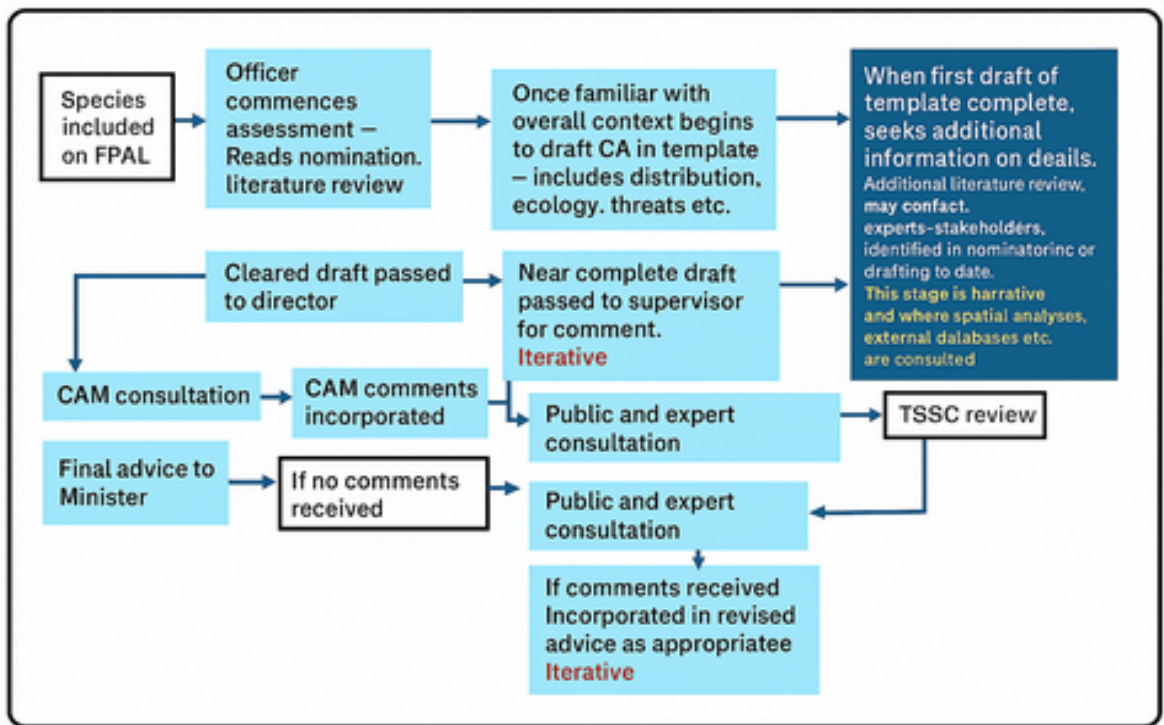


Figure 1: Diagrammatic representation of the process used within DCCEEW to draft a conservation planning document, usually a conservation advice (CA). The stage where information on the risks from climate and extreme weather would be considered is coloured very dark blue. CAM = common assessment Method; TSSC = Threatened Species Scientific Committee.

Having sufficient data to list a species or ecological community does not necessarily mean that the available information is sufficient to design appropriate protections or conservation actions. Most species will not have been the subject of explicit research on climate change vulnerability and their risk tolerance to climate change and its interactions with other threats may not be known. Additionally, spatial information about current climatically suitable habitat is often of very coarse resolution or unavailable and this is compounded by the uncertainty inherent in modelled projections of future climates.

A final consideration in the development of guidance for incorporating climate change in threatened species conservation planning is that both the officers drafting the documents and the end users of those documents (e.g. see section 3.2 below) are not usually an expert on either the individual species or climate change.

To facilitate climate considerations in planning documents in a manner that is consistent, defensible and useful, there is a need to identify:

- which climate information to use and when

4. Climate projections datasets

The information in this section was provided by John Clarke, Research Group Leader Regional Climate Intelligence, CSIRO and Sharna Nolan, Knowledge Broker Manager for NESP's Resilience Landscape Hub.

For biodiversity managers, choosing the right climate data for their needs can be complicated and confusing. Part of this difficulty is owing to the abundance of data sources available. This is further complicated by the need for the climate data to be matched to the needs of each use case, in terms of scale, type, and format. This means biodiversity managers (and users from other sectors) often need guidance from climate projections experts. In the sections below, brief details are provided for a range of relevant key data sources. However, there are other guides to climate data suitable for biodiversity managers that should also be consulted. For example:

- The NESP Adapt Land&Sea phase 1 – co-designed with biodiversity managers – was launched in 2025 and describes a range of key climate projections data sources. Phase 2 is scheduled to be launched in 2026.
- The NESP Climate Systems Hub's 2024 publication on Navigating Climate Portals provides guidance on the applicability of different sources.

It is important to note that new data products are being developed all the time.

4.1 Relevant information about climate projections to 2050 and beyond

There is an abundance of information and data on our future climate outlook – so much so that many potential users do not know where to start. A wide range of projections' information is available at various scales, from global to national and state. Most of these projections provide information and data that describe future climate for variables such as temperature and rainfall, either as change compared with a past time or, less commonly, absolute future values. An increasing number of sites provide derived data (or indices) such as days above/below temperature or rainfall thresholds, heatwaves, etc. Several sites now provide data tailored to ecological applications, such as BIOCLIM metrics. It is important to read the technical guidance that accompanies climate information, given that few sites provide projections' information and data derived from a full assessment of the relevant multiple lines of evidence (such as past trends, consistency with physical processes and observations, bias correction, multivariate evaluation of model results). This is important to ensure the data capture the full extent of change that has been assessed as plausible (DCCEE 2023).

Climate projections, visualisations and datasets

[Future climate data and information](#) can be classified into four broad groupings:

- 1) general descriptions
- 2) climatological change values
- 3) simulated weather-like datasets
- 4) value-added (or derived) indices and data (Adapt Land&Sea 2025).

These vary in complexity and may be available as descriptions, tables of data, spatial maps or data files in a range of formats. Selecting which type of data is most appropriate for a particular purpose can be difficult and expert advice may be useful. However, the following guidance may be helpful:

- Good climate projections will describe the full range of change that is considered scientifically feasible.
- Choose the least complex dataset that will provide the information needed.
- Climate projections are not predictions; rather they describe plausible futures.
- There is no such thing as the ‘best’ climate model; all models have strengths and weaknesses.
- For detailed assessments of future climate impacts, it will usually be best to use data from a curated subset of models that describe relevant ‘climate futures’.

Australian Climate Service interim platform

The Australian Climate Service (ACS) interim [Data Explorer platform](#) is an interactive online tool which presents and visualises a range of the datasets and indicators developed by the Australian Climate Service (ACS), a partnership between the Bureau of Meteorology (BOM), CSIRO, the Australian Bureau of Statistics (ABS) and Geoscience Australia (GA). A wide range of datasets has been developed, including bias-corrected ‘weather-like’ datasets for multiple variables. These data are derived from the sixth phase of the international Climate Model Intercomparison Project (CMIP6). This is the modelling upon which the Intergovernmental Panel on Climate Change (IPCC)’s Sixth Assessment Reports were based (IPCC 2021).

ACS datasets were developed from a suite of downscaling models in conjunction with global modelling results. Unlike the other data sources described here, the ACS data describe the future Australian climate under four ‘global warming levels’ (GWL).

A global warming level of 1.2 °C above pre-industrial is defined as the ‘current climate’. This recognises that the Earth has warmed significantly due to human burning of fossil fuels. Importantly, these datasets underpin the National Climate Risk Assessment so are useful for applications that require consistency with the NCRA or that need to be comparable across regions more generally. Not all datasets are available via the platform but may be obtained by contacting the ACS.

What is a ‘global warming level’?

Global warming level (GWL) describes the situation where the long-term (e.g. 10-year) average temperature of the planet reaches a specific temperature threshold compared with the climate of the pre-industrial era. The term came into widespread use following the Paris Agreement of 2015 where 195 parties (194 states and the EU) agreed to try to limit global warming to well below 2.0 °C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels. In principle, any GWL threshold can be used, but common ones include 1.5, 2.0 and 3.0 °C above the pre-industrial level.

Because different regions of the Earth warm at different rates, the response of other climate variables – such as rainfall, evaporation, coastal sea level – will also vary from region to region for a given GWL.

Climate Change in Australia

The [Climate Change in Australia website](#), developed by CSIRO and the Bureau of Meteorology in 2015 (CSIRO and BoM 2015), provides comprehensive information, data and guidance material derived from a thorough assessment of multiple lines of evidence. The information is primarily based on data from the Fifth Phase of the Coupled Model Intercomparison Project (CMIP5; the modelling upon which the Fifth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) were based; IPCC 2013). Additional data and information have been added over time, including some data

derived from the more recent CMIP6 (see IPCC 2021) collection of modelling (including high resolution modelling). Content of most relevance to terrestrial and freshwater ecological applications includes:

- Climate Analogues tool that provides a ‘space-for-time analogue’ approach that allows users to find an existing location within Australia that currently experiences the expected future climate of their area of interest. This is valuable as a first step in assessing climate change impacts and for communicating with stakeholders.
- Thresholds Calculator that provides information on the expected future number of days/months per year/season when various temperature and rainfall values fall above or below thresholds of interest, e.g. average number of days per year above 35 °C or average number of very dry months per year.
- Time series datasets of daily temperature, rainfall, evapotranspiration, relative humidity and solar radiation. These data are for expert users and are provided at 5 km resolution for the whole of Australia.
- Mean changes in average temperatures, rainfall, evapotranspiration, relative humidity and solar radiation for regions. (Regions are based on aggregations of Natural Resource Management (NRM) Regions.)
- High resolution (4 km) projections for Victoria based on bespoke modelling and drawing on multiple lines of evidence.

State-based projection data sources

Modelling teams in New South Wales, Queensland and Western Australia have produced dynamically downscaled, high resolution projection datasets complete with regional summaries for their respective states. These are designed to support state level policies and should be referred to alongside national projections datasets.

The extent to which these datasets are corrected for bias, draw on multiple lines of evidence, and represent a range of projected change can vary and are discussed in the technical notes that accompany each product.

- New South Wales:
 - [Interactive climate change projection maps](#)
 - AdaptNSW [Climate Data Portal](#)
- Queensland:
 - [Queensland Future Climate Dashboard](#)
- South Australia:
 - [South Australian climate projections viewer](#)
- Western Australia:
 - [Climate projections for Western Australia](#)
- Tasmania:
 - [Climate Futures for Tasmania](#)
- Victoria:
 - [Victoria’s changing climate](#)
 - [Victoria’s Future Climate Tool](#)

Hydrological projections

CSIRO and the Bureau of Meteorology have each developed a range of projections that are relevant to freshwater ecosystems. Each uses a different modelling method and, ideally, both sets of information should be considered together.

- CSIRO hydrological projections: available from the researchers (via CSIRO Enquiries)
- Bureau of Meteorology [Australian Water Outlook](#)

Coastal projections

Projections for coastal areas can be important for assessing the impacts of climate change on estuarine environments and their biota. Most of these projections are linked and so should provide similar information.

The [CoastAdapt portal](#) provides sea level rise projections and inundation maps for all local governments. CoastAdapt also provides comprehensive guidance for adaptation practitioners. In addition, CSIRO has produced an [updated regional sea-level projection dataset](#) based on AR6 and CMIP6, after some necessary corrections. CSIRO has also produced a [report describing the dataset](#). NESP CS2.10 produced factsheets to explain rising sea levels including:

- [What's driving sea-level rise?](#)
- [Understanding future sea-level rise](#)

The [Canute sea level calculator](#) provides estimates of the likelihood of extreme sea levels. Canute takes into account sea-level rise and the effects of tides, storm surges and ocean waves, also known as 'wave setup'.

The National Partnership for Climate Projections

The [National Partnership for Climate Projections](#) came out of the Climate Projections Roadmap for Australia (DCCEE 2023) and promotes cross-jurisdictional collaboration and coordination. It is likely that this will result in more standardised projections, coordinated advice for scenario selection and further improvement in the decision-readiness of projection products in the longer term.

4.2 Major gaps relevant to biodiversity

The complexity of the climate system, compounded by the complex nature of climate modelling and analysis, results in many information gaps. Key gaps of relevance to biodiversity impacts include:

- 1) Tipping points: These refer to major changes in the climate system that are irreversible, at least in the medium term, e.g. the collapse of the West Antarctic Ice Sheet or the cessation of the East Australia Current. Climate models do not currently account for (or predict) tipping points. There are large uncertainties regarding when such events may happen (CSIRO 2024).
- 2) Quantification of extreme events: Although the expected future direction of change (increase or decrease) is often well understood, quantification of many extreme events remains difficult.
- 3) Compound and coincident events: There is considerable interest in extreme weather/climate events occurring in sequence (such as the Black Summer of 2019–20, drought, heatwave and bushfires) or in combination (such as a storm surge occurring at the same time as inland flooding bringing high water levels to coastal areas).

- 4) Fire fuel loads and arrangement: There are large uncertainties in projected changes in vegetation community composition, structure and distribution. It is technically very challenging to incorporate such vegetation changes into climate modelling.

4.3 Data updates

The number of relevant databases is increasing and existing databases are updated frequently. Users should check the links above, as well as other guidance resources such Adapt Land&Sea, CoastAdapt and NESP.

In addition, the global climate modelling community produces updated future climate data on an approximate 7-year cycle. This is timed to provide evidence on which to base the next assessment of global climate change from the IPCC (see e.g. IPCC 2021). The international community publishes their data through the Coupled Model Intercomparison Project (CMIP).

The next (7th) phase of CMIP (CMIP7) will be published within the next five years. However, similar to the lag between CMIP5 and CMIP6, it will take time for these results to be analysed and for updated projections to be developed (especially comprehensive projections that involve downscaling to higher resolution). It is likely that the new modelling will result in improvements in at least some aspects of our understanding of future climate. However, 'newest' does not always equate to 'best' and previous projections products will remain useful for many years.

5. Plants

The information in this section was largely provided by Tom Le Breton, University of NSW. In addition, Rachael Gallagher provided a presentation in this topic at Workshop 1 (Appendix 13.1.1).

DCCEEW officers and other stakeholders (e.g. consultants) are advised to consult the relevant databases for plant species of interest at the stages indicated in Figures 1 and 2. The number of relevant databases is increasing and existing databases are updated frequently. Users should also check the internet and the [Adapt Land&Sea knowledge platform](#) for new products.

5.1 Relevant information

Australia is estimated to support 18,174 endemic, vascular plant species (Gallagher et al. 2023). Nonetheless, the proportions of endemic species with threat assessments is relatively low (39%), despite >70% of Australia's more than 2100 listed threatened species being plants ([Species Profile and Threats Database](#), accessed 4 December 2025).

The life cycles and demographics of plants are strongly linked to climate and disturbance events. The advent of climate change and the emergence of increasingly extreme weather events such as bushfires and flooding pose challenges for both species' persistence and conservation (Parmesan and Hanley 2015). In 2021, experts considered that fewer than 10% of threatened Australian plant taxa are threatened by climate change and severe weather (Ward et al. 2021). This estimate of the number of plant taxa threatened by these processes is likely to be highly conservative (Dudley et al. 2019; Laws et al. 2019) and is reflective of the variable nature of the impacts that have been observed across species and regions (Parmesan and Hanley 2015). While it is clear that climate change and extreme events are impacting Australia's native flora, knowledge is largely limited to case studies and is only broadly generalisable across functional groups and regions.

Across Australia, research has shown that climate change and extreme weather are having a range of impacts on native flora, including but not limited to:

- changes in phenology of flowering and fruiting (Beaumont et al. 2015)
- altering community composition in alpine regions (Hoffman et al. 2019)
- long-term drying across the highly biodiverse South-West Australian Floristic Region (Hoffman et al. 2019)
- delaying maturation and seedbank accumulation leading to increased vulnerability of certain species to fire (Enright et al. 2015)
- increased frequency and severity of fire weather leading to increased frequency of fires (Abram et al. 2021).

Key data on the sensitivity and adaptive capacity of endemic plant species to climate change and extreme events are largely lacking. While more information is becoming available through research, data are largely restricted to the scientific literature and there are no centralised resources specifically for sensitivity or adaptive capacity. Where the mechanisms are well understood, some plant traits can be used to infer sensitivity and adaptive capacity. For example, recent work linking larger genome size to increased extinction risk in herbaceous plants (Soto Gomez et al. 2024) could serve as a proxy or indicator of adaptive capacity. These data are already available for thousands of species through the [Plant DNA C-Values Database](#) through Kew Gardens.

The understanding of how extreme weather events like fire and flooding are impacting Australian native flora is much better than our understanding of the more direct impacts of climate change such

as temperature increases and rainfall shifts. Valuable resources are already available for understanding extreme weather impacts including the documentation to support the Commonwealth's 'Fire regimes that cause declines in biodiversity' Key Threatening Process (DAWE 2022) and recent work on frameworks for identifying the species and ecosystems most impacted by major fires. These frameworks link elements of the fire regime and species traits via explicit mechanisms to identify likely impacts (Auld et al. 2022), and are particularly useful for plants for which sensitive life-history traits have already been identified for the extreme event in question. For example, fire sensitive traits are well documented for plants and can be accessed through trait databases such as AusTraits (Falster et al. 2021) and the Fire Ecology Traits for Plants (Ferrer-Parris and Keith 2022).

Despite the significant gaps in our understanding of species' resilience and adaptive capacity to extreme weather events, generalisations are possible and can be usefully based on historical conditions and functional groups. For example, we can infer that rainforest species are likely to be less resilient to fire and drought but more tolerant of storms and flooding when compared with species from drier habitats. Similarly, while the specifics vary, it is well understood that obligate seeders that are killed by fire and rely on a soil seed bank for recovery are sensitive to increases in fire frequency (Keeley et al. 1999). There is also growing evidence of climate-driven changes to demographic processes such as recruitment success and time for plants to mature, which can lead to plants requiring longer gaps between fires to recover (Enright et al. 2015; Enright & Agne 2025). It is becoming increasingly clear that interacting and co-occurring threats greatly undermine species' resilience and adaptive capacity to climate change and extreme weather events (Nolan et al. 2021; Le Breton et al. 2023).

In summary, current knowledge of the impacts of climate change and extreme weather events on Australian flora is reasonable in that we have a general understanding of the types of impacts that are likely to occur. However, there is substantial evidence that impacts vary significantly between species. Species-level understanding of impacts, resilience, sensitivity and adaptive capacity are improving but limited. Consequently, we must often rely on generalisations, even though the consequences of some extreme events such as fire are increasingly well understood.

5.2 Data accessibility for non-specialists

Information on the impacts of climate change and extreme weather events on Australian flora, especially species' sensitivity and adaptive capacity, is likely to become increasingly available and comprehensive over the next few years. The number of relevant databases is increasing and existing databases are updated frequently. Users should check the internet and the [Adapt Land&Sea knowledge platform](#).

Efforts are underway to identify the key traits useful for assessing species' responses to droughts and extreme temperatures, which will allow scientists to build a mechanistic framework along the lines of the framework developed for fire. The traits data are accessible through the AusTraits database (see [AusTraits](#)).

Climate change is also being integrated into tools for assessing extinction risk. The online platform [sRedList](#) is working towards implementing a tool for assessing climate change impact on species habitat quality, which may be useful for several purposes (Mancini et al. 2024).

Initiatives like the [New South Wales Bushfire and Natural Hazards Research Centre](#) are expected to improve understanding of species and ecosystem vulnerability to shifting disturbance regimes. This

Hub has undergone an extensive co-design process aimed at maximising the usefulness of the research outputs for end-users and practitioners.

Several tools focussed on climate resilience relevant to *ex situ* conservation and translocation have recently become available online and will continue to be improved over the next five years:

The Royal Botanic Gardens Restore and Renew project contains two tools focussed on supporting climate-informed decision-making: (1) The RandR site matching tool; and (2) the RandR Webtool, a decision support tool for genetically-informed species restoration (Rossetto et al. 2019). These tools focus on New South Wales plants but are actively being updated to include a wider range of species and additional guidance for restoration options as more information becomes available.

The [Global Working List of Exceptional Plants](#) documents species that cannot be seed-banked or require alternative *ex situ* conservation methods. These alternative approaches tend to be time-consuming and expensive and often require novel research to be effective – a situation that makes it highly valuable to identify the relevant species. The public website includes a growing list of species, including many Australian species, and has links to information on how to identify exceptional species.

The [PlantSearch tool](#) operated by Botanic Gardens Conservation International (BGCI) lists how many plants of different species are in living collections in gardens around the world, enabling global and regional *ex situ* conservation capacity to be quantified. These data are being used to identify the climatic limits of species beyond their natural range and infer climate change resilience and adaptive capacity (e.g. Offord and Zimmer 2024). While the tool is accessible only to paying members of BGCI, data may be accessible through partnerships with organisations that are already members, such as the Australian National Botanic Gardens.

Species distribution models are another tool for understanding the impacts of climate change on plant species. These models continue to improve and can be very informative; however, they are only as good as the data used to build them. Many threatened plant species are either too rare or have too few records to build a strong model that accurately captures the climatic breadth of their current and historic range. Additionally, these models currently do not account for a species' adaptive capacity and need to be interpreted in the context of both adaptive capacity and the mechanisms via which climate change will drive range shifts of species of interest. Advances such as the development of 'ignorance maps' (Tessarolo et al. 2021), which incorporate uncertainty into species distribution models, can help to give managers and decision makers information on where they can be more confident about the likely current and future habitats of species of interest under climate change.

Observational data are improving and can be very informative for identifying impacts and risks from climate change and extreme weather events. Baseline data on the population size and life histories of threatened species are becoming increasingly available because of dedicated monitoring projects undertaken as part of state and national efforts to prevent extinctions. Meanwhile, shifts in temperature and precipitation driven by climate change are increasingly observable, and extreme weather events are occurring more frequently (Abram et al. 2021; Jain et al. 2022; Ridder et al. 2022). Consequently, these impacts are already being captured for many species during monitoring, allowing the observation of impacts in real time and providing information on what future impacts may look like as conditions worsen and exceed the tolerances of the species. Many of these observations are not publicly accessible but are available within conservation agencies and to species project officers.

Increasingly these tools and resources are being designed as open access or user friendly. The barrier to accessing this information is becoming lower; however, a reasonable level of knowledge is still required to understand and interpret the data.

5.3 Major gaps

There are still significant species-level knowledge gaps around the impacts of climate change and extreme weather events. These gaps create a situation where decision-makers can either move forward based on generalisations that may not be the best fit for a species or be paralysed by uncertainty, unable to conclude the best course of action in the absence of additional information. As Rumpff et al. (2023a; page 426) point out, 'uncertainty can be overwhelming but need not be crippling.' Specifying uncertainty can identify the need for targeted monitoring and research to address 'critical knowledge gaps, which, if resolved, will result in more effective management, because such gaps are "critical" to decision making' (Runge 2011). Conservation planning documents and approval conditions that incorporate an adaptive management approach and encourage the collection of data can be used to identify species' responses, impacts and adaptive capacity, while also allowing for validation of management actions. This strategy can support the adaptation of new methods to conserve species as new data become available, ensuring that the conservation needs of species of concern are constantly being advanced and adjusted toward the best outcome. Other steps that can be taken to make information more accessible and relevant include DCCEEW collaborating with researchers, perhaps through the NESP co-design process, to identify key questions around the impacts of climate change and extreme weather events for which there may already be data in the literature, and which could be synthesised and placed into a relevant repository like AusTraits (Falster et al. 2021).

The major gaps in this information are the species-level responses: understanding how resilient a taxon is and how much adaptive capacity it has. Few case studies exist on the effects of increased temperatures and changes to precipitation. The ones that do exist, do not cover a representative sample of Australia's threatened flora. Similarly, the impacts of extreme weather events such as heatwaves, droughts and flooding are still relatively poorly understood at a species level when compared to our understanding of the impacts of fire. Additionally, further work is needed to understand how interactions influence the impacts on species, including both biotic interactions between species and abiotic interactions between co-occurring or successive extreme weather events in different combinations. These are areas of growing research interest but there are limited data in the literature that would be useful and accessible to DCCEEW.

6. Invertebrates

This section was prepared by Jess Marsh, University of Adelaide.

6.1 Relevant information

Terrestrial and freshwater invertebrates constitute a large and complex grouping of species that show immense diversity in ecologies, life histories and sensitivities. Substantial intra-taxon diversity is exhibited by many taxa, even at lower taxonomic ranks such as at the family or genus level. This hyper-diversity, combined with widespread data deficiency, makes it difficult to standardise approaches amongst groups and presents challenges for assessing the impacts of climate change for many species.

For most invertebrates, a lack of monitoring means that there is sparse information on their responses to threats, and accordingly there are limited direct data at the species level on their sensitivity to climate change impacts or adaptive capacity. For most species, information on impacts must be inferred using available data on a species' physiological tolerances and sensitivities to changes in temperature and humidity. Again, species level data are not available for most taxa, therefore much of this information on physiological tolerances is itself inferred using secondary data, such as the microhabitat a species occupies. For example, if a species is a habitat specialist and restricted to shaded mesic areas, it is inferred it would be sensitive to a drying climate. Another approach is to use information on traits garnered from related taxa.

The number of relevant databases is increasing and existing databases are updated frequently. Users should check the internet and the [Adapt Land&Sea knowledge platform](#) for new products.

Traits data

While there are substantial data gaps for many species, traits and trait groupings offer the potential to predict which species may have increased sensitivity or reduced adaptive capacity to climate change impacts and therefore elevated extinction risk. There are now relatively well-established links between species' traits (and other attributes) and sensitivity to climate change or adaptive capacity. Traits or attributes associated with high risk include high habitat specificity, low physiological tolerance to abiotic changes, low dispersal, low vagility, highly specific interspecies dependencies, and short-range endemism (e.g. Thurman et al. 2020; Chichorro et al. 2022). Such attributes are common across some invertebrate taxa. For example, most land snails, mygalomorph spiders, velvet worms and millipedes are short-range endemics and share a suite of associated traits and susceptibilities (Harvey 2002). For these groups, data from related species may be used to infer corresponding traits of data poor species. Traits information is available at the species-level for a limited number of species, but trait conservatism, such as a propensity for short-range endemism, can allow for relatively robust inferences to be made based on the traits of related taxa. For other taxa and traits, there is substantial intra-taxon variation and trait values can be inferred with much less certainty.

6.3 Accessibility

Traits data for invertebrates are found in a diverse range of sources. Data in the literature and databases are two of the main ones. Much of the data have been collected indirectly (i.e. where data are collected for another purpose), e.g. body length measurements in the taxonomic literature, or records of plant-host interactions in ecological studies. There has been a recent increased focus on

the predictive power of traits data to elucidate the conservation risk of fauna, including invertebrates (e.g. Legge et al. 2022; Marsh et al. 2021) and a concurrent growth in databases holding traits data.

The databases holding invertebrate data can be roughly divided into two categories:

- 1) Trait specific, e.g. AnimalTraits (Herbestein et al. 2022), which holds data on body mass, metabolic rate, and brain size; and GlobTherm (Bennett et al. 2018), which holds data on thermal tolerances.
- 2) Taxon/group specific, e.g. The World Spider Trait database (Pekar et al. 2021), GlobalAnts (Parr et al. 2017), or aquatic macroinvertebrates (Kefford et al. 2020).

InverTraits (Bal et al. 2023), an openly accessible, centralised and living database of traits for Australian invertebrate species was under development at the time of writing (December 2025). InverTraits follows the schema of the plant traits database AusTraits (Falster et al. 2021), which uses a standardised traits vocabulary (Marsh et al. in prep. a). Once released, it will provide improved accessibility to traits data for Australian Invertebrates.

The ongoing development of InverTraits should further improve accessibility. Frameworks and susceptibility models to utilise traits data for assessing the sensitivity and adaptive capacity of invertebrates are in development (Marsh et al. in prep. b). These will likely increase the accessibility of traits data for Australian invertebrates to non-expert, time-poor DCCEEW officers.

In addition, a growing focus on finding ways to incorporate invertebrates into conservation, including the development of monitoring and surveillance methods, is likely to increase the amount of data on species-level sensitivity to climate change and adaptive capacity. These data will be made more accessible on the release of InverTraits, and by the development of clear workflows and frameworks by which to interpret traits data and its relation to sensitivity and adaptive capacity.

6.4 Major gaps

There are an estimated 320,465 species of invertebrates in Australia (Chapman 2009), of which an estimated 242,272 are non-marine endemics (Woinarski et al. 2024). Only around a third of these species has been described. Substantial data gaps exist for most Australian invertebrate species, including most described species and many of the known threatened species. As of December 2025, 109 invertebrate taxa were listed as threatened (Critically Endangered, Endangered or Vulnerable) by DCCEEW ([Species Profile and Threat Database](#), accessed 4 December 2025). Most invertebrate species do not have sufficient data to enable them to be assessed for listing and therefore this figure must represent a tiny fraction of the actual threatened invertebrate taxa.

Traits records

While traits data are useful for interpreting sensitivity and adaptive capacity, there is a lack of species-level traits information for many invertebrate species, a relatively limited representation of Australian invertebrate species in most global datasets, and little species-specific data for threatened invertebrate species. One of the key challenges in using invertebrate traits data, especially for non-specialists, is the lack of standardised terminologies across different invertebrate taxa, databases and the literature. InverTraits aims to address these challenges by developing an invertebrate traits dictionary, which is in development.

Occurrence records

Many species have no or very few locational records. This impacts the modelling of species distributions and assessment of the sensitivity or adaptive capacity of invertebrate species to climate change. Figure 3 shows that of the >45,500 Australian invertebrate species with at least one occurrence record, ~36% had only one occurrence record and only ~7% have >20 records). Under-sampling is the norm. Thus, it is often challenging to distinguish genuine short-range endemism, and hence conservation risk, from the paucity of records resulting from limited survey effort. The large number of historic records, combined with the absence of monitoring for most species, means that it is often not possible to assess whether species are still extant in areas where they have been historically found and whether mapped distributions reflect current species occurrences. The Western Australian Environmental Protection Agency (2009) (but not DCCEEW) attempts to address this problem by requiring development proponents to not only undertake comprehensive sampling of biodiversity at a site but also demonstrate that any potentially affected species also occurs elsewhere.

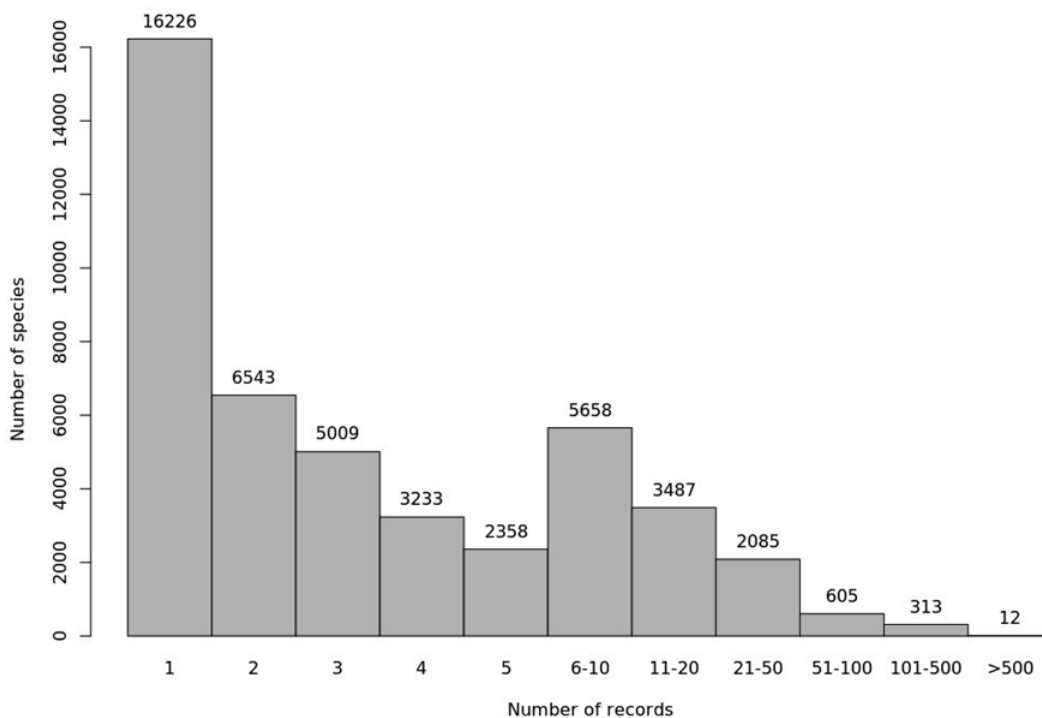


Figure 3. Cleaned occurrence data for described invertebrate species in Australia, adapted from Marsh et al. (2021). The data show that 36% of recorded invertebrate species have only one record, with only about 7% of recorded species having more than 20 records.

7. Vertebrates

This section was prepared by Natalie Briscoe, The University of Melbourne.

7.1 Relevant information

Climate change and extreme weather impact Australian terrestrial and freshwater vertebrates through a range of mechanisms. Some of the most obvious and highly publicised impacts are direct mortality due to extreme environmental conditions exceeding physiological limits; for example, the mass mortality of birds and flying foxes during heatwaves (Mo et al. 2021; Gardner et al. 2022) and fish populations during hot, dry conditions with low water flow (Stocks et al. 2021). Mortality or loss of habitat due to the impact of extreme weather or events such as fires, floods or cyclones are also increasingly being documented across some groups or species (Ward et al. 2020; Natural Resources Commission 2022). Climate change can also have more subtle impacts on an animal's energy and water requirements, activity, reproduction, development or growth (Conradie et al. 2019). Finally, changes in environmental conditions can cause an ongoing loss of potential habitat, for example via the loss of snow cover or change in vegetation (Hoffman et al. 2019). These impacts at the individual or local population level can result in altered abundances or distribution and hence vulnerability to extinction.

The perceived threats of climate change and extreme weather to the major groups of terrestrial and freshwater vertebrates differ widely (Ward et al. 2021). Vulnerability to climate change and extreme weather is influenced by a range of factors including the species' physiology, habitat, diet, dependency on another species, activity patterns and behaviour, phenological dependence upon seasonal climate triggers, life history, dispersal and movement capacity, occupied area and population size. While some studies consider one or a few factors in isolation, ideally analyses should consider how they interact.

Information about the sensitivity and adaptive capacity of terrestrial and freshwater vertebrates to climate change and extreme weather comes in the form of:

- **Documented evidence** of how a species is already affected by extreme weather events or recent climate change, or known environmental associations that indicate species' sensitivity. For example, flying fox mortality during past extreme heat events has been well-documented (Welbergen et al. 2007; Mo et al. 2021).
- **Projected impacts** of climate change on species' distribution or abundance from either correlative species distribution models or process-explicit (mechanistic) models. For example, Briscoe et al. (2016) projected the future distribution of koalas under climate change using a range of modelling approaches.
- **Trait-based assessments** of sensitivity and adaptive capacity to climate change or extreme weather events. For example, Garnett et al. (2014) assessed the sensitivity and adaptive capacity of all Australian birds using traits that reflect each species' degree of specialisation (e.g. number of habitat and food types used) and capacity to evolve and adapt (e.g. population size, intrinsic rate of population increase).
- Likely sensitivity and adaptive capacity based on **similar species**, laboratory studies, understanding of mechanisms through which climate change or extreme weather impacts on species. For example, studies that document links between breeding and specific environmental conditions (Hoffmann and Mitchell 2021).

7.2 Accessibility

Relative to plants and invertebrates, information that may be used to assess likely responses to climate change of terrestrial and freshwater vertebrates is more available and accessible. However, even for well-studied groups and species there are still gaps in our understanding that can lead to high uncertainty when predicting impacts to 2050. The number of relevant databases is increasing and existing databases are updated frequently. Users should check the internet and the [Adapt Land&Sea knowledge platform](#) for new products.

Documented climate change sensitivity

Direct evidence of climate change sensitivity is available through published peer-reviewed papers and government reports. For terrestrial and freshwater vertebrates, these are only available for a subset of species and tend to be focused on regions or taxa. For example, long-term monitoring in the Australian Wet Tropics that started in the 1990s has provided insights into the sensitivity of key vertebrate taxa to climate change, including shifts in the distribution and abundance of rainforest possums and birds (Williams and de la Fuente 2021; de la Fuente and Williams 2023). Similarly, long-term monitoring of individuals of 23 arid bird species at two semi-arid sites assessed the effect of extreme heat on survival (Gardner et al. 2022). Unfortunately, lack of resources means that such long-term datasets are rare and ongoing monitoring of those that do exist is often not guaranteed.

Documented mortalities in response to extreme events are available for some taxa, particularly those that can occur in large groups like birds, flying foxes and freshwater fishes (McKechnie et al. 2012; Mo et al. 2021; Stocks et al. 2021). There has been a substantial amount of research into responses and impacts of fire on threatened terrestrial and freshwater vertebrates, particularly following the 2019–2020 bushfires (Silva et al. 2020; Rumpff et al. 2023b).

Aside from monitoring studies that document population or distribution shifts in relation to past climate change or extreme events or weather, studies that identify how species are impacted by environmental factors can provide information relevant for assessing species' sensitivity. For example, Hoffmann and Mitchell (2021) identify an association between calling (breeding) of the white-bellied frog (*Geocrinia alba*) and soil water potential, suggesting that ongoing drying will likely impact these species. This type of information can often help highlight important regions or populations for the species. Additional information and knowledge (including likely changes in environmental factors under future scenarios) are needed to incorporate such findings into assessments of species' sensitivity, which may sometimes be challenging for assessors.

Challenges in accessing information include identifying relevant studies and extracting relevant information, particularly from studies that examine many species and may not report results for the target species of interest. Provision of species-specific summaries via web pages is a promising option, as was done for a [recent study of climate change impacts on Wet Tropics birds](#).

Correlative species distribution models (SDMs)

Sufficient occurrence data exist to allow modelling of species distributions under current and future climates for many terrestrial and freshwater vertebrates. Projected changes in distribution have been estimated for species mentioned in projects ranging from large modelling studies focused across many hundreds of species, to single-species studies (Reside et al. 2013; Briscoe et al. 2016). For example, Archibald et al. (2024) modelled the current and future distributions of 60% of all Australian mammal species, 77% of amphibian species, 50% of reptile species and 71% of bird species for five

future timepoints and a range of future climate scenarios. Tims and Saupe (2023) modelled 154 species of Australian freshwater fishes, 29 of which were classified as threatened.

As explained above, accessing individual species projections from these studies in a timely fashion can be challenging unless data are provided online, and not all studies provide predictions for required time periods or scenarios. While large modelling studies or reports that have high coverage across species are convenient sources of information, these tend to use generic covariates and methods for all species, which can result in less reliable forecasts for individual species than targeted studies that use predictors that are more directly relevant to the species (Elith and Leathwick 2009).

Despite being technically feasible for many species, correlative SDMs have several important limitations when used to predict future distribution of species under climate change:

- 1) Biased or incomplete occurrence data (including from species that have suffered large reductions in range due to other threats such as land-use change or invasive predators) can result in models that fail to accurately capture the range of environments in which the species could occur; the fossil record may be of assistance (Archer et al. 2019).
- 2) Climate change may result in novel environments, requiring model extrapolation.
- 3) Processes such as dispersal or population constraints, landscape dynamics or weather extremes are not typically accounted for, yet will strongly shape future distributions of many vertebrate taxa (Briscoe et al. 2019).

Further, model outputs can be highly sensitive to modelling decisions, including choice of occurrence data, algorithm and covariates, resulting in high uncertainty (Elith and Graham 2009; Morán-Ordóñez et al. 2018). The literature on best practice in correlative SDMs is extensive (e.g., Araujo et al. 2019; Valavi et al. 2022) but can be difficult to navigate for non-specialists. Visintin and Wintle (2022) provide information directly relevant to species modelling by DCCEEW.

Mechanistic or process-explicit models

Models that explicitly model processes such as physiology, dispersal, demography and biotic interactions are expected to offer more robust predictions of species responses to climate change (Briscoe et al. 2019). Incorporating demographic information can better account for lags in extinction (Fordham et al. 2016), while models that incorporate species' physiology or rely on the principles of biophysics can avoid the problems with extrapolation commonly faced by correlative SDMs (Kearney and Porter 2009). The additional data, skills and computational requirements needed, mean that these models cannot currently be applied to all threatened terrestrial and freshwater vertebrate species. Forecasts from process-explicit models are thus currently available only for individual – often well-studied – species (e.g. pygmy blue tongues, Fordham et al. 2012; koalas, Briscoe et al. 2016; greater gliders, Kearney et al. 2010).

Trait-based assessments

Trait-based assessments are available from both IUCN's global vulnerability assessments (e.g. Foden et al. 2013) and Australian-focused taxon-level assessments (Garnett et al. 2014; Chessman et al. 2013; Cabrelli et al. 2015). These assessments typically combine information on a species' exposure (potentially from a correlative SDM), sensitivity and adaptive capacity. For example, Garnett et al (2014) assessed the vulnerability of Australian bird species to climate change using information on their projected change in climate space (exposure), and key traits that reflect their degree of specialisation (e.g. number of habitat and food types used) and capacity to evolve and adapt (e.g. population size, intrinsic rate of population increase).

Accessing trait information can be challenging for terrestrial and freshwater vertebrates because trait databases tend to focus on taxa or certain types of traits and are not typically Australian-focused. Key global databases include: Amniote (life history traits of mammals, birds and reptiles; Myhrvold et al. 2015); AVONET (morphological, ecological and geographical data for all birds; Tobias et al. 2022); SquamBase (morphological, ecological, life history, conservation related traits of squamates; Meri et al. 2024); FishBase (morphological, ecological and life history traits of fish; www.fishbase.org); AmphiBIO (life history, diet, ecological traits of amphibians; Oliveria et al. 2017); and GlobTherm (thermal tolerance traits of terrestrial and aquatic organisms; Bennett et al. 2018). Trait information is available from taxonomic guides to Australian fauna and past studies have also collated key traits for many Australian species. For example, Southwell et al. (2021) compiled key traits for all threatened terrestrial and aquatic species, with missing data gaps filled via imputation.

7.3 Major gaps

Occurrence data for vertebrates (and other taxa) are available via the [Atlas of Living Australia](#) and state data repositories; however, these data are largely biased presence-only data. Higher quality presence-absence or abundance data are infrequently collected and tend to remain within a particular research group or department. Investing in collecting high-quality monitoring data and collating existing data into publicly available repositories would allow models to be fitted that better deal with key issues such as bias and enable robust tests of how well existing models capture shifts in distribution or population size. Studies that explicitly consider biotic interactions and how these influence sensitivity and adaptive capacity of terrestrial and freshwater vertebrates are rare.

Efforts to characterise sensitivity and adaptive capacity would benefit from a better understanding of the likely mechanisms through which climate change and extreme weather affect populations. Mechanistic frameworks, which link changes in animal populations to components of climate change and extreme weather for specific taxonomic groups, could help fill this gap. Several examples exist. For example, conceptual frameworks have been used to predict the impact of extreme heat on birds (McKechnie et al. 2012) and demographic frameworks capturing fire impacts on threatened Australian mammals and reptiles have recently been developed and applied (Santos et al. 2022a, 2022b).

To maximise coverage across species, traits-based assessments have tended to use few generic traits that may not capture important facets of climate-change sensitivity and adaptive capacity. Consequently, species such as grey headed flying foxes that have high movement capacity, large ranges, and large population sizes may not be identified by these analyses as vulnerable to climate change and extreme weather unless information on the physiology and behaviour of a species is considered, or impacts are already apparent and such data are incorporated into analyses. Greater consideration of morphological, behavioural and physiological traits that can capture the mechanisms through which climate change and extreme weather impact upon species are needed (Payne et al. 2023; Ding et al. 2024). Trait-based assessments usually provide only a relative ranking among the species assessed in the specific study, and research has shown that estimated risk across studies that used different methods can vary substantially (Wheatley et al. 2017). Comparisons of trait-based assessments and observed distribution or population changes have mixed results (Wheatley et al. 2017; Ding et al. 2024). More validation is needed to test how well different approaches capture vulnerability to climate change and weather extremes.

8. Adaptation options

The NESP Climate Systems Hub project 2.7 *Climate-effective management for threatened species and protected places* has developed improved decision-making processes for climate action. Project outputs include AdaptLog, a searchable database of adaptation options for species and ecological communities, and a decision support tool to help government and on-ground managers consider and select likely options for long-term adaptation. The following section was prepared by Claire Mason, CSIRO from the project team.

8.1 Relevant information

The [Adaptation Catalogue for Conservation](#) is a searchable repository of >400 climate adaptation interventions for species and ecological communities (Mason et al., 2024b). A climate adaptation intervention is an on-ground conservation activity that specifically addresses climate change vulnerability and/or incorporates climate information. The information has been collected from publicly available sources via *ad hoc* and formal searching from 2018 until mid-2024, using the methods developed by Mason et al. (2021). The conservation planning documents (conservation advice and recovery plans) of the list of 110 priority species (DCCEEW 2022) were scanned to extract implemented or suggested actions. Additional actions were added incidentally as they were encountered through a co-development process with conservation practitioners. Beta-testing with a larger group in late 2024 enabled the collection of additional interventions to fill gaps in AdaptLog’s coverage (e.g. ecological communities, invertebrates). In version 3 of AdaptLog, there are 458 interventions from a range of taxonomic groups (Figure 4).

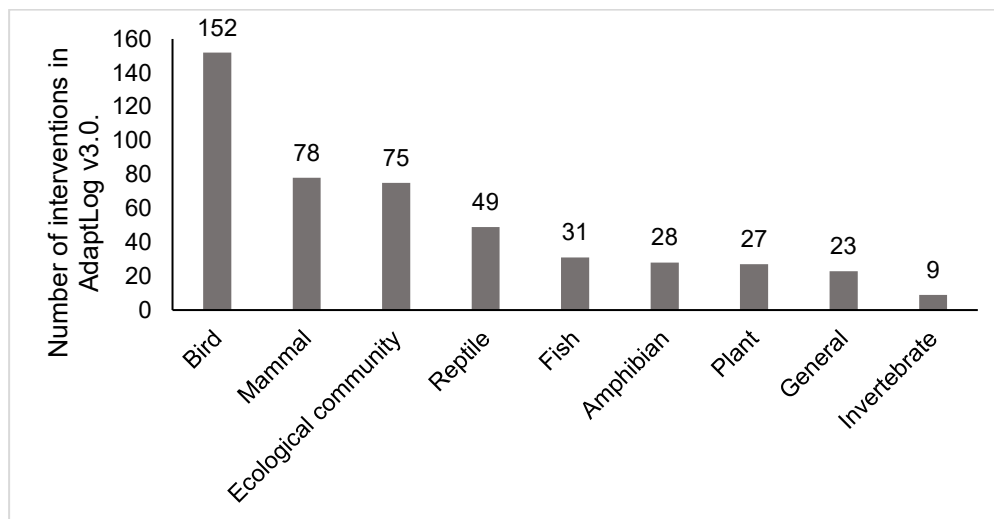


Figure 4. Coverage of major taxonomic groups in the Adaptation Catalogue for Conservation (AdaptLog v3.0, November 2024). Note a small number of interventions in AdaptLog target multiple species. Source: Claire Mason, CSIRO. The number at the top of each bar represents the actual number of interventions.

8.2 Accessibility

[AdaptLog](#) is a standalone website set up through CSIRO systems to remain in place and operational for 2–5 years from 2024. Version 3 of AdaptLog (with additional interventions and associated decision support) was released through a public webinar hosted by the Climate Systems Hub in November 2024. From 2025, the Climate Systems Hub project 4.3 *The Adapt Land&Sea* knowledge platform

guides traffic to AdaptLog and provide context and supporting materials. AdaptLog and its guidance information will also be integrated into the Resilient Landscapes Hub's platform 'Northern Rivers Adapt'. The Climate Systems Hub is still exploring options to fund maintenance and small updates of the AdaptLog database and online platform.

The content and design of AdaptLog have incorporated two classifications to provide insight into the quality and relevance of information? in response to a need to be accessible for non-experts as follows:

- 1) A classification of the maturity of an intervention included in AdaptLog as either: (a) a recommendation, (b) a policy or planning action, or (c) an on-ground activity.
- 2) A classification of the source documents used to complete entries in AdaptLog as either: (a) scientific research, (b) government documents or websites, (c) conservation organisation documents or websites, (d) university media documents or websites, (e) news articles, or (f) social media content.

AdaptLog is a brainstorming and discovery tool, rather than an exhaustive resource. These classifications provide insight into the kind of activity described and the information sources in AdaptLog.

The AdaptLog website is a free and publicly available resource and hosts a user guide and detailed background information (Mason et al. 2024 a and b). Members of the project team have done their best to make the resource intuitive through multiple rounds of beta-testing with potential end-users including staff from several DCCEEW divisions. AdaptLog hosts information in downloadable packages and pages for ease of saving and sharing. Downloadable information includes the situational reports that provide spatially explicit climate information, consideration wheels and implementation guidance, and a full record page for each intervention. This approach is designed to increase accessibility by collating, sorting and summarising information to speed up the research process for users.

AdaptLog provides scalable hierarchies of information enabling the user to undertake searches ranging from superficial to in depth (Figure 5) depending on their needs. The approach acknowledges that the available evidence is patchy; many species and ecosystems have no evidence. Users are provided with tools to help with their critical thinking based on available information and the decision context. The AdaptLog website links to external information where available.

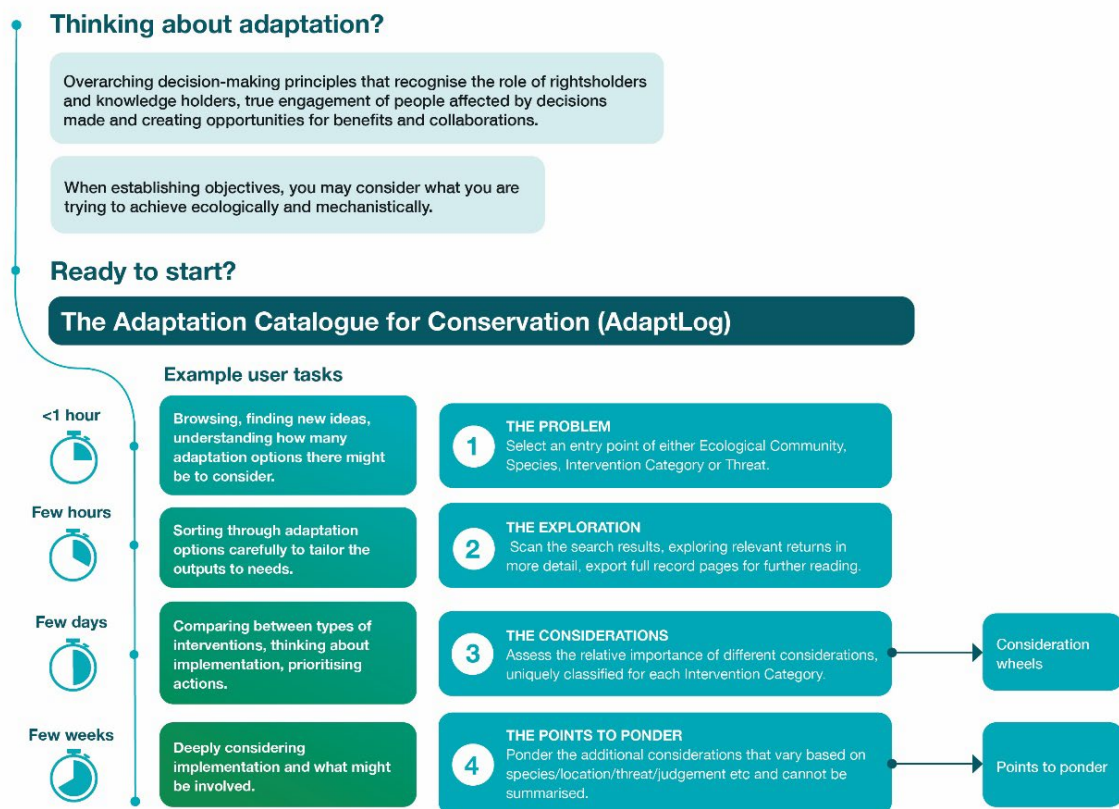


Figure 5. Decision support that scaffolds AdaptLog and provides scalable hierarchies of information to serve multiple use cases. Source: Claire Mason, CSIRO.

8.3 Major gaps

AdaptLog is not designed to be an exhaustive resource for each intervention. Rather it is a starting point to enable the user to understand what was done and provide them with links to further information sources to support individual research. The emphasis is on encouraging users to think innovatively and consider adopting approaches from different places and contexts. AdaptLog captures a variety of examples to help stimulate thinking about options and inform transitions to new approaches to conservation under climate change.

The search process of AdaptLog is not a standalone decision-making step, rather, it is a tool to be used within the context of a larger decision-making process, such as those undertaken by DCCEEW officers.

This approach captures richness and variety rather than exhaustive details. An evidence-based quality rating or evaluation of effectiveness would allow DCCEEW officers to weight interventions in the decision-making process based on their likely impact and effectiveness. Figure 5 provides insight into the large and complex landscape in which the decision to implement an intervention occurs.

9. Needs and opportunities

9.1 DCCEEW identified needs

The second workshop highlighted information gaps, questions and the need for products that might support DCCEEW in accounting for climate change impacts on listed threatened freshwater and terrestrial species and ecological communities in both the conservation planning and approvals processes. The team from DCCEEW articulated their ongoing need for a framework or set of tools to support decision making in the context of climate change (Figure 6).

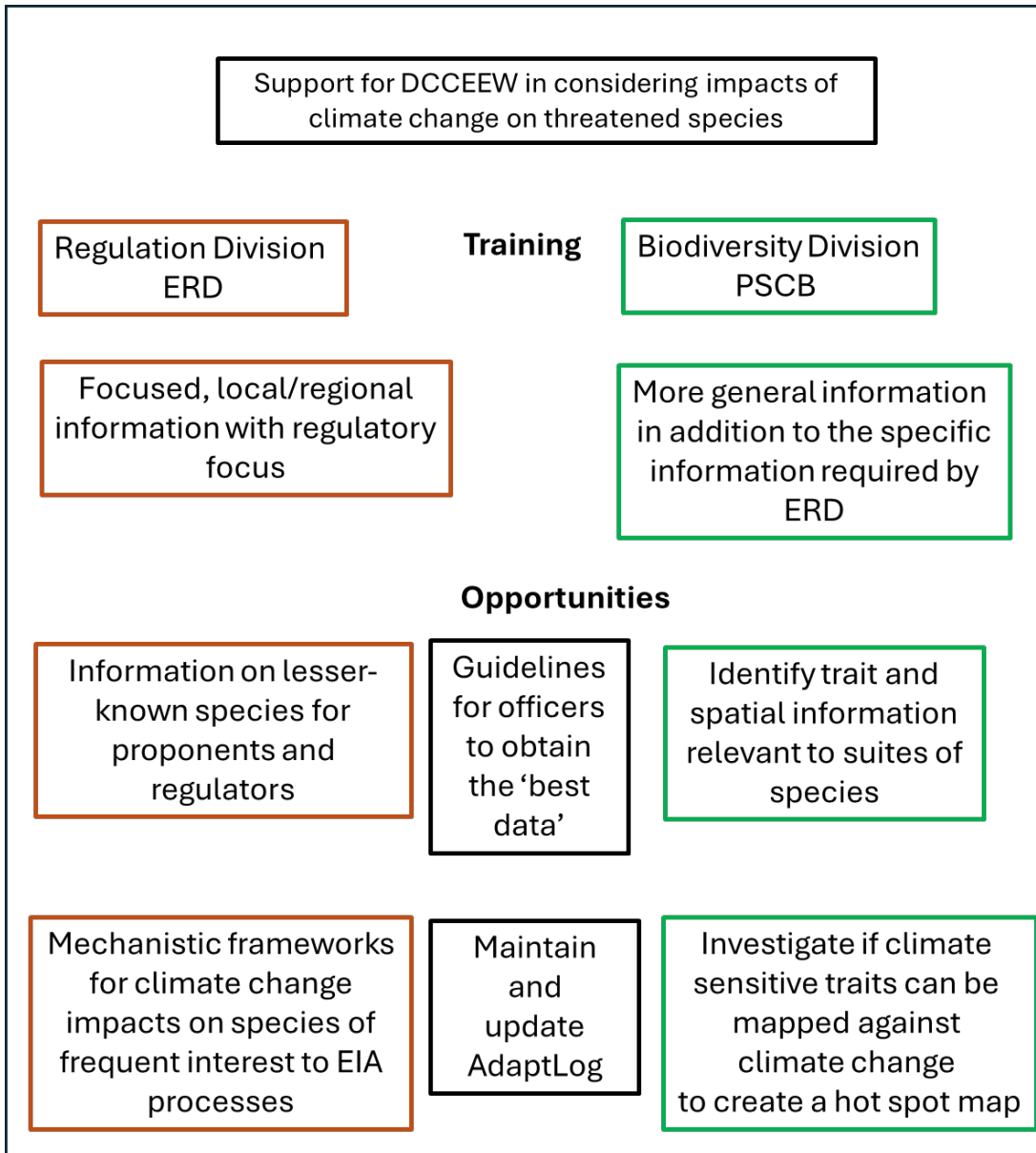


Figure 6. Framing of decision support approach and needs from DCCEEW. The materials of particular relevance to Environment Regulation Division are outlined in red brown, those for the Biodiversity Division in green, and those for both Divisions in black. Despite this difference in emphasis, it is likely that much of this information would be useful to both divisions.

9.2 Outstanding questions

The workshop also raised the following explicit questions for DCCEW:

- 1) What are the options to keep officers in the Protected Species and Communities Branch and the Environment Regulation Division abreast of relevant climate science? Should DCCEW consider appointing officers with specialist knowledge who can keep abreast of developments in climate science as a pathway to this knowledge becoming mainstream, as in the Office of the Threatened Species Commissioner?
- 2) What is the best approach to providing guidance to listing officers in the Protected Species and Communities Branch on climate futures for species or ecological communities when preparing a case for listing?
- 3) What are the advantages and disadvantages of focusing on protecting ecological communities rather than species? It was noted that listing ecological communities is much more complex than listing species.
- 4) Can the Environment Regulation Division design and implement policy change to enable offsets to be placed in areas where climate change is less risky for the target MNES? If so, what are the conditions under which offsets should be established in less climate vulnerable parts of the range of species and ecological communities of regulatory interest?

9.3 Opportunities for further work

The workshop identified opportunities for the NESP program to support DCCEW through future collaborations or partnerships:

- 1) Developing a framework of tools to support decision making in DCCEW including:
 - i. tools for the Biodiversity Division (Office of the Threatened Species Commissioner and the Protected Species and Communities Branch)
 - ii. tools for approvals officers, including tools to use in discussions with proponents.
- 2) **Training and guidelines for assessment officers to understand and access 'best' data on climate and extreme weather.** This was a need for both the Protected Species and Communities Branch and Environment Regulation Division. Immediate training could be provided to existing staff with co-development of guidance to support new staff and as a prompt in the future.
- 3) Guidance on future refugia for threatened species and/ecological communities and the connections between them.
- 4) Guidance to enable a traits-based approach to be developed for suites of species.
- 5) Regional guidance regarding 'hotspots' of high climate risk across Australia.
- 6) Guidance on the response of species and ecological communities of frequent regulatory interest or on the Priority List of Threatened Species to climate change or extreme weather events.

10. A way forward

The workshop highlighted several opportunities for future collaborations and research:

- 1) Dedicated training on climate change science and using projection information with accompanying co-designed guidance materials. This training might be developed through the cross-hub project 'Adapt Land&Sea'.
- 2) Investigation of options to sustain and update AdaptLog.
- 3) Co-developing a framework for decision-making with DCCEEW.
- 4) Testing the use of trait-based and/or regional assessment approaches to identify taxa at risk from climate change.
- 5) Developing an approach to documenting information on the interactions between biodiversity threats and climate change and extreme events.
- 6) Developing an approach to documenting Indigenous Knowledge of climate change and extreme events on threatened entities.

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12. Appendices

12.1 Agenda and attendees

Workshop 1

An online workshop to ensure participants have a common understanding of the intent of the workshops, held on 11 April 2024. This workshop comprised presentations on the following topics:

- 1) **Introduction** (Helene Marsh)
- 2) **The types of information that would assist in the preparation of guidance documents** on how to account for the impacts of climate change on protected species and ecological communities in conservation plans (Ivan Lawler DCCEEW)
- 3) How the Climate Systems Hub can help design a potential project (Sarah Boulter et al.)
- 4) **How ecologists** (Rachael Gallagher [plants] and [Natalie Briscoe](#) [animals]) could help design a potential project
- 5) **Next steps** (Helene Marsh)

Workshop 2

Workshop on risks to threatened terrestrial and freshwater species from extreme weather and climate change, 6 September 2024

Objective:

To use the exposure-sensitivity-adaptative capacity framework to provide guidance for DCCEEW on how to interpret and translate existing and emerging information on the impacts of climate change and extreme weather events on threatened terrestrial and freshwater species by eliciting and discussing:

- 1) the information available in a format accessible to proponents and relevant to DCCEEW officers to 2050
- 2) how they could evaluate its quality and relevance
- 3) whether additional, accessible information is required for species of high regulatory interest.

Attendees

Convenors: Sarah Boulter (NESP Initiative Lead, Climate Adaptation), Helene Marsh (NESP Initiative Lead, Threatened and Migratory Species and Threatened Ecological Communities).

Topic Experts: Dr Natalie Briscoe (University of Melbourne), Mr John Clarke (CSIRO), Professor Iain Gordon (TSSC), Dr Tom Le Breton (UNSW), Dr Jess Marsh (University of Adelaide), Dr Claire Mason (CSIRO), Dr Patrick Norman (Griffith University).

DCCEEW officers: Catherine Atkinson, Rod Dann, Ivan Lawler, Lauren Smith.

Venue: CSIRO Black Mountain Canberra, Synergy Building, Ground Floor-Stringybark

Workshop 2 Timetable

0830	Arrival and coffee	
0900	Welcome Introductions Purpose of Day	Sarah Boulter and Helene Marsh
0915	DCCEEW perspective Where, when and what information is needed Other needs	Ivan Lawler
0945	What information is available about exposure to extreme weather and climate change to 2050 at local and regional scales and how is this expected to improve in the next 5 years	John Clarke
1045	Morning coffee	
1100	What information is available about the sensitivity and adaptive capacity of the major groups of terrestrial and freshwater species listed as threatened to extreme weather and climate change to 2050? How is this expected to improve in the next 5 years and how accessible is it to time poor non-specialists? : Plants Vertebrates Invertebrates	Tom Le Breton Natalie Briscoe Jess Marsh
1200	Discussion and questions	
1245	Lunch	
1330	What information is currently available about adaptation options for the major groups of terrestrial and freshwater species listed as threatened to extreme weather and climate change to 2050. How is this expected to improve in the next 5 years and how accessible is it to time poor non-specialists?	Claire Mason
1430	What needs to be done to improve the accessibility of this information to DCCEEW officers?	Group work
1530	Next steps	Sarah Boulter and Helene Marsh
1600	Close and taxis to airport	

12.2 Links and references to relevant databases.

This information is being updated regularly and users should check the internet for updates.

Area	Type of database	Description	Links and references if available ¹
Climate	Guide on how to conduct a risk assessment	An index to different places to find climate information and describe the features of each source.	Understanding data inputs for a climate risk assessment
	State-based climate projection data sources.	Climate projections for New South Wales	Interactive climate change projections map
		Climate projections for Queensland	Queensland future climate dashboard
		Climate projections for South Australia	South Australian climate projections viewer
		Climate projections for Tasmania	Tasmania list map
		Climate projections for Victoria	https://vicfutureclimatetool.indraweb.io/cmip6/
		Climate projections for Western Australia	https://library.dpir.wa.gov.au/cs_factsheets/1/
	Hydrological projections	Bureau of Meteorology Australian Water Outlook	Australian water outlook
		CSIRO	Available from researchers
		The National Partnership for Climate Projections promotes cross-jurisdictional collaboration in climate projections	Coastal extremes tools and data – Canute tool National climate risk assessment

¹ Complete references in reference list section 10

Area	Type of database	Description	URL and References if available ¹	
	Coastal projections	The CoastAdapt portal provides sea level rise projections and inundation maps for all local governments.	CoastAdapt ; see also Coastal extremes tools and data	
Australian biodiversity	Atlas of Living Australia	Australian biodiversity occurrence records categorised by species, taxon, dataset, region, date, location, data provider	Atlas of Living Australia	
	EPBC listed threatened entities	List of fauna and flora listed as threatened under EPBC Act	Species profile and threats database – fauna Species profile and threats database – flora	
	NSW Bushfire and Natural Hazards Research Centre		NSW Bushfire and Natural Hazards Research Centre	
Plant databases	AusTraits	AusTraits is an open-source, harmonized database of Australian plant trait data.	AusTraits	Falster et al. 2021
	Plant fire response trait database	Fire Ecology Traits for Plants	Fire ecology database / Plants NSW	Ferrer-Paris, J. R. and Keith, D. A. 2022
	Global Working List of Exceptional Plants	Exceptional plants provide conservation challenges because they cannot be effectively conserved in conventional seed banks.	Global working list of exceptional plants	
	Plant DNA C-Values Database through Kew Gardens	C-value is the DNA amount in the unreplicated gametic nucleus of an organism, irrespective of the ploidy level of the taxon. The Plant DNA C-values Database currently contains C-value data for 12,273 species comprising 10,770 angiosperms, 421 gymnosperms, 303 pteridophytes (246 ferns and fern allies and 57 lycophytes), 334 bryophytes, and 445 algae.	Plant DNA C-values database	Ecological Archives E096-269 https://esapubs.org/archive/search.php

¹ Complete references in reference list section 10

Area	Type of database	Description	URL and References if available ¹	
Plants databases	PlantSearch tool operated by Botanic Gardens Conservation International (BGCI)	Lists plants of different species in living collections in gardens around the world,	PlantSearch	
	The Royal Botanic Gardens Restore and Renew project	Restore & Renew enables ecological restoration practitioners to incorporate the latest science into their toolkit, helping them to restore diverse, resilient and adaptable ecosystems.	Check on-line for link	Rossetto et al. 2019
Animal traits	AnimalTraits	Curated database containing body mass, metabolic rate and brain size measurements across a wide range of terrestrial animal taxa	AnimalTraits	Herbestein et al. 2022
	GlobTherm	A global database on thermal tolerances for aquatic and terrestrial organisms	GlobTherm (data descriptor)	Bennett et al. 2018
Invertebrates	Aquatic macroinvertebrates	An integrated database of stream macroinvertebrate traits for Australia	AUSRIVAS bioassessment: macroinvertebrates	Kefford et al. 2020
	Global Ants	Data on the abundance and traits of ants in local assemblages worldwide	The Global Ants Database	Parr et al. 2017
	InverTraits	A curated and standardised database of traits data for Australia's invertebrate taxa	AusInverTraits	Bal et al. 2023
	The World Spider Trait database	Centralised global open repository for curated data on spider traits	World spider trait database	Pekar et al. 2021
Vertebrates	Amniote	Life history traits of mammals, birds and reptiles	Amniote life history database	Myhrvold et al. 2015
	AmphiBIO	Life history, diet, ecological traits of amphibians	AmphiBIO global database	Oliveira et al. 2017

¹ Complete references in reference list section 10

Area	Type of database	Description	URL and References if available ¹	
	AVONET	Morphological, ecological and geographical data for all birds	AVONET	Tobias et al. 2022
	Fishbase	Morphological, ecological and life history traits of fish	FishBase	Froese and Pauly 2000
	SquamBase	Morphological, ecological, life history, conservation related traits of squamates	Data Papers https://onlinelibrary.wiley.com/doi/10.1111/gcb.13812	Meiri et al. 2024
Adaptation options	AdaptLog	Repository of conservation adaptation interventions from Australia and around the world	AdaptLog	
	Adapt Land&Sea Portal	Adapt Land&Sea Portal aims to meet information needs of adaptation practitioners	Adapt Land&Sea	Mason et al. 2021

¹ Complete references in reference list section 10