SAVING OUR SPECIES

Persistence in Landscapes Project

Modelling future-ready conservation options for landscape managed threatened fauna

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Cover photo: Glossy Black-Cockatoo (*Calyptorhynchus lathami*). Matthew Jones/DPE

Published by:

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ISBN 978 1 XXXX XXX X
EES 2021/XXXX
September 2022

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Shortened forms

ACT – Australian Capital Territory

ANUCLIM – a software package that enables users to obtain estimates, in point and grid form, of monthly, seasonal and annual mean climate variables from supplied climate surfaces

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DPE – NSW Department of Planning and Environment

DPIE – former NSW Department of Planning, Industry and Environment, now DPE

ENM – environmental niche model/modelling

ESRI – Environmental Systems Research Institute, an international supplier of geographic information system software, web GIS and geodatabase management applications

GCM – global circulation model

Landscape capacity – sometimes denoted as Pi. It is a measure of a location's capacity to support occupancy of landscape-managed species given its environmental properties and its proximity and connectivity to other habitat

LCOT – landscape capacity over time

MaxEnt – Software for modelling species niches and distributions by applying a machine-learning technique called maximum entropy modelling

MVH – minimum viable habitat area

NARCliM – NSW and ACT Regional Climate Modelling project

NSW – New South Wales, Australia

OEH – former NSW Office of Environment and Heritage, now DPE

Species landscape characteristics – used within REMP model to characterise the quantum of connected habitat needed to support a population, and minimum and maximum movement abilities of the species for home-range and dispersal movements

PLP – Persistence in Landscapes Project

SEED – NSW Government Sharing and Enabling Environmental Data portal

SoS – NSW *Saving our Species* threatened species conservation program

CCRI - The combined climate refugia index. It is a combined refugia measure in relation to the full set of species

R1, R2, R3 – used to denote the three regional climate models developed in the NARCliM project

RCM – regional climate model

REMP – Rapid Evaluation of Metapopulation Persistence model

TPI – topographic position index

TWI – topographic wetness index

Acknowledgements

This research was funded by the NSW Department of Planning and Environment through the Saving our Species program and Science, Economics and Insights Division. It was supported by the Department of Planning and Environment, the University of New England (UNE), and Macquarie University (MQ). Many thanks to the people who contributed and offered advice over the course of the project.

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We also acknowledge the invaluable help of species experts from various universities, government departments and private consultancies: Rohan Bilney (Forestry Corporation NSW), Greg Clancy (gregclancyecologistguide.com), Jacob Crisp, Stephen Debus (UNE), Mark Drury (Forestry Corporation NSW), Peter Ewin (Biodiversity Conservation Trust) Mark Fitzgerald (CSU), Hugh Ford (UNE), Sarsha Gorissen (USyd), Alex Holmes (GHD), Victor Hurley (DELWP, Vic), Tony Hunt, Dean Ingwersen (Birdlife Australia), Rod Kavanagh (SCU & USyd), Francis Lemckert (Eco Logical, Australia), Michael Mahony (UON), David Milledge (Landmark Ecological Services), David Newell (SCU), Richard Noske, Paul Oliver (GU), Trent Penman (UoM), Mick Roderick (Birdlife Australia),Ross Sadlier (Outwest Reptile Consulting Services), Chris Slade (Forestry Corporation NSW), Jacob Sife (Ku-ring-gai Council), Andrew Smith (setscan pty.ltd.), Mr Janne Torkkola (UQ), Simon Verdon (LTU).

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1. Overview

1.1 Summary

Threatened fauna species with widespread distributions and large home ranges cannot be secured within well-defined sites, making conservation for these species a challenging task. Such species are managed within the landscape managed stream in the NSW Saving our Species (SoS) program. The Persistence in Landscapes Project (PLP) is helping SoS identify priority areas now and under future climate scenarios to support landscape managed species.

SoS is a world-class conservation framework that helps threatened species live safely in the wild by combining science and data with effective on-ground action. The PLP brings together these essential elements of successful conservation, drawing on climate science, species metapopulation data and modelling technology to provide us with tools to guide practical action.

The PLP has analysed 75 of the 111 landscape managed species SoS is currently working to conserve in New South Wales.

The species-specific outputs include sets of maps or grids predicting landscape capacity for each species over the next 50 years, as well as individual species forecasts. These identify where species' populations can persist through expected geographic shifts to their climatic envelopes due to projected climate change. They highlight the location of refugia: important areas that have supported occupancy by threatened fauna from pre-industrial times and are expected to continue supporting relatively high densities of species into the future. In addition, these forecasts inform us that with targeted management such as translocation or creation of habitat linkages, some species may have the potential to adapt to climate change impacts by occupying new areas. These gridded data can be converted into vector format for use with SoS's Conservation Hotspots approach, which identifies optimal ways to allocate resources to different conservation projects, including identifying sites where conservation actions will benefit multiple species.

The data for all species have been aggregated into maps of New South Wales showing areas where multiple species could persist and how summed landscape capacity (that is, the total capacity of the landscape to support all species included in the project) is expected to change over time.

Full environmental layers/model results of the PLP are publicly available via the NSW Government's Sharing and Enabling Environmental Data (SEED) portal.

The modelling for each species was undertaken using environmental niche modelling (ENM) to predict the distribution of suitable habitat across New South Wales in the years 1750, 2000, and projected to 2030 and 2070 using NSW NARCliM climate projections. It has considered the type and condition of habitat, its extent and distribution, and the amount of connected habitat available for populations through time and across various climate scenarios. Through this modelling, we have developed a new way to look at how these fauna species occupy the landscape.

Although the PLP framework accounts for projected climate change as a general trend, it does not explicitly include specific climatic, or climatic-induced events such as drought and wildfire. Thus, this framework assumes gradual change arising from climate change, whereas in fact, these changes are sometimes expressed as dramatic, step-wise changes.

The PLP supports SoS in applying an evidence-based approach to delivering practical help for threatened species. SoS can use the insights provided by the PLP in our prioritisation processes and to guide the allocation of resources. The program will be better able to quantify the relative benefits of undertaking habitat conservation and repair actions across New South Wales, with more certainty about the impacts of climate in coming decades.

The PLP has been a collaboration involving the Department of Planning and Environment (DPE), the University of New England and Macquarie University. An extensive process of expert elicitation and review at various stages of the modelling project has drawn on ecologists from DPE, other agencies, universities, and private individuals.

1.2 PLP objectives and approach

The PLP is designed to inform spatial priorities for the conservation of SoS's landscape managed threatened fauna in New South Wales. This includes considering habitat suitability, ecological condition, species-specific landscape connectivity, and expected geographic shifts in climate suitability in response to future climate change.

The project objectives are to:

- identify and help prioritise places where suitable habitat is likely to exist for each species, now and under projected climate change, assuming the extent of native vegetation is kept constant.
- where possible, consider where populations of each species can potentially persist, with i) sufficient resources at the home range scale (the spatial scale at which a species moves daily), and ii) sufficiently connected habitat at the dispersal scale (the spatial scale at which a species disperses to colonise new ranges).

1.3 Saving our Species and PLP

The Saving our Species (SoS) program is one of the NSW Government's largest ever conservation commitments. It aims to secure the long-term viability of populations of threatened plants and animals in the wild over the next 100 years. This requires:

- identifying priorities and optimising investment in the management of threatened species.
- encouraging community and government participation in the effective conservation of threatened species.
- making decisions about ongoing management based on best available evidence and evaluation of outcomes, which may mean deprioritising or ceasing investment in unviable projects.

This program has three main foci: prioritising adaptive strategies to save specific plants and animals, maximising the number of species under management, and maintaining a database with detailed information on project sites to increase community awareness, knowledge, and involvement.

Under SoS, all threatened species are allocated to one of six management streams, according to their distribution and ecology: landscape managed, site managed, iconic, data deficient, partnership, and keep watch species.

Landscape managed species are threatened plants and animals that need landscape-scale conservation projects. They are best assisted by addressing widespread threats such as habitat loss or degradation within a landscape. These species are often widely distributed, highly mobile or rely on long-range dispersal.

Projects currently being undertaken by SoS to conserve landscape managed threatened species include habitat restoration, enhancing landscape connectivity and management programs.

The PLP aligns with the SoS priority research themes of improving management effectiveness and program decision support.

1.3.1 Improving management effectiveness

The PLP approach reduces uncertainty around the impacts of climate change. By modelling landscape capacity into the future, the PLP supports SoS, guiding on-ground conservation management actions for landscape managed species.

1.3.2 Program decision support

Priority mapping and associated spatial data from the PLP will support decision-making in evaluating the impact of different conservation proposals on species persistence. Priority maps have been designed to integrate into SoS prioritisation processes to guide conservation investment to where it will have the most impact across multiple species, from a climate-adaptation perspective.

Given that there is no way of knowing which, or if any, of the numerous projected future climates will be realised, the PLP adopted an ensemble approach. It considers a range of plausible outcomes using the 12 NARCliM projections for NSW, finding areas of agreement between these. The approach seeks to find robust and resilience-building responses to the uncertainty posed by climate change, to achieve acceptable or least-worst outcomes across the range of plausible futures (Carpenter 2002; Haag & Kaupenjohann 2001; Peterson et al. 2003).

1.4 The PLP in the context of other projects

Prior to the PLP NSW Department of Planning and Environment developed landscape modelling that extended state-wide vascular plant-based, community-level biodiversity assessment to account for expected spatial shifts in climatic niches across a range of climate projections (Drielsma et al. 2017; Drielsma et al. 2015; OEH 2016). The work included novel modelling, visualisations, and plain-text messaging, designed to engage conservation practitioners and the community in the complexity of managing biodiversity in an uncertain future. Further discussion with DPE researchers led to the idea of extending this work to apply to widespread, highly-mobile fauna.

The PLP has been developed in three stages (see Table 1). Stages 1 and 2 were pilots in which the overall approach, collaboration and modelling software were developed. These projects provided the foundation for Stage 3 of the PLP. Stage 3 is further divided into versions 3.0 (initial modelling of 75 species and draft species forecasts) and version 3.1, for which further model refinement was undertaken based on expert review. Unless stated otherwise the methods and results reported here refer to PLP v3.1. As modelling is an iterative process, there is always room for model improvement, such as applying a greater range of modelling covariates or applying updated climate predictions and including new species records. PLP v3.1 therefore should serve as a foundation for evolving impact and adaptation work on threatened species in NSW.

A separate project, the Koalas In The Landscape (KITL) project broadly follows the PLP approach, although just for koalas in inland New South Wales (DPE in prep.). KITL is currently being extended to include coastal regions of NSW as part of an ARC linkage project led by the University of Queensland (as part of the ‘Private Land Conservation in a Dynamically Changing and Risky World’ project).

Kavanagh et al. (2022) included results for seven PLP models (*Aepyprymnus rufescens, Atrichornis rufescens, Mixophyes balbus, Ninox connivens, Ninox strenua, Petauroides volans* and *Tyto tenebricosa*) in their forest monitoring assessment. The results reported here vary from those, due to further refinements to PLP after publication of Kavanagh et al. (2022).

Table 1 The three stages of model development of the PLP

	Stage 1	Stage 2	Stage 3
Species modelled	6 species	30 species (including 6 stage one species)	75 species (including 30 stage two species)
NARCliM climate projections	4 global climate models x 3 regional climate models	CSIRO x 3 regional climate models	4 global climate models (averaged regional climate models)
Epochs modelled	1750, 2000 baseline and 6 decadal time-steps (to 2070)	1750, 2000 baseline and 6 decadal time-steps (to 2070)	1750, 2000 baseline; 2030 and 2070

2. Methods

2.1 General modelling framework

2.1.1 Overview

The PLP study area covered all New South Wales, including all tenures. The project adopted a three-phase schema, which aimed at providing the flexibility needed to derive a range of primary (landscape capacity) and secondary (priority maps and multi-species refugia maps) products, to help inform conservation action.

- Phase 1: Environmental niche modelling (ENM) involved: filtering species records; fitting habitat suitability models using ANUCLIM (Xu & Hutchinson 2013) and substrate covariates; and interpolating models across space (New South Wales and the ACT) and time (2030 and 2070). Habitat suitability maps were produced for each species for each climate/time-step/modification combination (referred to below as portrayals – see 2.1.3).
- Phase 2: Rapid Evaluation of Metapopulation modelling (REMP). This step was only applied to species that were expected to be responsive to metapopulation dynamics modelling, within the limitations of the model framework; that is, generally species that operate within a band of spatial scales coarser than the granularity of the available spatial data (250 metres for climate data and 90 metres for other covariates) and fine enough so that movements are sufficiently constrained within the study area where significant areas of suitable habitat are not functionally connected. For those species falling outside of these requirements, the preferred landscape capacity model resulting from Phase 2 was equated to the Phase 1 ENM (see Table 7). Information arising from Phase 2 was used to create species forecasts.
- Phase 3: Model synthesis, whereby results for individual species were combined to highlight areas of conservation significance for multiple species into the future (see Section 6).

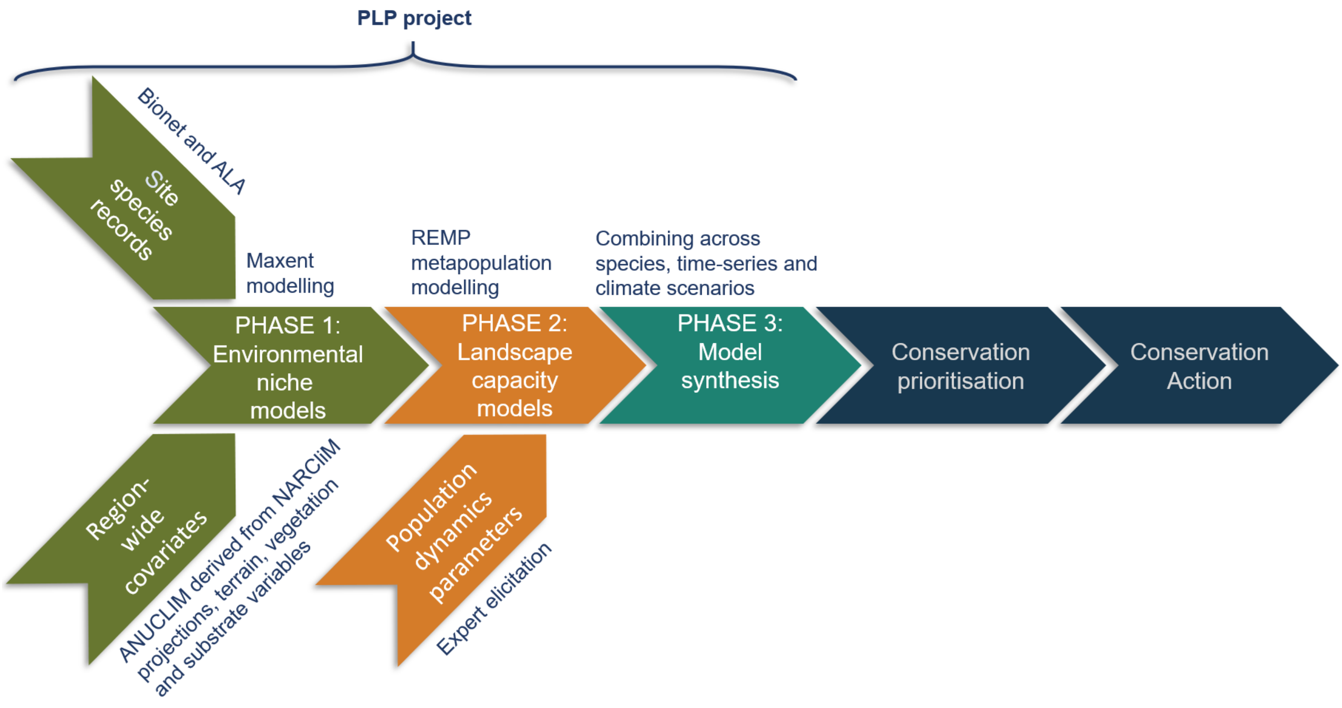


Figure 1 PLP modelling framework

Phase 1 (ENM modelling) was undertaken by the NSW Biodiversity Node at MQ using custom R code based on the MaxEnt package (Philips et al. 2006). Baseline (2000 epoch) ENMs were projected into future climates using the NARCliM climate projections (Evans et al. 2014).

An overview of the species models produced in the PLP is provided in Table 2. Of 111 landscape managed species, 88 priority species were initially chosen. Koala, black-tailed antechinus and grey-headed flying-fox were excluded as they are the subject of separate projects. Plants, invertebrates, and highly localised species were deemed unsuitable for modelling at this stage. The non-breeding superb parrot model was discarded in favour of the model based on distribution records collected during their breeding season. In total, 75 species were processed in the PLP. These are listed in Table 4 (See **Error! Reference source not found.** for list of species rejected and reasons why).

In Phase 2, a subset of ENM models (25 of the 75) were further refined to consider metapopulation dynamics using the REMP model (Drielsma & Love 2021; Drielsma & Ferrier 2009). REMP is a form of ‘process modelling’ based on current understandings of habitat space requirements and movement abilities. Population dynamic parameters needed for the REMP modelling sourced from previous DPE studies were refined in this study, and new parameters for additional species were derived through a process of expert elicitation.

Some amphibians, which move too little in relation to the granularity of the spatial data used (90 metre grids) were removed from Phase 2 (REMP modelling). Some species (including some raptors and bats) whose high mobility enables them to potentially access all suitable habitats in NSW regardless of connectivity, were also unsuitable for phase 2. A further 19 species were later removed from Phase 2 because the ENM was found to better represent the plausible distribution of the species in the baseline epoch. Many of these models could be further improved with REMP, but this would require additional model development and refined movement parameters.

Figure 2 below shows the more detailed steps of the PLP process, illustrating the roadmap of potential pathways for deriving landscape capacity, including iterative revision and refinement. In Phase 3, the model synthesis stage, landscape capacity surfaces for individual species were combined to provide insights for multi-species conservation.

Models were refined based on expert review (Phase 2a) by returning to earlier points in the process as required. Revision could lead back to the start of the modelling process (i.e., the ENM stage); to the REMP parameterisation stage; to the spatial treatments stage; or away from the REMP option and to the ENM-only path. Spatial treatments included a range of optional model treatments that comprised:

- spatial masks to constrain model interpolation to locations that were considered feasible for species occupancy now and into the future,
- distance to water modifiers,
- ecological condition weighting and/or
- masking to native vegetation extent.

Spatial treatments were applied as a stepwise process and were not mutually exclusive.

The ENM and REMP modelling both produced continuous-value grid outputs with values ranging from zero to one. Of these, the model which most closely represented landscape capacity (after considering ecological expert review) was deemed the final model for each species, and was progressed to Phase 3.

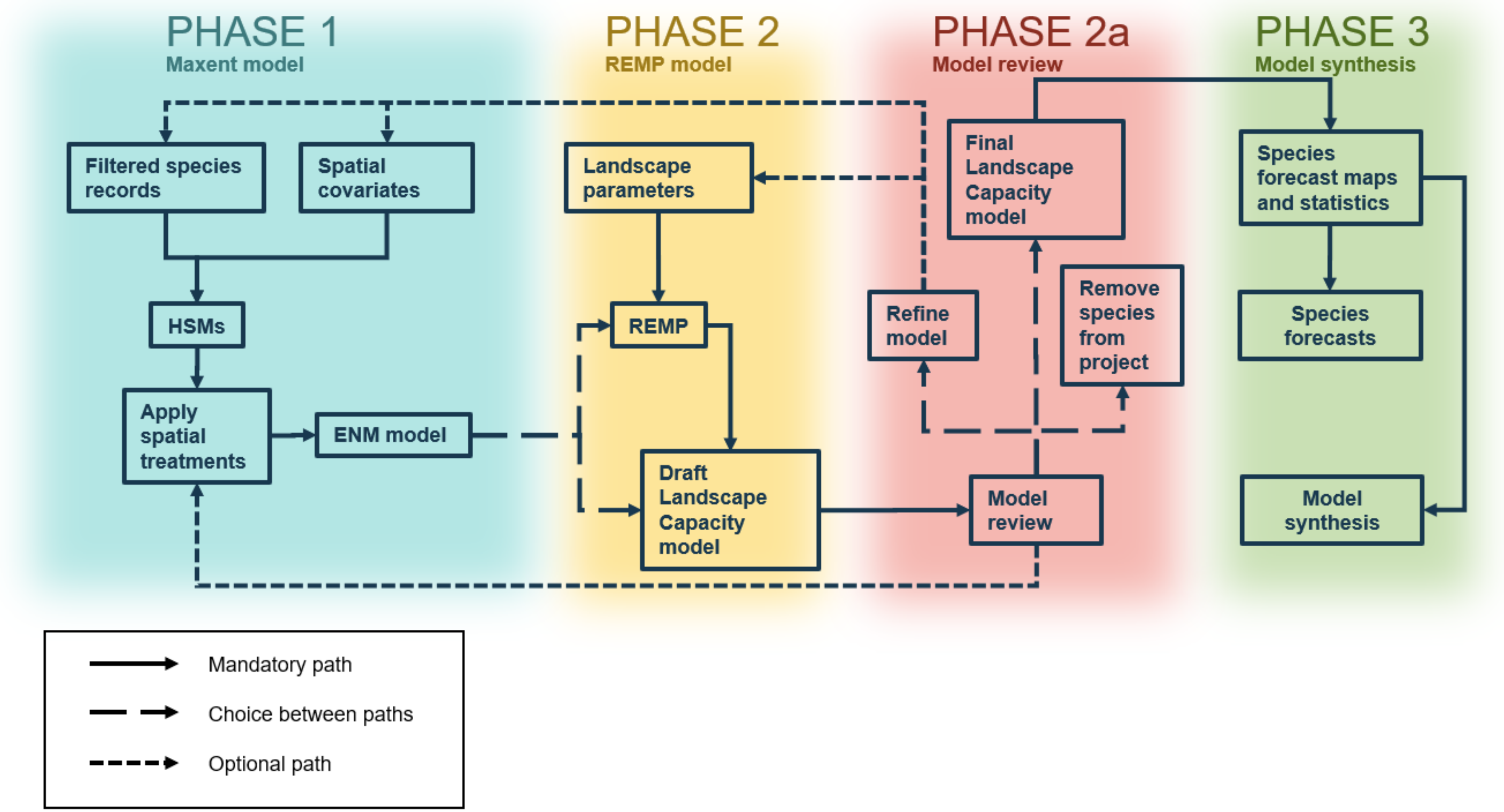


Figure 2 **Pathways for producing PLP products**

Table 2 Overview of PLP species modelling

	Number of species
SoS landscape managed species	111
Initial PLP target species	88
Final PLP species	75
ENM only models	50
REMP models	51

2.1.2 Climate modelling

To assess future habitat conditions under climate change, ENMs were produced for a baseline epoch (1990–2009) and two future scenario periods (2020–2039 and 2060–2079). The shorthand references for the epochs are 2000, 2030 and 2070, respectively. Projected ENMs were produced by replacing ANUCLIM climatic spatial predictors for the 2000 baseline with their future counterparts. The twelve GCM-RCM combination model ensemble was derived from the NARCliM 1.0 climate scenarios (Evans et al. 2014; see Appendix A).

NARCliM comprises four global climate models (GCMs), covering the breadth of plausible future temperature and precipitation scenarios:

- CSIRO_MK30 (abbreviated to CSIRO) – a warm-dry model, relative to the baseline epoch, developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Meteorology
- CCCMA31 (CCCMA) – a hot-wet model, developed by the Canadian Centre for Climate Modelling and Analysis
- ECHAM5 (ECHAM) – a hot-dry model, developed by the Max Planck Institute for Meteorology, Hamburg, Germany
- MIROC32 (MIROC) – a warm-wet model, cooperatively produced by the Japanese research community, known as the Model for Interdisciplinary Research on Climate.

In the NARCliM project, each of these four GCMs was downscaled using three regional climate models (RCMs), denoted R1, R2 and R3 (Evans et al. 2014), thereby creating 12 projections per epoch, for each species. Phase 1 modelling was undertaken based on each of the 12 projections. For each species, the three RCM-based results were averaged to produce a single result for each GCM, which was used in Phase 2 and 3.

The 'raw' output from the ENM modelling was a pre-industrial model ('unmodified', with no impacts from clearing or degradation of habitat applied). The pre-industrial version of the 2000 epoch equates to conditions expected to have occurred in 1750, with reconstructed pristine habitats modelled into areas currently cleared or otherwise altered since European settlement (commencing AD 1788). For future epochs, the pre-industrial version reflects the level of habitat suitability that could occur if habitat were reconstructed in those areas in the future. These models were then modified according to the treatments detailed in Table 7.

2.1.3 Model portrayals

We refer to individually configured models as model portrayals. Each portrayal was a single run of the ENM/REMP model based on a combination of the following model dimensions (see Figure 3):

- the species examined
- one of four GCMs
- one of three RCMs (R1, R2 or R3)
- one of three epochs (2000 baseline, 2030 and 2070)
- one of two disturbance regimes (1750 pre-industrial, or modified).

In Phase 1, the ENMs for all 12 NARCliM climate projections were used (four GCMs, each combined with each of the three RCMs). ENM outputs for each RCM were then averaged for their respective GCM, which was then progressed to Phases 2 and 3. The entire process generated 26 pre-industrial (circa 1750, where all original habitat is assumed intact and at optimal vegetation condition) model portrayals for each species: one 2000 climate baseline, and 12 GCM/RCM combinations each for 2030 and 2070 (see Figure 3). A total of 1900 model portrayals were produced in Phase 1:

Total portrayals = ((4 GCMs x 3 RCMs x 2 future epochs) + 1 x baseline) x 75 species

To reduce computational and data management demands, RCMs were averaged across each GCM, reducing the total portrayals to 850, which were then progressed to Phase 2 and 3.

Ecological condition (Love et al. 2020a) was initially applied as a treatment (multiplier) to derive a ‘modified’ habitat state, where the contemporary pattern of vegetation clearing, and modification tempers the habitat value at each location (Gibbons & Freudenberger 2006; Love et al. 2020a; Tehrany et al. 2017; Zerger et al. 2006). The appropriateness of this initial treatment was part of the review process following Phase 2 of the PLP process.

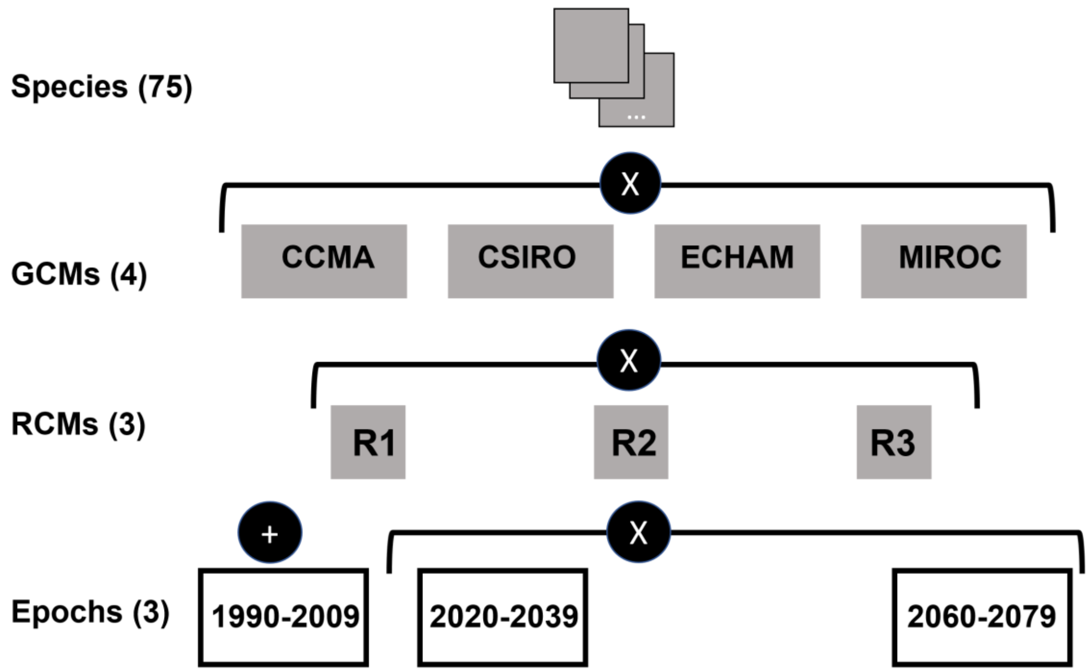


Figure 3 Model structure for each species

This figure illustrates how a total of 1900 initial model portrayals were generated for the PLP based on combinations of the three epochs, three RCMs, four GCMs and 75 species.

2.1.4 Species selected

A panel of species experts and DPE accountable officers worked with the SoS team to decide which of the 111 landscape managed threatened species under the SoS program should be considered as priorities to be analysed by the PLP. Initially 88 species were selected. Of these, 12 were filtered out, principally: plants and invertebrates (which were considered unsuitable due to the relative coarse granularity of the climate data used), species with separate projects outside of PLP, and species that could not be modelled satisfactorily within the constraints of the project. The excluded species and the reasons for their removal from the PLP are provided in Table 3. There may be scope to re-visit some or all of the excluded species, as well as species not prioritised, at a later date.

Table 3 Species removed from PLP and reasons for removal

Species	Reason for not including model
Anseranas semipalmata	Poor model
Antechinus arktos	Separate project
Cheilanthes sieberi subsp. pseudovellea	Fine granularity plant
Dentella minutissima	Fine granularity plant
Diplodactylus ameyi	Confusion with records after recent species split from *D.platyurus*
Eulamprus leuraensis	Poor model – fine granularity – ground water dependant
Lophoictinia isura	Poor model
Meridolum corneovirens	Fine granularity invertebrate
Petalura gigantea	Fine granularity invertebrate
Phascolarctos cinereus	Separate project
Polytelis swainsonii (non-breeding)	Only the breeding mode of this species was modelled
Pteropus poliocephalus	Separate project
Rhodamnia rubescens	Fine granularity plant

The greater glider (*Petauroides volans*) was not initially included as part of the PLP as it is not currently listed as threatened in NSW. It was later included due to its relevance to forest monitoring (Kavanagh et al. 2022). Evidence is emerging that the greater glider has suffered declines in recent decades, which have been attributed to climate change (Smith and Smith 2020; Wagner et al. 2020).

The final 75 species included in the PLP are detailed in Table 4.

Table 4 Landscape managed species modelled for the PLP (75 species) and their status within NSW and the Commonwealth (mammals are divided into two groups: bats and 'mammals, other').

Scientific name	Common name	Taxa	Commonwealth status	NSW status
Assa darlingtoni	pouched frog	Amphibians	Not listed	Vulnerable
Heleioporus australiacus	giant burrowing frog	Amphibians	Vulnerable	Vulnerable
Litoria littlejohni	littlejohn's tree frog	Amphibians	Vulnerable	Vulnerable
Mixophyes balbus	stuttering frog	Amphibians	Vulnerable	Endangered
Mixophyes iteratus	giant barred frog	Amphibians	Endangered	Endangered
Philoria loveridgei	loveridge's frog	Amphibians	Not listed	Endangered
Chalinolobus picatus	little pied bat	Bats	Not listed	Vulnerable
Miniopterus australis	little bent-winged bat	Bats	Not listed	Vulnerable
Nyctophilus corbeni	corben's long-eared bat	Bats	Vulnerable	Vulnerable
Phoniscus papuensis	golden-tipped bat	Bats	Not listed	Vulnerable
Saccolaimus flaviventris	yellow-bellied sheathtail-bat	Bats	Not listed	Vulnerable
Scoteanax rueppellii	greater broad-nosed bat	Bats	Not listed	Vulnerable
Vespadelus baverstocki	inland forest bat	Bats	Not listed	Vulnerable
Artamus cyanopterus cyanopterus	dusky woodswallow	Birds	Not listed	Vulnerable

Scientific name	Common name	Taxa	Commonwealth status	NSW status
Atrichornis rufescens	rufous scrub-bird	Birds	Not listed	Vulnerable
Botaurus poiciloptilus	australasian bittern	Birds	Endangered	Endangered
Burhinus grallarius	bush stone-curlew	Birds	Not listed	Endangered
Callocephalon fimbriatum	gang-gang cockatoo	Birds	Not listed	Vulnerable
Calyptorhynchus banksii samueli	red-tailed black-cockatoo (inland subspecies)	Birds	Not listed	Vulnerable
Calyptorhynchus lathami	glossy black-cockatoo	Birds	Not listed	Vulnerable
Certhionyx variegatus	pied honeyeater	Birds	Not listed	Vulnerable
Chthonicola sagittata	speckled warbler	Birds	Not listed	Vulnerable
Cinclosoma castanotum	chestnut quail-thrush	Birds	Not listed	Vulnerable
Circus assimilis	spotted harrier	Birds	Not listed	Vulnerable
Climacteris picumnus victoriae	brown treecreeper (eastern subspecies)	Birds	Not listed	Vulnerable
Coracina lineata	barred cuckoo-shrike	Birds	Not listed	Vulnerable
Cyclopsitta diophthalma coxeni	coxen's fig-parrot	Birds	Endangered	Critically endangered
Daphoenositta chrysoptera	varied sittella	Birds	Not listed	Vulnerable
Dasyornis brachypterus	eastern bristlebird	Birds	Endangered	Endangered
Glossopsitta pusilla	little lorikeet	Birds	Not listed	Vulnerable

Scientific name	Common name	Taxa	Commonwealth status	NSW status
Grantiella picta	painted honeyeater	Birds	Vulnerable	Vulnerable
Haliaeetus leucogaster	white-bellied sea-eagle	Birds	Vulnerable	Not listed
Hieraaetus morphnoides	little eagle	Birds	Not listed	Vulnerable
Ixobrychus flavicollis	black bittern	Birds	Not listed	Vulnerable
Lathamus discolor	swift parrot	Birds	Critically endangered	Endangered
Lophochroa leadbeateri	major mitchell's cockatoo	Birds	Not listed	Vulnerable
Melanodryas cucullata cucullata	hooded robin (south-eastern form)	Birds	Not listed	Vulnerable
Melithreptus gularis gularis	black-chinned honeyeater (eastern subspecies)	Birds	Not listed	Vulnerable
Menura alberti	albert’s lyrebird	Birds	Not listed	Vulnerable
Neophema pulchella	turquoise parrot	Birds	Not listed	Vulnerable
Ninox connivens	barking owl	Birds	Not listed	Vulnerable
Ninox strenua	powerful owl	Birds	Not listed	Vulnerable
Oxyura australis	blue-billed duck	Birds	Not listed	Vulnerable
Pachycephala inornata	gilbert's whistler	Birds	Not listed	Vulnerable
Pachycephala olivacea	olive whistler	Birds	Not listed	Vulnerable
Pandion cristatus	eastern osprey	Birds	Not listed	Vulnerable

Scientific name	Common name	Taxa	Commonwealth status	NSW status
Petroica boodang	scarlet robin	Birds	Not listed	Vulnerable
Petroica phoenicea	flame robin	Birds	Not listed	Vulnerable
Podargus ocellatus	marbled frogmoth	Birds	Not listed	Vulnerable
Polytelis swainsonii	superb parrot (breeding)	Birds	Vulnerable	Vulnerable
Ptilinopus magnificus	wompoo fruit-dove	Birds	Not listed	Vulnerable
Ptilinopus regina	rose-crowned fruit-dove	Birds	Not listed	Vulnerable
Stagonopleura guttata	diamond firetail	Birds	Not listed	Vulnerable
Stictonetta naevosa	freckled duck	Birds	Not listed	Vulnerable
Tyto tenebricosa	sooty owl	Birds	Not listed	Vulnerable
Aepyprymnus rufescens	rufous bettong	Mammals, other	Vulnerable	Vulnerable
Cercartetus nanus	eastern pygmy-possum	Mammals, other	Not listed	Vulnerable
Dasyurus maculatus	spotted-tailed quoll	Mammals, other	Endangered	Vulnerable
Macropus dorsalis	black-striped wallaby	Mammals, other	Not listed	Endangered
Macropus parma	parma wallaby	Mammals, other	Not listed	Vulnerable
Ningaui yvonneae	ningaui	Mammals, other	Vulnerable	Vulnerable
Petauroides volans	greater glider	Mammals, other	Vulnerable	Not listed
Petaurus norfolcensis	squirrel glider	Mammals, other	Not listed	Vulnerable

Scientific name	Common name	Taxa	Commonwealth status	NSW status
Phascogale tapoatafa	brush-tailed phascogale	Mammals, other	Not listed	Vulnerable
Pseudomys oralis	hastings river mouse	Mammals, other	Endangered	Endangered
Thylogale stigmatica	red-legged pademelon	Mammals, other	Not listed	Vulnerable
Aprasia parapulchella	pink-tailed legless lizard	Reptiles	Vulnerable	Vulnerable
Coeranoscincus reticulatus	three-toed snake-tooth skink	Reptiles	Vulnerable	Vulnerable
Delma impar	striped legless lizard	Reptiles	Vulnerable	Vulnerable
Harrisoniascincus zia	rainforest cool-skink	Reptiles	Not listed	Not listed
Hoplocephalus bitorquatus	pale-headed snake	Reptiles	Not listed	Not listed
Hoplocephalus stephensii	stephen’s banded snake	Reptiles	Not listed	Vulnerable
Silvascincus tryoni	tryon’s skink	Reptiles	Not listed	Vulnerable
Brachyurophis fasciolatus	narrow-banded snake	Reptiles	Not listed	Not listed
Varanus rosenbergi	rosenberg's goanna	Reptiles	Not listed	Vulnerable

3. Phase 1: Environmental niche models

Environmental niche models (ENMs) estimate the suitability of a region for a species, based on the assumption that the environmental tolerances and preferences of the species are described by the location of current populations (Franklin 2010; Guisan et al. 2017).

ENMs fall into two broad categories—those that use both the presences and absences of the target species (presence-absence models) and those that require presence only data. Repeated comparisons of algorithms have failed to identify a single 'best' approach, although generally presence-absence models have higher predictive performance (see Elith et al., 2006). However, presence-absence data is both rare and restricted in taxonomic and geographical coverage. In contrast, presence-only data (e.g., specimen-backed museum and herbarium records, or incidental observations from diverse sources) are plentiful and cover a wider geographical extent. Given the abundance of presence-only data, presence-only ENMs are now widely applied to problems in biodiversity conservation. Fitting presence-only ENMs was selected as the most feasible method for PLP species.

ENMs can be used to map the distribution of suitable habitat and assess the suitability of a region under altered environmental conditions, including climate change. Applying a fitted model to new environmental data to produce a map of predicted suitability is referred to as 'model projection'. Suitability maps produced by ENMs are an important input to dynamic models of populations in the landscape (e.g., REMP) as they indicate areas in which populations may persist, or that are suitable for establishment following dispersal, due to favourable environmental conditions. In contrast, occupancy models based on presence-absence data produce probability of occurrence maps that account for the influence of environmental variables and survey methods on the probability of detecting species.

While presence-only ENMs are useful tools for exploring the distribution of suitable habitat, they do not directly predict the distribution of a species *per se*. Rather, they identify the location of putatively suitable habitat with respect to the environmental variables used to fit the model. There are numerous reasons why a region may be predicted to have high suitability yet have no documented population: dispersal limitations preventing the species from occupying the location; additional covariates, such as those related to competition or resources, are absent from the model; local extinction occurred before records were obtained; or sampling in that location has been inadequate. Alternatively, model resolution or fitting may be sub-optimal.

Extensive research has shown that a number of critical factors influence the performance of presence-only ENMs. The most important factors include spatial and temporal biases in the sampling of occurrence records, selection of the region from which data is drawn for model fitting, and adjusting software settings to optimise predictive performance.

Sampling biases affect the degree to which available occurrence records provide an accurate representation of the range of occupied environments. A biased representation of environments leads to a model which may over-predict suitability in areas with a higher density of occurrence records and, conversely, under-predict in low-density areas. Therefore, it is vital that the impact of sampling biases in occurrence records be accounted for during ENM fitting (often referred to as 'mode calibration') (Merow et al. 2013; Syfert et al., 2013). Several methods are now available that adjust for sampling biases (Merow et al. 2013). For PLP species we applied the spatial thinning method (Aiello-Lammens et al., 2015).

For PLP, we elected to fit ENMs using MaxEnt, a presence-only machine learning method. MaxEnt has shown good predictive performance (Elith et al., 2006), and is supported by reliable and robust software tools. Presence-only ENMs such as MaxEnt require the user to supply the coordinates of a set of locations (i.e., within dispersal distance) available to individuals of the species being modelled, but that are not known to be occupied (Merow et al., 2013). These locations are referred to as ‘background locations’ although they may be inappropriately referred to as ‘pseudo-absences’ in older ENM literature (see Syfert et al., 2013). Defining the region within which a random sample of background locations is drawn can influence the quality of a fitted MaxEnt model. For PLP species we used the method described by VanDerWal et al. (2009) which sets a circular buffer around occurrence records to constrain background selection. The radius of the buffer is determined for each species to represent the distance which individuals might be expected to access during their lifetime.

Research has also highlighted the necessity of exploring alternate model fitting settings to maximise the predictive performance of ENMs, a process referred to as ‘model tuning’ (Merow et al., 2013) or model optimisation. For MaxEnt models, the most influential settings are the types of derived variables (‘features’) included in the model, and a parameter which controls the overall tightness of fit to the data (the ‘regularisation’ parameter).

Like many machine-learning methods, MaxEnt uses not only the original covariates, but computes covariates derived from the original set. These derived covariates allow the model to incorporate non-linear relationships between the species and the environment, as well as accommodate interactions between covariates. Collectively, the potential covariates (original plus derived) are referred to as ‘features’. Some features available for MaxEnt models have been shown to produce highly disjointed or non-smooth relationships and lead to overfitted models. Physiological theory suggests that organisms have smooth responses to environmental gradients, and thus to avoid disjointed and possibly over-fitted models, it is usual to restrict the features used in a MaxEnt model to linear (i.e., the original covariate value), products between covariates (accounting for interaction effects) and quadratic values (products of covariates with themselves to allow for smooth non-linear aspects of species-environment relationships). We used only linear, product and quadratic features in the MaxEnt models fitted to PLP species.

MaxEnt’s regularisation parameter also controls the tightness of fit to occurrence data. Model tuning, undertaken by fitting models along a gradient of regularisation values, makes it possible to identify the value which produces a model with maximum predictive performance (Merow et al., 2013). Predictive performance is assessed using a cross-validation process whereby the occurrence and background data are split into ‘training’ and ‘test’ subsets. The model is fitted to the training data, and the model’s ability to correctly classify the test data is measured. This process is repeated several times at each regularisation value to ensure that a reliable estimate of performance is produced.

As documented in a section 3.3, in applying the MaxEnt method we took steps to adjust for sampling bias, constrain the region for background location selection, and optimise predictive performance by tuning the fitted model for each species.

3.1 Role of ENMs in PLP

Our objective was to refine the baseline ENM to maximise its quality using robust model performance criteria, project into future climates and use these as inputs to the REMP modelling framework (see Section 4).

The initial ENMs described the shifting climate-habitat envelopes for the species but did not account for the condition of habitat and to what extent that habitat enables species movements.

ENMs are commonly used to predict climate impacts on species distributions. For this project, the ENM for each species was projected onto the 12 NARCliM scenarios (i.e., four GCMs each downscaled using three RCMs), for the 2030 and 2070 epochs. Initially, 25 ENMs were produced for each species (one 2000 baseline, 12 for 2030 and 12 for 2070), at 250 metres resolution. ENMs were subsequently averaged across GCMs and RCMs for each species/epoch combination resulting in three ENMs per species (2000, 2030 and 2070). These models are hereafter assumed to represent the pre-industrial models (i.e., the habitat model circa 1750, illustrating what could be conserved and reconstructed in the current and future epochs). For most models, a layer of ‘ecological condition’ (Love et al. 2020a), with a continuous value range of 0–1, was then multiplied by each of the three pre-industrial models creating a set of models representing ‘modified’ habitat conditions. The ecological condition layer represents the intactness of native vegetation at and around the baseline epoch and is assumed, for the purposes of this assessment, to remain static (no further clearing or development) up to 2070. For a subset of species, a binary non-native/native layer was deemed more appropriate (see Table 7 for details of modifiers applied to each model).

Figure 4 below shows examples of ENM modelling for the pre-industrial and 2000 (baseline) modified habitat suitability, for three species. The panels on the left for each species show raw ENM outputs without any modifiers applied. These are referred to as ‘unmodified’, which approximates to 'pre-industrial' or 'pristine' conditions circa 1750. They indicate potential landscape capacity through successful ecological restoration. The panels on the right show the ENM multiplied by species-specific modifiers. These are referred to as 'modified' habitat suitability. In Figure 4, brown indicates very low habitat suitability (species unlikely to occur), cream indicates moderate suitability habitat; dark blue indicates most suitable habitat.

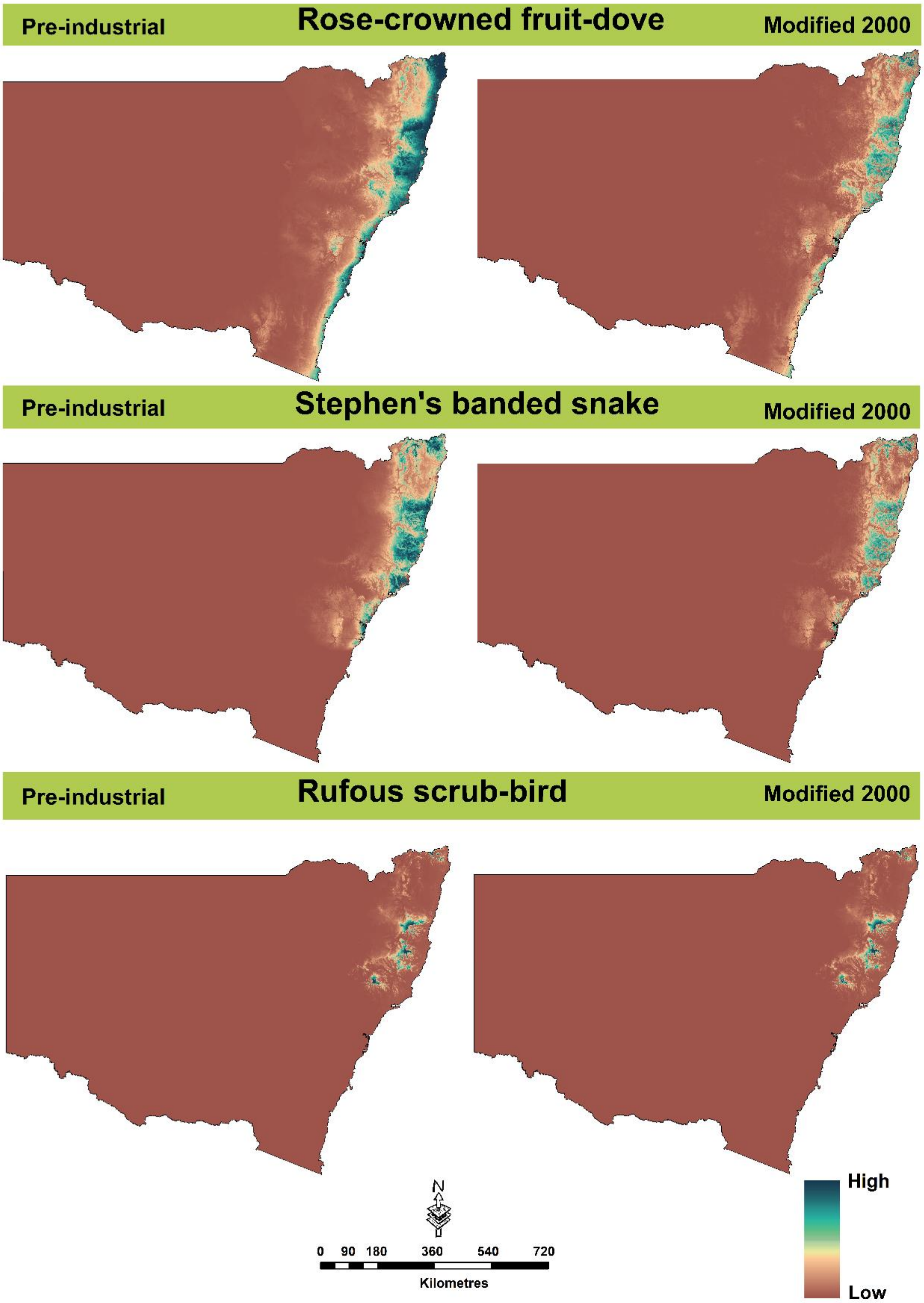


Figure 4 **ENMs for three SoS landscape managed species, comparing 'pre-industrial' portrayals (derived as the unmodified 2000 epoch model) with 'modified' portrayals (the 2000 epoch model with condition applied)**

3.2 Environmental covariates

ENMs were fitted using a panel of prospective environmental covariates covering three classes of variables: basic bioclimatic variables, topographic features and basic soil properties (see Table 6, Appendix B). Cumulative experience suggests that this panel of covariates can reliably model environmental suitability for a wide variety of species (Wilson, pers. obs.; Beaumont, pers. obs.).

The basic bioclimatic variables included the original 19 BIOCLIM variables (Booth et al., 2014), sourced from the NARCliM data set. Current or baseline data, and future data, was represented by climate data as described in Section 2.1.2.

The three topographic variables used were slope and aspect of grid cells, and the Topographic Wetness Index (TWI) which provides a measure of hydrological inflows into each grid cell from upslope areas. It is computed as the natural logarithm of the upslope area divided by the grid cell slope (Gallant and Austin, 2012). Finally, three basic measures of soil physical composition where included. They represent the percent of the soil in a grid cell present as clay, sand, or silt (Viscarra et al., 2014a, b, c). The topographic and soil composition data was assumed to remain stable over the time frame covered by the PLP project (i.e., to 2070).

All covariate data was sampled and projected onto a 250 m grid on the Australian Alber’s Equal Area projection.

3.3 Occurrence data

Species occurrence data for the 75 landscape managed fauna species was downloaded from the Atlas of Living Australia (ALA) and the NSW government's BioNet atlas as the primary data set for each species. These two sources contain records for the whole of Australia and NSW, respectively. The majority of BioNet records are incorporated into ALA and therefore many records appear in both databases. The duplicated records were removed during the data preparation and cleaning as indicated below.

Some of the species are classed as sensitive and their exact locations are not displayed or made readily available to the public through ALA. To ensure these models were as accurate as possible we sought permission to access the denatured records from their custodians i.e., the Queensland Department of Environment, Land and Water; Victoria Department of Environment, Land, Water and Planning; South Australia Department for Environment and Water; and ACT Environment, Planning & Sustainable Development Directorate. This combination of databases provided a complete, accurate and current as possible set of species occurrence records. We used records from the whole of Australia, beyond the boundary of the NARCLiM study area, to ensure species' realised environmental envelopes could be captured as accurately as possible. The baseline model review led to further refinement of occurrence records. Expert reviewers identified instances of spurious records and the existence of an additional dataset or datasets which led to new MaxEnt models being developed for 16 species.

We collated and cleaned occurrence data for each species using the following protocol:

1. Load occurrence data from BioNet when available
2. Load data from ALA (using both specimen-backed records and incidental observations)
3. Load data from other sources (if available)
4. Remove records with missing coordinates (affecting ALA data in particular)
5. Remove records prior to 1950
6. Using an example environmental raster, filter collated records so that only one record per grid cell is retained (this substantially aids in reducing spatial sampling bias)
7. Plot occurrence data and remove suspected outlier records by reference to expert feedback and range maps for the species or sub-species.

Steps 1 to 6 were completed automatically using an R script, while step 7 was performed using the GIS program ArcGIS.

The final number of occurrence records used for each species is shown in Table 7 (Appendix B).

3.4 MaxEnt modelling for the PLP

ENM models were fitted to the 75 landscape managed fauna species using the MaxEnt method (Phillips et al., 2006; Elith et al., 2011) as implemented in the R package maxnet (Phillips et al., 2017). The protocol for model fitting included the following steps:

1. Occurrence data collation and cleaning
2. Adjusting for sampling bias by thinning occurrence records

3. Selecting and applying a radius around occurrence records to constrain background point selection (with the radius for a species selected to reflect the probability of individuals accessing adjacent regions)

4. Fitting a sequence of models along a gradient of regularisation values

5. Selecting the best performing value of regularisation

6. Projecting the optimal model onto baseline and each future epoch.

The above protocol or workflow was implemented as a series of R scripts to ensure computational efficiency and reproducible outputs.

Table 7 also shows the main environmental covariates (those contributing more than 5%) for each MaxEnt species model. Detailed model reports for each MaxEnt model are provided in the PLP data pack.

4. Phase 2: Landscape capacity

ENMs help us predict how climate change may affect regions and their suitability for landscape managed species. For sound management it is also critical to predict a population's ability to access and occupy sufficient suitable habitat to support long-term persistence. This is dependent on the effective area of patches and their placement across a region. Phase 2 of the PLP focused on spatial prediction of landscape capacity (denoted Pi, also known as ‘potential occupancy’) across New South Wales.

Landscape capacity is a measure of each location’s (each 90 x 90 m grid cell) capacity to support occupancy of a particular species. It is dependant on that location’s habitat suitability and its connectivity to other suitable habitat. The PLP considers landscape capacity at the home range scale (for sustaining individuals), and connectivity between habitats at the species’ dispersal scale, to show potential for colonisation of vacant territories. By doing this it factors in the time-lagged equilibrium state arising from population dynamics. For example, a location may have the resources needed by a species and the species may be found there, but due to a reduction of habitat and connectivity to nearby habitat, that area may not be capable of supporting a population into the future. In such a situation it is said that 'extinction debt has yet to be paid'.

Pi is essentially a species-centric landscape metric. As such, Pi provides us with information on the capacity of locations to support occupancy in the absence of other factors such as interspecific competition, predation, disease, road-kills and stochastic events such as fire and storms. Thus, it is useful for informing management decisions that relate specifically to the quality and distribution of habitat.

Pi is a downstream or value-adding product of the ENM process. ENMs are largely a product of field data, reporting on the relationship between bio-physical variables and historic observations. Pi has the general effect of negating or downgrading the ENM results in areas with insufficient distribution of suitable habitat to support a population. Likewise Pi improves the outlook for regions that do have sufficient habitat distribution, even in places where local habitat quality may be suboptimal.

4.1 Rapid Evaluation of Metapopulation Persistence

Where the scale of species landscape interactions allows, Pi is derived using a process-based modelling approach known as the Rapid Evaluation of Metapopulation Persistence (REMP) methodology, and the associated REMP tool (Drielsma & Love 2021; Drielsma &

Ferrier 2009). In addition to an ENM input, REMP requires a set of population dynamics and model performance parameters for each species.

After completion of Stage 2 of the PLP, REMP was fundamentally overhauled (Drielsma & Love 2021). Changes made to the model resolved some methodological issues, which helped address apparent underprediction in previous versions for some species.

REMP was originally developed to assess the net impacts of land-use changes on species persistence. The initial focus was on the effects of clearing of native vegetation for agriculture and the establishment of private reserves to offset clearing persistence (see Drielsma et al. 2016). The method can also be used to assess persistence for species groups. REMP has since been applied across a range of regional assessments in New South Wales (Foster et al. 2017; Love et al. 2015; Taylor et al. 2012; Taylor et al. 2016). Doerr et al. (2013) and then Foster et al. (2017) applied the method using a generic focal species approach. Doerr et al. (2013) applied the approach to a range of future climate and land-use scenarios. The PLP represented another step in a process of continual improvement of the REMP model. It is the first attempt to extend REMP analysis to the broader spatial scale of New South Wales. Lower spatial resolution than previous studies was used, due to accommodate the current resolution of climate projection data.

4.1.1 Species landscape characteristics

For some species, PLP used species landscape characteristics developed in previous projects (Drielsma et al. 2016; DECCW 2009; Taylor & Drielsma 2012; Taylor et al. 2016). For the PLP, parameters for additional species were drawn from scientific literature and through a process of expert elicitation. For some birds and reptiles, for which parameters were not available from other sources, parameters were approximated based on a relationship that was established between movement ability, and body weight and size. REMP performance parameters were selected that achieved an acceptable mix of rigor and computational efficiency.

The species landscape characteristics are detailed in Table 8 (Appendix B), summarised as:

1. minimum viable habitat area (MVH)
2. minimum and maximum home range (day-to-day) movement ability
3. minimum and maximum dispersal movement ability.

In the PLP, MVH was defined as the minimum area of ideal habitat (in hectares) that would be required to sustain a population for 100 years, assuming a circular-shaped patch with ideal habitat suitability and maximum permeability to movement throughout the patch. REMP species were modelled using two spatial scales/resolutions (finer resolution for analysing finer-scale home range movements; and coarser resolution for dispersal movements). Each spatial scale/resolution required minimum and maximum average movement abilities (for worst and best permeability conditions, respectively).

Experts, from within and outside DPE, with intimate knowledge of the PLP species, were engaged to provide species' movement capabilities. An expert elicitation protocol was developed using a combination of 'wisdom of the crowd' theory, the psychology of making estimates with limited evidence and group discussion. Th is was used in a series of workshops, organised around species groups (e.g., micro bats, raptors, songbirds). Forming a relationship with these experts was an important part of the process.

Discussions in the workshops between experts and the modelling team were sometimes lengthy, as there was often confusion about what information was being sought, and there was difficulty in parsing technical/modelling language to language that aligned with the field experience of experts for a particular species. It was also difficult to find meeting times suitable for all the participants, as they were often involved in fieldwork. To help manage these challenges, a presentation was prepared to explain the project, what parameters were needed, and how the modellers would use the information. It included a set of straight-forward questions, allowing the team to derive useable parameters from their answers. The presentation was shared with experts prior to workshops. In some cases, the PLP team pursued alternative approaches, including one-on-one phone calls.

The PLP collated species population dynamic parameters for 56 species modelled in PLP, including the 25 species deemed ultimately suitable for REMP modelling (see Table 8). Figure 5 depicts species landscape characteristics charted for 47 species. Average dispersal ability is charted on the horizontal axis; average home range movement on the vertical axis; the bubble areas are in proportion to the MVH needed to support a population, adapted from Drielsma et al. (2022). As an example, the parameters for powerful owl (species number 68) are highlighted in the top right breakout. The approximately linear relationship on the log-log chart indicates a power-law between home range and dispersal movement, which is more marked within taxonomic groups, indicated by the different colours on the chart (adapted from Drielsma et al. 2022). Species and parameters associated with each PLP number shown here are provided in Table 8.

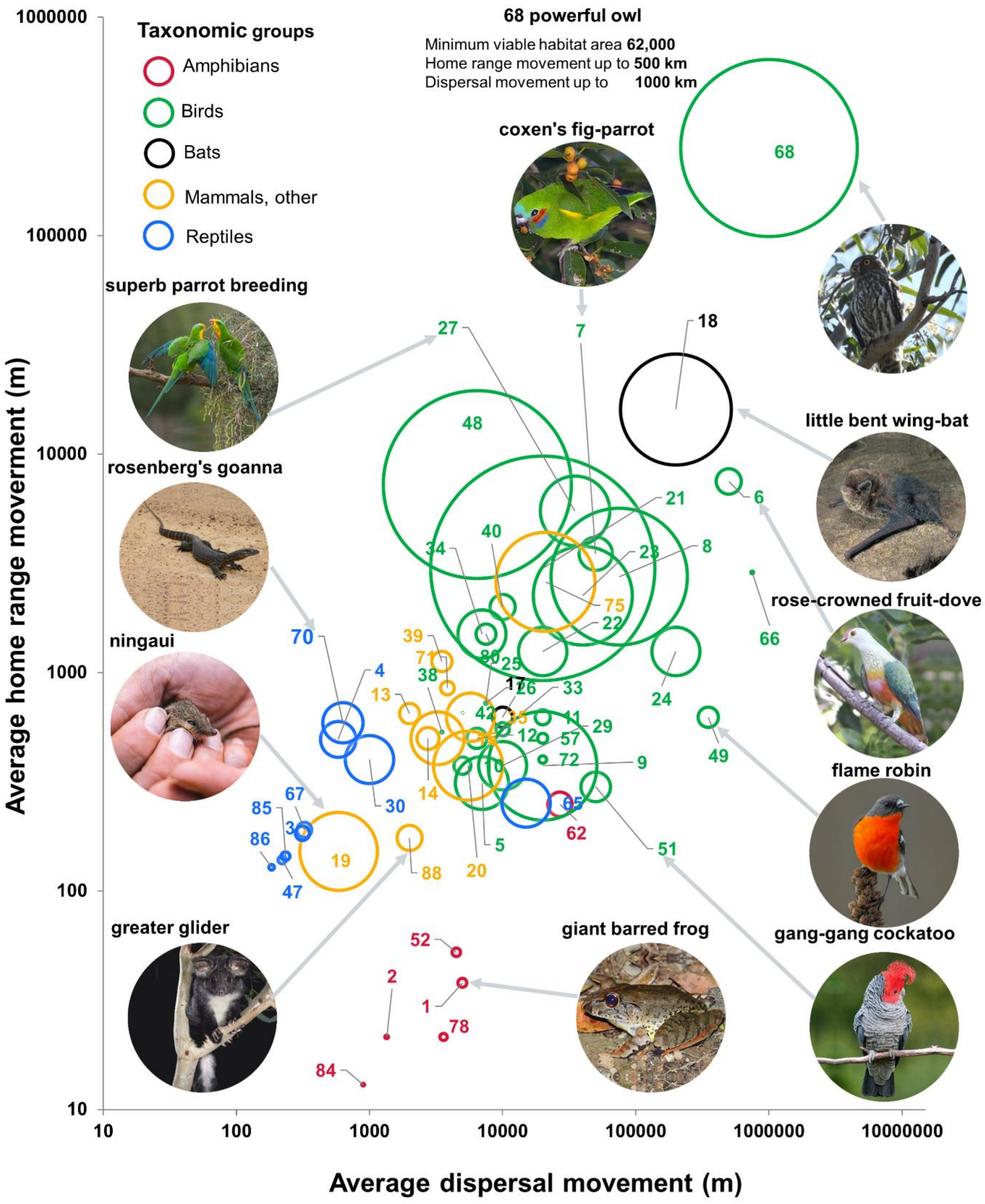


Figure 5 **Species landscape characteristics plotted for 56 landscape managed species modelled in the PLP**

5. Phase 2a: Expert review of Phase 2 outputs (ENM or REMP)

To facilitate the review process, two online components were developed and provided to expert reviewers: interactive story maps and a PDF map. Further information on the review process is provided in Appendix C.

Recent advances in digital geographic information system (GIS) technologies provide new opportunities for engaging scientists/experts and members of the public. ArcGIS story maps are very useful interactive tools for communication and information sharing. The interactive nature of the story maps moves significantly beyond other presentation software, such as Microsoft PowerPoint, allowing the experts/reviewers to display and interrogate our draft models easily. Being able to pan in and out of the map can help our reviewers better understand our models and relate them to the on-ground reality.

5.1 v3.1 Refinements

In response to reviewer comments, the following actions were taken for some species as required:

- Re-running MaxEnt models with improved plot data (new data or additional filtering) or alternative MaxEnt parameterisation
- Replacement of REMP models with ENM-only models in Phase 2 when the ENM-only model was found to better represent the baseline distribution as expressed by the plot data, or by expert knowledge
- Application of one or more of the following modifiers (each with a range of zero to one, applied multiplicatively) to the ENM model (prior to REMP stage, where applicable):
    - Ecological condition (higher weight for higher condition)
    - Native/non-native vegetation (weight of one for native vegetation; otherwise, zero)
    - Distance to water (higher weight for closer to water)
    - Geographic mask (one for in expected range; zero for outside)

The v3.1 refinements that were applied are provided in Table 7 (Appendix B).

6. Phase 3: Model synthesis

The model synthesis phase integrated model portrayals (combining species, climate projections, epochs, and pre-European/condition variants of the model) from Phases 1 and 2, to provide insights into management options. The synthesised products of the PLP comprised individual species forecasts, a ‘climate refugia map’ and a ‘landscape capacity over time map’. Combining multiple data can accumulate error and uncertainty, and the factor or combination of factors that are driving the result is often obscured in the output map. However, the approach can successfully highlight locations or regions where there is strong model agreement about climate refugia. This shows locations where the prospect of maximising conservation benefit across multiple species is most likely achieved (Drielsma et al. 2017).

6.1 Species forecasts

Species forecasts were prepared for each of the 75 species. For each model portrayal, the preferred model (ENM or REMP, with or without additional refinements) produced a grid of landscape capacity. For the purposes of reporting overall trends, the percentage of landscape capacity remaining was calculated for each epoch, by dividing the sum of Pi across NSW at that epoch by the summed Pi for the unmodified model x 100[1].

Each species forecast includes two maps. The 'distribution of landscape capacity over time' map, prepared for the individual species forecasts is a multi-band map showing landscape capacity projected throughout the epochs according to colour: green for pre-industrial (unmodified model), blue for pre-industrial and 2000, yellow for pre-industrial and 2070, and red for new habitat projected to emerge by 2070. Additive combinations of colours occur where these overlap, including white, indicating continuous landscape capacity throughout the epochs up to 2070. These white areas indicate climate refugia.

The second map in the species forecasts is a consensus map of modified ENM-level models, based on the 2070 epoch. It captures both the magnitude of habitat suitability, and the agreement across GCM-level outputs. The habitat suitability consensus was calculated for each 90 metre pixel as the number of GCM models for which the landscape capacity in 2070 was above a threshold of 0.25 (25% of the maximum value of one). Thus, the range of values in the consensus map was between zero (no GCM models above threshold) and four (all GCM models above threshold). Areas with higher consensus values are to be considered most suitable for the species going forward. The rating associated with the consensus map is an expert-assessment of how well the GCM models agree (NB: if all 4 GCMs predict little or no landscape capacity across NSW, the consensus map will have low or zero values across NSW, and the consensus rating will be 'G' i.e., good agreement).

6.2 Combined climate refugia index

The combined climate refugia index (CCRI) identifies areas that provide landscape capacity across multiple species, time-steps, and climate projections: that is, areas that score high CCRI are expected to support the highest densities of PLP species over the next 50 years. CCRI provides a measure of relative conservation *importance* across space with respect to the PLP species.

CCRI is calculated at each location as a weighted sum of landscape capacity across the PLP species and across epochs. Greater weight was given to the most threatened species, persisting and emerging habitat, and species with restricted ranges. These were implemented as follows:

1. Greater weight was given to the most threatened species - a weight (w_s) was applied to component models according to their listed NSW species listing categories (not listed: 0.5; vulnerable: 0.67; endangered: 0.83).
2. To recognise the focus of conservation efforts on the future, differential weighting (w_t) was applied to model outputs from each of the three epochs (2000: 1.0; 2030: 2.39; 2070: 3.08).
3. Restricted range species were given a higher weight than wide ranging species. This was a simple linear transformation based on a threshold (t_r) of 2.0 x 10^7, which

[1] For the purposes of calculating statistics and for mapping, where spatial masks were developed for a species model, this was applied to all epochs, including the pre-Industrial epoch.

approximately equals summed Pi for the most widespread of the species in PLP. The range weight (w_r) for each species was calculated as:

$$w_r = \frac{(t_r - \sum P_i)}{t_r}$$

Equation 1

This ensures that w_r equals close to 1.0 for the most restricted-range species, and close to 0.25 for the most widespread species. A final adjustment was to divide by the sum of w_t (i.e., 6.47) to maintain the overall value range at the species level at between zero and one.

Thus, locations were weighted according to their conservation importance in supporting the most threatened and range-restricted species into projected future climate. The climate refugia value h_i for grid cell i was expressed as:

$$h_i = \left[\sum^{t}\sum^{s}\left(p_i^{st}.w_s.w_t.w_r\right)\right]/6.47$$

Equation 2

The CCRI design means that h_i can be interpreted as having units of 'species equivalents' i.e., if Pi for all 75 species was hypothetically at its maximum (1.0) at a location, and all weights were at the maximum (also 1.0), then h_i at that location would equal 75. In practice, the number of species will never reach the maximum of 75 at any site; with the downward effect of the weights, maximum h_i values become significantly less than the potential maximum.

Four CCRI maps were produced based on:

1. the three epochs (as described above)
2. the 2000 epoch only
3. the 2070 epoch only
4. the net change, denoted Δh_i, between the 2000- and 2070-only epoch.

Δh_i attempts to show how considering climate change has influenced the distribution of conservation benefits, as calculated using the CCRI approach. Δh_i represents the *net* change in species equivalents for a location, i.e., at any given location species can remain, colonise, or fade through time; Δh_i captures the net result of these dynamics. Each location will experience different dynamics: at different locations it is not necessarily the same species that are being retained, gained, or lost. Thus, Δh_i gives no indication of the total number of species being lost or retained across New South Wales; it shows the changes to aggregated landscape capacity at each location.

6.3 Landscape capacity over time map

The landscape capacity over time (LCOT) map was developed to show aggregated results across all species and epochs, including pre-industrial (unmodified model), on a single map. It shows how the aggregated landscape capacity has changed in the past and how it is projected to change with future climate change.

The map (Figure 9) is a three-band composite image where foundational colours are assigned to the summed landscape capacity modelled at three epochs: pre-industrial (green); 2000 (blue); and 2070 (red). When landscape capacity extends across multiple epochs, the resulting colour on the map is a combination (sum) of the colours. When the summed Pi across the 75 species is (relatively) high for all three epochs, the combined colour on the map is white; when landscape capacity at an epoch is partial (between zero and the maximum for NSW), the tint is adjusted accordingly (brighter for higher values and darker for lower values). Each component band is calculated as:

$$L_t = \sum_{s=1}^{76} P_i^s$$

Equation 3

where L_t is the LCOT component for epoch *t*, and each species is indexed by *s*. The multi-band layer was derived using the ArcMap composite bands function.

7. Results

7.1 Phase 2: Species-specific products

7.1.2 Landscape capacity grids

The PLP has generated landscape capacity (Pi) spatial data grids for each of the 75 landscape managed species for 1750 (the unmodified pre-industrial model), 2000, 2030 and 2070. Some of these grids are based on the ENM and some have used REMP modelling. The grids have been given specific refinement treatments where necessary (Table 7, Appendix B).

7.1.3 Species forecasts

Species forecasts have been prepared for each species. The first section of the species forecasts document is an explanation of how to read the individual species forecasts.

The forecasts have six components:

i) general species information and photo

ii) summary diagnostics

iii) a table of expected landscape capacity (summed Pi) through time

iv) species landscape characteristics, where available, that affect landscape capacity for that species, as used in REMP for 25 of the 75 landscape managed species

v) a multi-band map showing landscape capacity projected throughout the epochs

vi) a map providing a geographic depiction of the degree of consensus between the climate models regarding projected future landscape capacity for that species.

7.2 Phase 3: Model synthesis

7.2.1 Combined climate refugia index

Figure 6 below is a map of the combined climate refugia index. The magnified section of the map at the top right of Figure 6 contains some of the highest rated climate refugia index (CCRI) areas (grey) in NSW, including within Willi Willi and Cottan-Bimbang National Parks. The northeast quadrant of this section shows low CCRI results for the Walcha district of the

New England Tablelands, a highly developed farming area. The magnified section in the bottom right of the figure centres on the greater Sydney region, which has an extremely low CCRI. It highlights the refugia importance of the national parks surrounding greater Sydney.

Figure 7 shows CCRI calculated individually for 2000 and 2070 (temporal weights equal 1 in each calculation), and the change in CCRI from 2000 to 2070. The largest reductions in CCRI are expected in the relatively species-rich north coast of New South Wales and the west of the state where the degree of projected climate change is greater. However, despite this, it is evident in Figure 6 that vegetated parts of coastal regions retain relatively high CCRI, when the index is calculated across three epochs (2000, 2030 and 2070). This is despite some significant losses of landscape capacity across the 75 species. High altitude areas such as Mt Kaputar, Coolah Tops, Barrington Tops, and the Alpine region of NSW show relatively high CCRI in 2000 and show increases over the 2000-2070 period. The wheat-sheep belt of central NSW also shows moderate increases over this period.

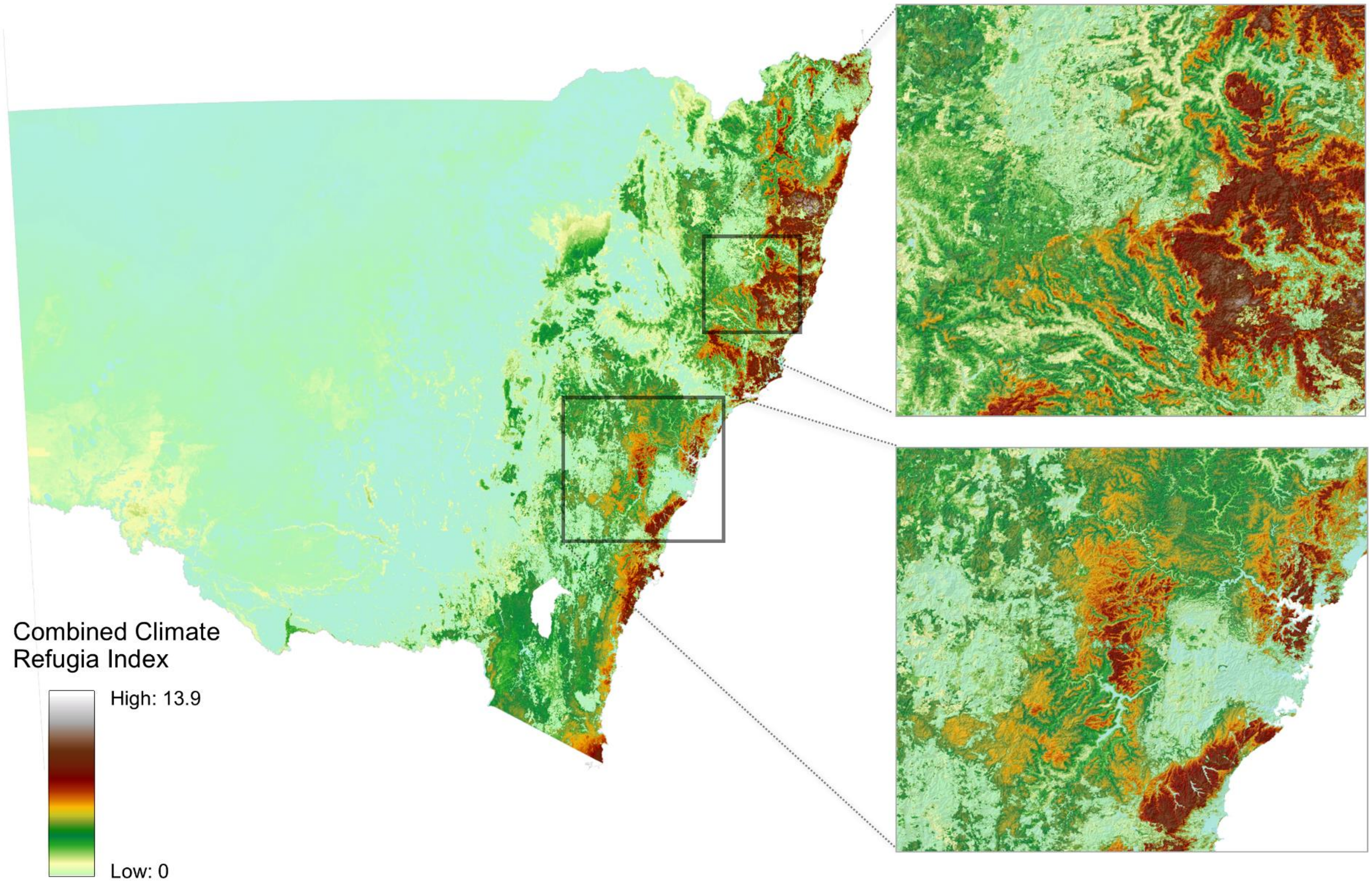


Figure 6 **Combined climate refugia index calculated for the 2000, 2030 and 2070 epochs, for the 75 landscape managed species**

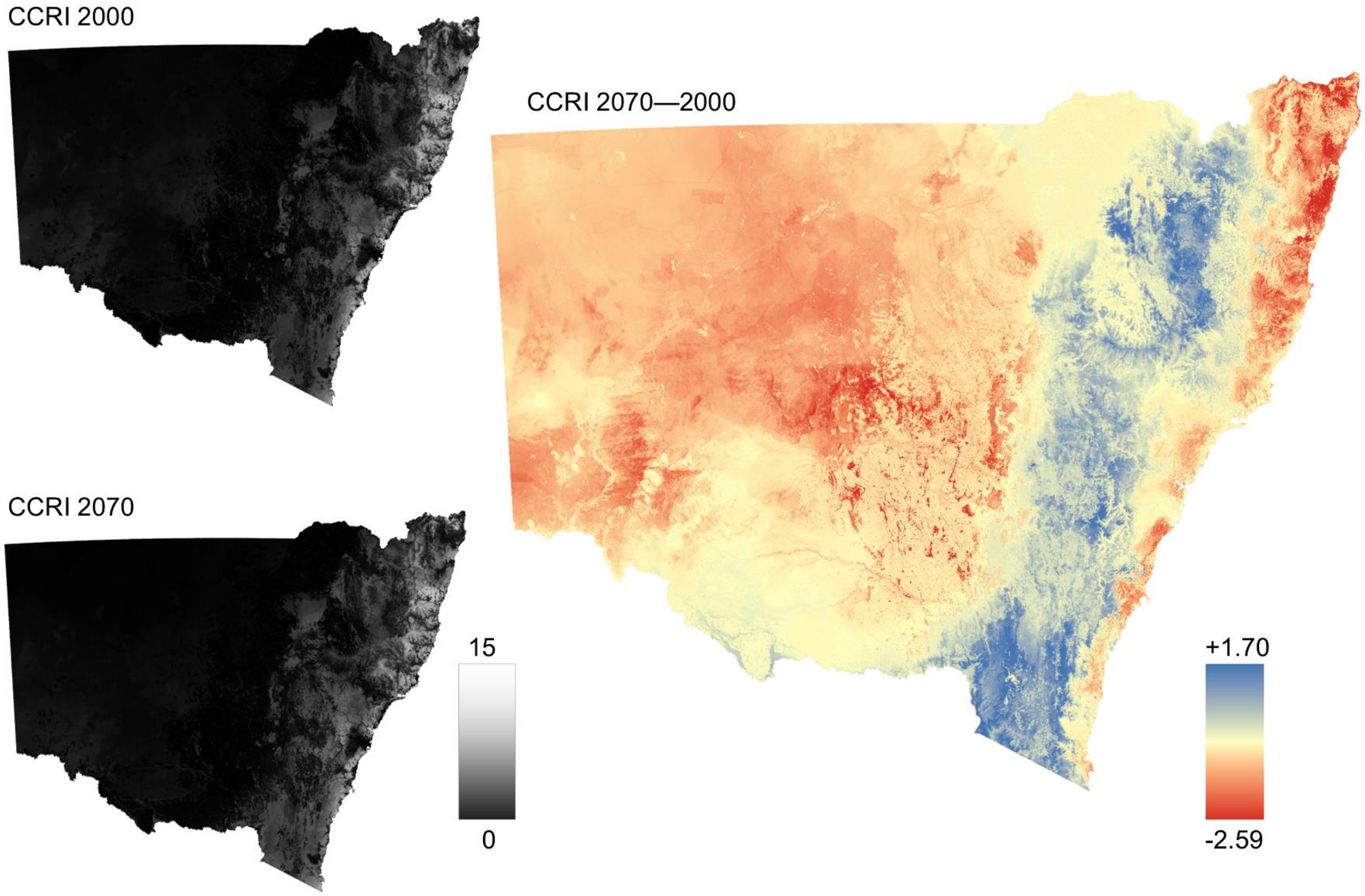


Figure 7 **Combined climate refugia index calculated on 75 landscape managed species considering 2000 alone (left-top) and 2070 alone (left-bottom), and the change between 2000 and 2070, where cream colour indicates little or no change (right).**

7.2.2 Landscape capacity over time

Landscape capacity over time (LCOT) was calculated for three epochs (pre-industrial, 2000, and 2070 as the sum of landscape capacity across NSW for each epoch. The results are presented in Table 5 and Figure 8. LCOT values are in units of 'number of species'. The potential cell values for this assessment range from 0 (no landscape capacity for any of the modelled species) to 75 (all species at maximum capacity). The value of 75 is not realised, due to natural variability of habitats across space and differing habitat requirements among the species. A maximum value of 40.34 is achieved in the pre-industrial era. The results indicate a continuous downward trend for the combined 75 species, beginning shortly after 1750, from the time of colonisation and extending to at least 2070. Up to the present day this loss was driven largely by habitat loss and invasive species. This same general trajectory is forecast to continue to at least 2070, but it will be driven by climate change - it is assumed in the assessment that there will be no further non-climate related clearing or degradation beyond the baseline epoch[2].

Table 5 Results of summed landscape capacity across 75 species for pre-industrial 2000 and 2070 epochs.

Epoch	Min. cell value	Max. cell value	Mean	STD	Sum
Pre-industrial	0	40.34	14.77	6.46	1.46E+09
2000	0	37.21	8.39	6.10	8.32E+08
2030	0	33.13	6.58	5.79	6.52E+08
2070	0	32.76	5.61	5.67	5.56E+08

[2] Although the baseline epoch is set climatically to 2000, ecological condition is based on the best available data at 2017, which includes 2013 input data (Love et al. 2020a).

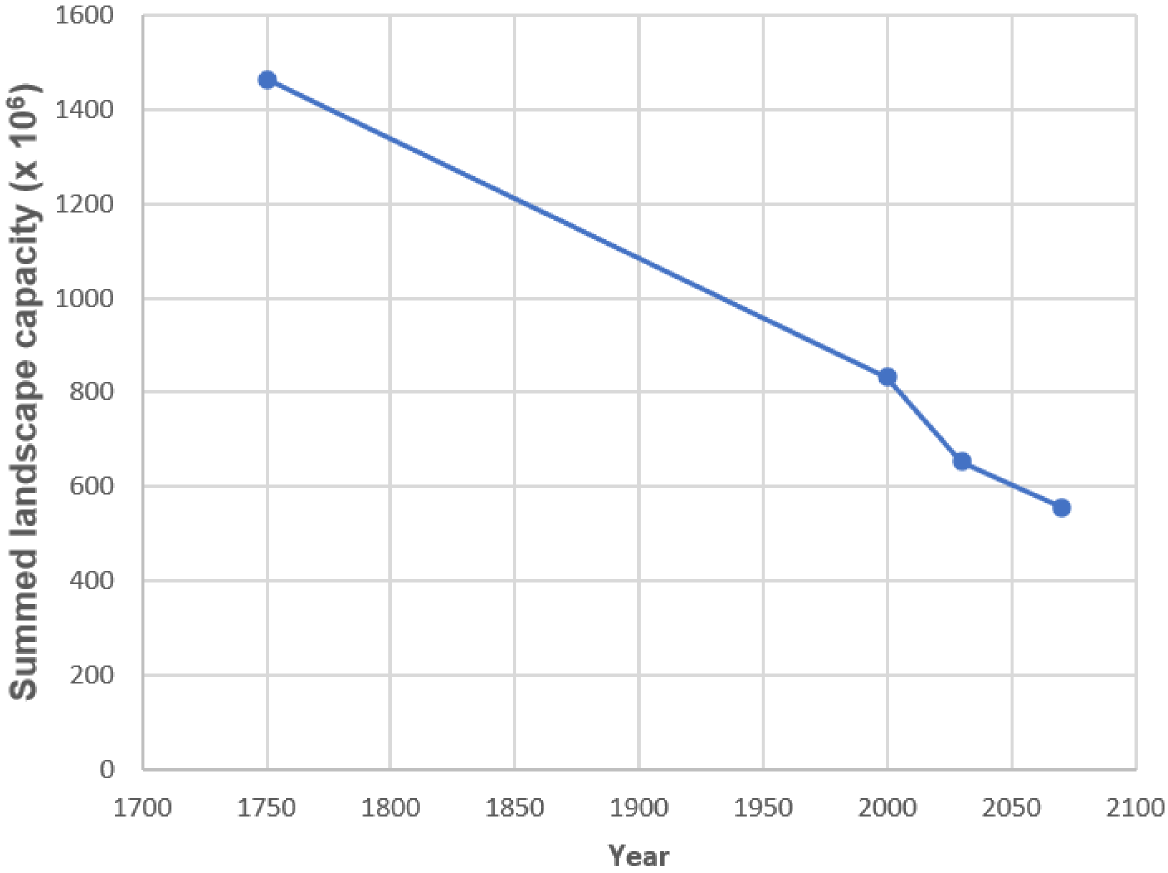


Figure 8 **Summed landscape capacity for 75 species for pre-industrial, 2000 and 2070 epochs. The general trend of decline is almost linear, beginning with European settlement in 1750 and projected into future climate change to 2070.**

The slopes of the Australian Alps region also show increases, but as has been previously reported, the alpine peaks show declines in landscape capacity (Thapa in review; Love et al. 2020b). Potential increases will likely be tempered by the requirement for species' habitat and food resources being or becoming available in the emerging habitats they seek to colonise.

A map of landscape capacity over time (LCOT) shows the aggregated landscape capacity (Pi) across the full suite of 75 PLP species models (Figure 9). The map combines three components, shown in the pyramid legend: aggregated Pi in 1750 or pre-industrial (coloured green); aggregated Pi at 2000 (blue); and aggregated Pi at 2070 (red). Thus, the map provides an overview of the combined status and forecast of the 75 species across time.

The top box legend in Figure 9 shows the five component combinations that appear most commonly on the map. These main colours are part of a continuum of possible colour combinations illustrated by the colour 'pyramid' in the bottom-right of the figure, which also indicates the approximate position of each of the common categories across the colour palette. Not all possible colour composites are represented within this analysis of New South Wales; for example pure red does not appear, as the 75 landscape managed species have different habitat requirements, there are no locations where all are expected to appear by

2070[3]. The best candidate areas for multiple species retention up to 2070 are in the white and pink regions of the map. It should be noted that these are in areas historically rich in species; for example, along the eastern escarpment and the coast. However, there are some species with continuing western distributions that are not well represented by this map. These can be better examined in the species forecasts.

The LCOT map indicates that much of the original, pre-industrial occupancy within the central wheat-sheep belt was already depleted by 2000 (green, pre-industrial only). The generally intact, high-altitude habitats of the eastern ranges provide relatively secure habitats from pre-industrial times through to 2070 (indicated by white and pale pink colours). Closer examination of the individual species models in the high-altitude areas reveals there is considerable turnover of species through time with some habitats disappearing and others migrating in over that period.

7.3 Data

7.3.1 Availability

Full environmental layers/model results of the PLP have been added to the NSW Government's SEED portal. These comprise the underlying spatial data for: the two maps in the species forecasts (distribution of landscape capacity over time, and climate model consensus); the combined climate refugia index of 75 species (Figure 6 and Figure 7); and landscape capacity over time (Figure 9).

7.3.2 Projection

The ENMs have been developed in the GDA 94 Geographic Coordinate System (EPSG:4283) at 0.0009DD pixel resolution, predominantly reflecting their source data. Once data were combined into the habitat suitability models, these were projected to the Australian Albers (GDA 94) equal area projected coordinate system (EPSG:3577). Using an equal area projection ensured that each 90 metre pixel across the entire study area represented, as closely as possible, an equivalent (on-ground) area (0.81 hectares), not accounting for topographic relief.

7.3.3 Granularity

The ENMs were limited to a maximum granularity of 250 metres (the spatial resolution of the ANUCLIM data). When combined with ecological condition (Love et al. 2020a), this resulted in 90 metre granularity for 'modified' portrayals. All Pi outputs were produced at 90 metre granularity.

[3] This map is a multi-species version of the first map in the individual species forecasts derived through combining the results across all modelled species.

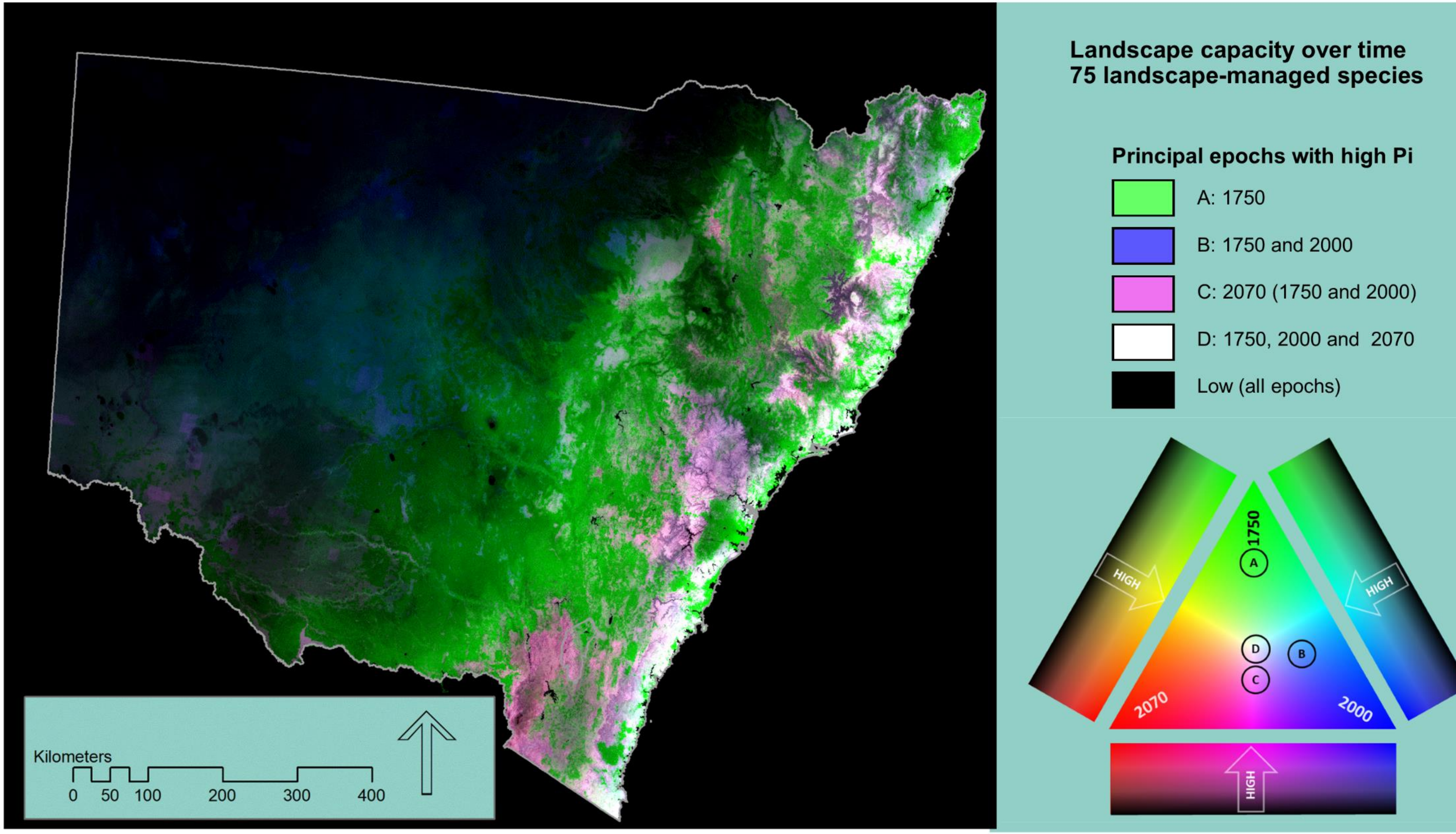


Figure 9 **Landscape capacity over time (LCOT) for 75 species. Colours in the legends box are representative examples only. Their positions on a continuum in the colour pyramid (bottom-left chart) are indicated by their letters (A-D).**

8. Discussion

The PLP has shown that despite uncertainties about climate change and how it will impact the landscapes of New South Wales over the next 50 years, we can identify areas that are likely to be important for conservation of landscape managed threatened species.

The strength of the PLP's modelling is that it has been undertaken across a range of plausible climate futures. This approach is well suited to situations where uncertainty, in this case future climate, prevents a deterministic approach to conservation planning. This is vital to building resilience against a range of plausible futures.

Having both species-specific and aggregated products such as hotspot maps provides SoS with valuable information about how to secure individual species in the wild for the long term. They also provide guidance on ways to prioritise our efforts and resources to help multiple species with a single action or set of actions.

The PLP and its products have added significantly to the SoS decision-making toolbox. These products will direct practical on-ground action to places where it is most likely to achieve positive results. It is this approach that has made SoS a world-class framework for threatened species conservation.

8.1 Insights into the modelling

The modelling undertaken within this project was sophisticated in comparison to many alternatives; however, it remains simplistic in contrast to the real-world complexities of species–habitat–climate interactions. There are areas for potential improvement in the modelling, including the development or sourcing of a wider range of modelling covariates. Finding ways to consider stochastic events, including extreme drought and wildfire, which are known to have historically shaped the distributions of species and ecosystems and will continue to do so, would also be useful.

The species forecasts consider a long timespan from pre-industrial times to 2070. They provide an outlook *at this time* (2021) reported against what we estimate as the conditions in pre-industrial times. Inevitably, as the future unfolds this outlook will evolve. Projections will be superseded by realisation, allowing models to be updated and improved.

This modelling is not an attempt at predicting future outcomes; rather, it is an assessment of risk and opportunity that has necessarily been tempered by practical limitations relating to the available data, models, and project resources. As always, end users need to consider the fit-for-purpose aspect of the outputs of this project; in each instance the risks associated with using these data need to be balanced against the risks of ignoring them.

Specific limitations of this project include:

- **Resolution** – Although the 90 and 250 metre granularities can be considered 'high resolution' in terms of a NSW state-scale analysis, it is too coarse to fully account for the habitat interactions of some species that respond to fine-grained habitat features (e.g., creeks) or have very localised movements.
- **ENMs** – The ENMs were developed using a limited, common set of environmental predictors (covariate). For some species, the environmental drivers of their distribution were not well represented among these. For example, the presence of nesting hollows cannot currently be accounted for, even for the current epoch. This had the effect of making the habitat availability to species such as the superb parrot seem much higher than is known to be the case.
- **REMP** – REMP is an idealised perspective on population dynamics that does not suit the life histories of all species equally. The analytical basis of the REMP model was

progressively improved through the course of the PLP (Drielsma & Love 2021). These improvements were applied in the Stage 3 project.

- **Climate projections –** Climate projections will improve and be replaced over time as projections are superseded by reality. The PLP drew climate projections from NARCliM 1.0. An updated version, NARCliM 2.0, which will provide more up to date projections, is currently at its testing stage and should be available for subsequent updates to the PLP, although its adoption for PLP analysis will rely on downscaling of ANUCLIM variables to 250 metres or finer.
- **Aggregated products –** There are many other potential products arising from aggregating model portrayals in various ways. The examples are indicative only of the full range of possibilities.

9. References

Aiello-Lammens ME, Boria RA, Radosavljevic A, Vilela B, & Anderson RP 2015, spThin: an R package for spatial thinning of species occurrence records for use in ecological niche models, *Ecography*, vol.38, pp.541–545.

Booth TH, Nix HA, Busby JR, & Hutchinson MF 2014, BIOCLIM: the first species distribution modelling package, its early applications and relevance to most current MaxEnt studies, *Diversity and Distributions*, Vol.20, pp.1-9.

Carpenter SR 2002, Ecological futures: building an ecology of the long now, *Ecology*, vol.83, no.8, pp.2069–2083.

DECCW (Department of Environment, Climate Change and Water) 2009, *Border Ranges Rainforest Biodiversity Management Plan*, NSW Department of Environment, Climate Change and Water, Sydney, www.environment.gov.au/resource/border-ranges-rainforest-biodiversity-management-plan.

Doerr V, Williams K, Drielsma M, Doerr E, Davies M, Love J, Langston A, Low Choy S, Manion G, Cawsey ME, McGinness H, Jovanovic T, Crawford D, Austin M and Ferrier S 2013, *The architecture of resilient landscapes: scenario modelling to reveal best-practice landscape designs*, report prepared for the National Climate Change Adaptation Research Facility, CSIRO Climate Adaptation Flagship, Canberra.

DPE (Department of Planning and Environment) in prep., 'Koalas in the landscape (KITL): Mapping climate-ready priority areas for koala in inland NSW', NSW Department of Planning and Environment.

Drielsma M and Love J 2021, An equitable method for evaluating habitat amount and landscape capacity, *Ecological Modelling*, vol.440: 109388, doi.org/10.1016/j.ecolmodel.2020.109388.

Drielsma MJ and Ferrier S 2009, Rapid evaluation of metapopulation persistence in highly variable landscapes, *Biological Conservation*, vol.142, pp.529–540, doi.org/10.1016/j.biocon.2008.11.018.

Drielsma MJ, Foster E, Ellis M, Gill R, Prior J, Kumar L, Saremi H and Ferrier S 2016, Assessing collaborative, privately managed biodiversity conservation derived from an offsets program: lessons from the Southern Mallee of New South Wales, Australia, *Land Use Policy*, vol.59, pp.59–70, doi.org/10.1016/j.landusepol.2016.08.005.

Drielsma MJ, Love J, Thapa R, Taylor S and Williams KJ 2022, General Landscape Connectivity Model (GLCM): a new way to map whole of landscape biodiversity functional connectivity for operational planning and reporting, *Ecological Modelling,* Vol.465, pp.109858, doi.org/10.1016/j.ecolmodel.2021.109858.

Drielsma MJ, Love J, Williams KJ, Manion G, Saremi H, Harwood T and Robb J 2017, Bridging the gap between climate science and regional-scale biodiversity conservation in south-eastern Australia, *Ecological Modelling*, vol.360, pp.343–362, doi.org/10.1016/j.ecolmodel.2017.06.022.

Drielsma MJ, Manion G, Love J, Williams KJ, Harwood TD and Saremi H 2015, *3C modelling for biodiversity under future climate*, retrieved from www.terranova.org.au/repository/3c-modelling-east-coast-central-slopes-and-murray-basin-nrm-collection/draft-report-3c-modelling-for-biodiversity-management-under-future-climate, doi.org/10.13140/RG.2.1.4072.6161.

Elith J, S., Phillips J, Hastie T, Dudík M, Chee YE, & Yates CJ 2011, A statistical explanation of MaxEnt for ecologists, *Diversity and Distributions*, Vol.17, pp.43–57, Elith J, Graham CH, Anderson RP, Dudík M, Ferrier S, Guisan A, Hijmans RJ, Huettmann F, Leathwick J, Lehmann A, Li J, Lohmann LG, Loiselle BA, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton JM, Peterson AT, Phillips SJ, Richardson K, Scachetti-Pereira R, Schapire RE, Soberón J, Williams S, Wisz MS and Zimmermann NE 2006, Novel methods improve predictions of species' distributions from occurrence data, *Ecography*, vol.29, pp.129–151.

Evans JP and Ji F 2012a, *Choosing GCMs*, NARCliM Technical Note 1 (7pp.), NARCliM Consortium, Sydney.

Evans JP and Ji F 2012b, *Choosing the RCMs to perform the downscaling*, NARCliM Technical Note 2 (8pp.), NARCliM Consortium, Sydney.

Evans JP, Ji F, Lee C, Smith P, Argueso D and Fita L 2014, Design of a regional climate modeling projection ensemble experiment – NARCliM, *Geoscientific Model Development*, vol.7, pp.621–629, doi.org/10.5194/gmd-7-621-2014

Foster E, Love J, Rader R, Reid N and Drielsma M 2017, Integrating a generic focal species, metapopulation capacity, and connectivity to identify opportunities to link fragmented habitat, *Landscape Ecology*, vol.32, no.9, pp.1837–1847, doi.org/10.1007/s10980-017-0547-2.

Franklin J 2010, *Mapping species distributions: spatial inference and prediction*, Cambridge University Press, Cambridge, UK.

Gallant J, & Austin J. (2012). Topographic Wetness Index derived from 1" SRTM DEM-H. v2. Retrieved from: https://doi.org/10.4225/08/57590B59A4A08.

Gibbons P and Freudenberger D 2006, An overview of methods used to assess vegetation condition at the scale of the site, *Ecological Management and Restoration*, SUPP/1: S10–S17.

Gorrod EJ, Childs P, Keith DA, Bowen S, Pennay M, O'Kelly T, Woodward R, Haywood A, Pigott JP, & McCormack C 2017, Can ecological thinning deliver conservation outcomes in high-density river red gum forests? Establishing an adaptive management experiment, *Pacific Conservation Biology*, Vol.23, pp.262–276, doi: https://doi.org/10.1071/PC16040.

Graham EM, Reside AE, Atkinson I, Baird D, Hodgson L, James CS, & VanDerWal JJ 2019, Climate change and biodiversity in Australia: a systematic modelling approach to nationwide species distributions, *Australasian Journal of Environmental Management*, Vol.26, pp.112-123, doi: 10.1080/14486563.2019.1599742.

Guisan A, Thuiller W and Zimmermann NE 2017, *Habitat Suitability and Distribution Models*, Cambridge University Press, Cambridge, UK.

Haag D and Kaupenjohann M 2001, Parameters, prediction, post-normal science and the precautionary principle – a roadmap for modelling for decision-making, *Ecological Modelling*, vol.144, pp.45–60.

Hutchinson M and Xu T 2015, *Methodology for generating Australia-wide surfaces and associated grids for monthly mean daily maximum and minimum temperature, rainfall, pan evaporation and solar radiation for the periods 1990–2009, 2020–2039, 2060–2079*, report to the NSW Office of Environment and Heritage, Sydney.

Kavanagh R, Law B, Drielsma M, Gonsalves L, Beaumont L, Jenkins R, Wilson PD, Binns D, Thinley P, Bulovic N, Lemckert F, Brassil T, & Reid N 2022, NSW Forest Monitoring and Improvement Program - Final Report. Project 2: Baselines, drivers and trends for species occupancy and distribution, NSW Natural Resources Commission, Sydney. https://www.nrc.nsw.gov.au/news/80-bio-study-report.

Love J, Drielsma MJ, Williams KJ and Thapa R 2020a, *Integrated model–data fusion approach to measuring habitat condition for ecological integrity reporting: Implementation for* *habitat condition indicators*, Biodiversity Indicator Program Implementation Report, NSW Department of Planning, Industry and Environment, Sydney.

Love J, Thapa R, Drielsma M, & Robb J 2020b, *Climate change impacts in the NSW and ACT Alpine region: Impacts on biodiversity*. NSW Department of Planning, Industry and Environment, Sydney, Australia.

Love J, Taylor S, Drielsma MJ, Rehwinkel R and Moyle K 2015, *Southern Rivers NRM Stream 1 Habitat and connectivity modelling project*, NSW Office of Environment and Heritage, Armidale.

McCarthy MA, & Lindenmayer DB 1999, Incorporating Metapopulation Dynamics of Greater Gliders into Reserve Design in Disturbed Landscapes, *Ecology*, Vol.80, pp.651-667, doi: 10.2307/176642.

Merow C, Smith MJ, & Silander JA 2013, A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter, *Ecography*, Vol.36, pp.1058–1069.

OEH (Office of Environment and Heritage) 2016, *Biodiversity impacts and adaptation project (final report) – NSW and ACT Regional Climate Modelling Project*, NSW Office of Environment and Heritage, Armidale.

Peterson GD, Cumming GS and Carpenter SR 2003, Scenario Planning: a Tool for conservation in an uncertain world, *Conservation Biology*, vol.17, no.2, pp.358–366.

Phillips SJ, Anderson RP, Dudík M, Schapire RE, & Blair ME 2017, Opening the black box: an open-source release of MaxEnt. *Ecography*, Vol.40, pp.887–893.

Phillips SJ, Anderson RP, & Schapire RE 2006, Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, Vol.190, pp.231–259.

Skamarock WC 2008, *A Description of the Advanced Research WRF Version 3*, NCAR, Boulder, CO, USA.

Smith P and Smith J 2020, Future of the Greater Glider (*Petauroides volans*) in the Blue Mountains New South Wales. *Proceedings of the Linnean Society of New South Wales*, Vol.142, pp.55–66.

Syfert MM, Smith JM and Coomes DA 2013, The effects of sampling bias and model complexity on the predictive performance of MaxEnt Species Distribution Models, PLoS ONE, doi: 8. 10.1371/annotation/35be5dff-7709-4029-8cfa-f1357e5001f5.

Taylor RJ, Christian N, Drielsma MJ, Mazzer L and Bollard K 2012, *Biodiversity Conservation Plan for Namoi Catchment*, report to Namoi Catchment Management Authority, NSW Office of Environment and Heritage, Dubbo.

Taylor RJ and Drielsma M 2012, *Western Woodlands Way, Volume 2: Priorities for investment in remnant vegetation and connectivity*, NSW Office of Environment and Heritage, Dubbo.

Taylor S, Drielsma MJ, Taylor RJ and Kumar L 2016, Applications of Rapid Evaluation of Metapopulation Persistence (REMP) in Conservation Planning for Vulnerable Fauna Species, *Environmental Management*, vol.57, pp.1281–1291, doi.org/10.1007/s00267-016-0681-7.

Tehrany MS, Kumar L and Drielsma MJ 2017, Review of Native Vegetation Condition Assessment Concepts, Methods and Future Trends, *Journal for Nature Conservation*, vol.40, pp.12–23.

Thapa R, Love J, Drielsma MJ, Lamsal P, & Reid M in review, Climate change impact modelling on vegetation movement of the Australian alpine and its surrounding regions.

VanDerWal J, Shoo LP, Graham C, & Williams SE 2009, Selecting pseudo-absence data for presence-only distribution modeling: How far should you stray from what you know?, *Ecological Modelling*, Vol.220, pp.589–594,

Viscarra Rossel R, Chen C, Grundy M, Searle R, Clifford D, Odgers N, Holmes K, Griffin T, Liddicoat C, & Kidd D. (2014a). Soil and Landscape Grid National Soil Attribute Maps - Clay (3" resolution) - Release 1. v5. Retrieved from: https://doi.org/10.4225/08/546EEE35164BF

Viscarra Rossel R, Chen C, Grundy M, Searle R, Clifford D, Odgers N, Holmes K, Griffin T, Liddicoat C, & Kidd D. (2014b). Soil and Landscape Grid National Soil Attribute Maps - Sand (3" resolution) - Release 1. v5. Retrieved from: https://doi.org/10.4225/08/546F29646877E

Viscarra Rossel R, Chen C, Grundy M, Searle R, Clifford D, Odgers N, Holmes K, Griffin T, Liddicoat C, & Kidd D. (2014c). Soil and Landscape Grid National Soil Attribute Maps - Silt (3" resolution) - Release 1. v5. Retrieved from: https://doi.org/10.4225/08/546F48D6A6D48.

Wagner B, Baker PJ, Stewart SB, Lumsden LF, Nelson JL, Cripps JK, Durkin LK, Scroggie MP, & Nitschke CR 2020, Climate change drives habitat contraction of a nocturnal arboreal marsupial at its physiological limits. *Ecosphere*, Vol.11, pp.e03262, doi: https://doi.org/10.1002/ecs2.3262.

Xu T, & Hutchinson MF 2013, New developments and applications in the ANUCLIM spatial climatic and bioclimatic modelling package. *Environmental Modelling & Software*, Vol.40, pp.267–279.

Zerger A, Gibbons P, Jones S, Doyle S, Seddon J, Briggs SV and Freudenberger D 2006, Spatially modelling native vegetation condition, *Ecological Management and Restoration*, vol.7(Supplement 1), pp.S37–S44.

Appendix A – NARCliM climate futures

NARCliM downscaled four global climate models (GCMs) (Evans & Ji 2012a) based on a single socioeconomic scenario, SRES A2 equivalent to Representative Concentration Pathway (RCP) 8.5, using three regional climate models (RCMs) (Evans & Ji 2012b). RCMs were based on the Weather Research and Forecasting (Skamarock 2008) model with three different physics schemes applied (R1, R2 and R3). The four GCMs: MIROC3.2, ECHAM5, CCCMA3.1 and CSIRO-Mk3.0 were chosen to capture the full range of uncertainty within the Coupled Model Intercomparison Project's Phase 3 (CMIP3) GCMs while providing the most independent set of climate scenarios that spanned the largest range of plausible future climates. The three RCMs were used to dynamically downscale each of the four GCMs separately, resulting in 12 equally plausible future climate scenarios.

The four GCMs each represented a different climate trajectory of either warmer or hotter and wetter or drier future conditions (Figure 10). The increase in temperature from the 2000 centred baseline to the 2070 centred projections ranges approximately from 1.9°C under CSIRO-Mk3.0 to 2.8°C under ECHAM5. The change in precipitation ranges approximately from a 12% decrease under CSIRO-Mk3.0 to a 14% increase under MIROC. This range of projected climate futures allowed the NARCliM scenarios to span all likely future conditions rather than attempting to predict a single most likely climate outcome, which at the time was expected to fall somewhere within these trajectories.

A full set of ANUCLIM and MTHCLIM (monthly climate) variables (Hutchinson et al. 2015) were developed at a 0.0025 (~250 metre) resolution for the 2000 centred baseline and each future climate scenario centred on 2030 and 2070. The 2000 centred baseline variables were derived from observed Bureau of Meteorology monthly mean climate data from 1990 to 2009. Projected variables were based on each of the NARCliM climate scenarios for 2020–2039 for the 2030 centred 'near future' and 2060–2079 for the 2070 centred 'far future'.

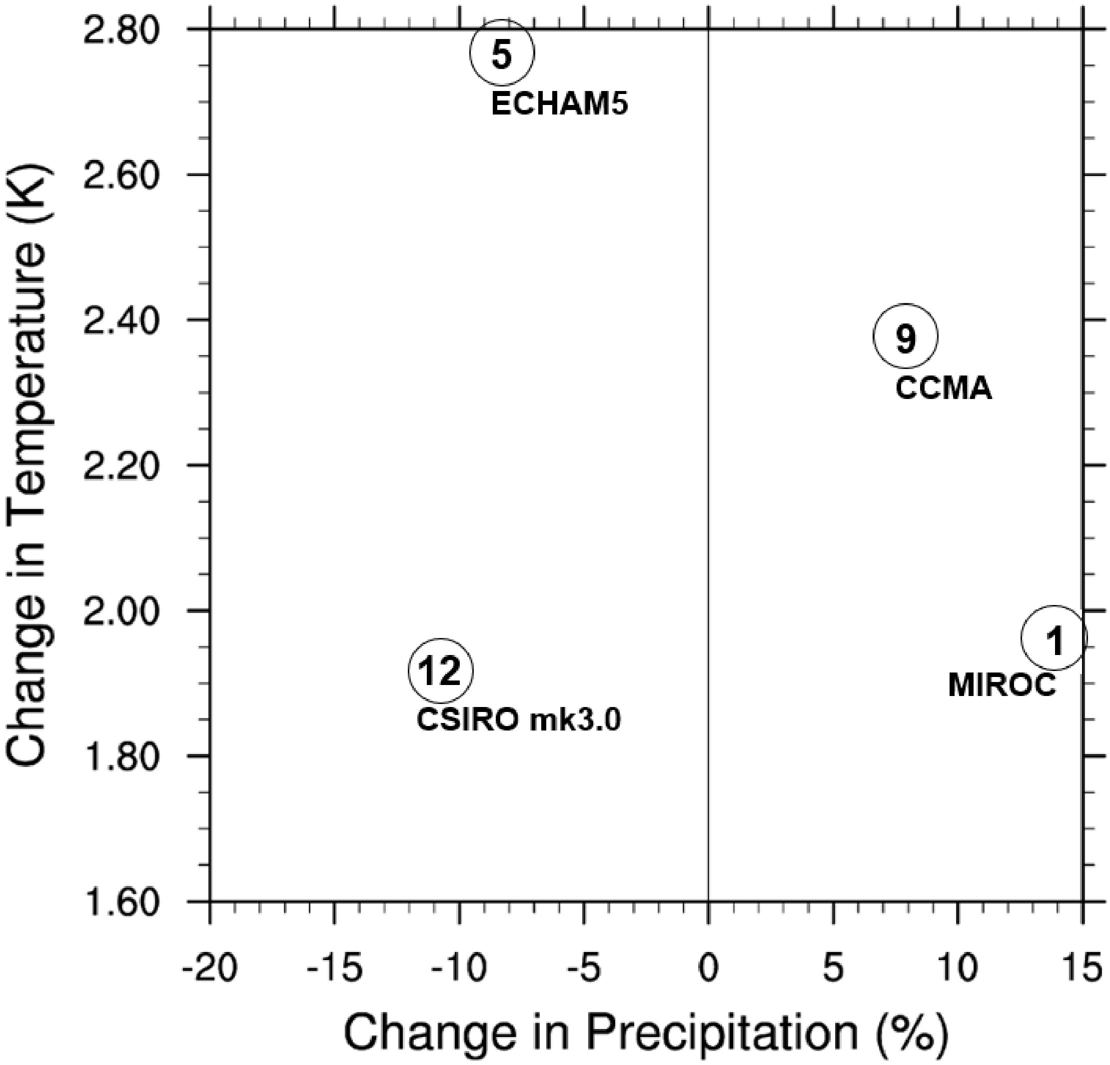


Figure 10 **The climate trajectories of the four GCMs downscaled under NARCliM showing their model independence rankings (numerical values, circled) and the far future (2070 centred) projected climate change space they cover relative to the 2000 centred baseline (adapted from: Evans and Ji 2012a).**

By 2070, the MIROC scenarios project a warmer wetter future climate while ECHAM5 projects a hotter drier future. CCCMA projects a hotter wetter future and CSIRO mk3.0 a warmer drier future climate.

By 2070, the MIROC scenarios project a warmer wetter future climate while ECHAM5 projects a hotter drier future. CCCMA projects a hotter wetter future and CSIRO-Mk3.0 a warmer drier future climate.

See NARCliM model selection on the AdaptNSW website for further information about the NARCliM climate scenarios and how the models were selected and downscaled.

Appendix B – Model inputs and refinements

Table 6 Covariates used in MaxEnt model fitting

Covariate	Definition	Source
bio01	Annual mean temperature	NARCliM
bio02	Mean monthly temperature range	NARCliM
bio03	Isothermality	NARCliM
bio04	Temperature seasonality (bio	NARCliM
bio05	Max monthly temperature	NARCliM
bio06	Min monthly temperature	NARCliM
bio07	Annual temperature range	NARCliM
bio08	Mean temp. wettest quarter	NARCliM
bio09	Mean temp. driest quarter	NARCliM
bio10	Mean temp. warmest quarter	NARCliM
bio11	Mean temp. coldest quarter	NARCliM
bio12	Annual precipitation	NARCliM
bio13	Wettest monthly precipitation	NARCliM
bio14	Driest monthly precipitation	NARCliM
bio15	Precipitation seasonality	NARCliM
bio16	Precipitation of wettest quarter	NARCliM
bio17	Precipitation of the driest quarter	NARCliM
bio18	Precipitation of the warmest quarter	NARCliM
bio19	Precipitation of the coldest quarter	NARCliM
slope	Slope within the grid cell (degrees)	CSIRO Slope derived from 1" SRTM DEM-S
aspect	Aspect of the grid cell with respect to True North	CSIRO Aspect derived from 1" SRTM DEM-S
TWI	Topographic Wetness Index: index which represents likely flows of water into the cell from upslope areas	CSIRO Topographic Wetness Index derived from 1" SRTM DEM-S
clay	Percent clay content of the soil	CSIRO Soil and Landscape Grid National Soil Attribute Maps
sand	Percent sand content of the soil	CSIRO Soil and Landscape Grid National Soil Attribute Maps
silt	Percent silt content of the soil	CSIRO Soil and Landscape Grid National Soil Attribute Maps

Table 7 **Parameters and modelling variables.**

Main predictor variables used, and number of occurrence records used for each MaxEnt model; condition modifier applied ('r' - none, 'c' – ecological condition, 'n' – native/non-native); distance to water modifier ('1' – applied, '0' – not applied); geographic mask ('1' – applied, '0' – not applied); and phase 2 method ('REMP' – REMP model was applied, 'ENM-only' – REMP model was not applied). Further information on MaxEnt models can be found in model reports in the PLP datapack.

PLP number	Scientific name	Common name	Covariates contributing more than 5% to model suitability scores	No. records	Condition modifier	Distance to water	Geog. mask	Phase3 method
84	*Assa darlingtoni*	pouched frog	bio04, bio10, bio18	340	c	0	1	REMP
52	*Heleioporus australiacus*	giant burrowing frog	bio01, bio02, bio05, bio12, bio13, bio18, bio19,	1,442	c	0	1	REMP
62	*Litoria littlejohni*	littlejohn's tree frog	bio02, bio12, bio13, bio15	6,263	c	0	1	ENM-only
78	*Mixophyes balbus*	stuttering frog	bio06, bio13, bio18, clay, silt	1,350	c	0	0	REMP
1	*Mixophyes iteratus*	giant barred frog	bio02, bio04, bio13	1,477	c	0	0	ENM-only
2	*Philoria loveridgei*	loveridge's frog	bio04, sand	93	c	0	1	REMP
61	*Chalinolobus picatus*	little pied bat	bio03, bio04, bio05, bio15, bio18, clay	480	c	0	1	ENM-only
18	Miniopterus *australis*	little bent-winged bat	bio04, bio06, bio12, bio14	2,979	c	0	1	ENM-only
43	*Nyctophilus corbeni*	corben's long-eared bat	bio02, bio11, bio13, bio14, bio15, bio17, bio18, clay	485	c	0	1	ENM-only
17	*Phoniscus papuensis*	golden-tipped bat	bio04, bio06, bio18, clay, sand, slit	1381	c	0	0	REMP
83	*Saccolaimus flaviventris*	yellow-bellied sheathtail-bat	bio04, bio12, bio15, bio17, clay	3,414	n	0	1	ENM-only
55	*Scoteanax rueppellii*	greater broad-nosed bat	bio04, bio06, bio07, bio14, bio15, bio18	2,137	n	0	0	ENM-only
58	*Vespadelus baverstocki*	inland forest bat	bio01, bio14, bio15, bio18, clay	3,015	c	0	1	ENM-only
46	*Artamus cyanopterus cyanopterus*	dusky woodswallow	bio06, bio13, bio14, clay	6,879	c	0	1	ENM-only

PLP number	Scientific name	Common name	Covariates contributing more than 5% to model suitability scores	No. records	Condition modifier	Distance to water	Geog. mask	Phase3 method
11	*Atrichornis rufescens*	rufous scrub-bird	bio06, bio07, bio11, bio12	1,462	r	0	1	ENM-only
31	*Botaurus poiciloptilus*	australasian bittern	bio01, bio06, bio07, bio10, bio15, bio17, slope	1,819	c	1	0	ENM-only
40	*Burhinus grallarius*	bush stone-curlew	bio04, bio12, bio13, bio15, sand	9,120	c	0	1	ENM-only
51	*Callocephalon fimbriatum*	gang-gang cockatoo	bio01, bio04, bio13, bio17, clay	28,837	c	0	1	REMP
69	*Calyptorhynchus banksii samueli*	red-tailed black-cockatoo (inland subspecies)	bio04, bio06, bio14, clay	1,630	c	0	0	ENM-only
54	*Calyptorhynchus lathami*	glossy black cockatoo	bio06, bio07, bio15, bio18, clay	20,157	n	0	0	ENM-only
66	*Certhionyx variegatus*	pied honeyeater	bio06, bio14, bio15, bio19	3,654	n	0	1	ENM-only
26	*Chthonicola sagittata*	speckled warbler	bio04, bio11, bio14, bio15, bio18, clay	11,041	n	0	1	ENM-only
42	*Cinclosoma castanotum*	chestnut quail-thrush	bio03, bio04, bio11, bio12, bio16, bio19, clay	3,123	c	0	0	REMP
74	*Circus assimilis*	spotted harrier	bio01, bio04, bio05, bio07, bio12, bio15	6,728	c	0	0	ENM-only
38	*Climacteris picumnus victoriae*	brown treecreeper (eastern subspecies)	bio01, bio02, bio13, bio15, bio16	19,039	c	0	1	REMP
32	*Coracina lineata*	barred cuckooshrike	bio03, bio04, bio05, bio11, bio15, bio18	1,099	c	0	1	ENM-only
7	*Cyclopsitta diophthalma coxeni*	coxen's fig-parrot	bio04, bio10, sand	183	c	0	1	ENM-only
80	*Daphoenositta chrysoptera*	varied sittella	bio01, bio12, clay	21,011	c	0	0	ENM-only
10	*Dasyornis brachypterus*	eastern bristlebird	bio07, bio12, bio17, bio18	2,794	c	0	0	ENM-only
24	*Glossopsitta pusilla*	little lorikeet	bio01, bio04, bio10, bio17, clay	12,218	c	0	0	ENM-only

PLP number	Scientific name	Common name	Covariates contributing more than 5% to model suitability scores	No. records	Condition modifier	Distance to water	Geog. mask	Phase3 method
25	*Grantiella picta*	painted honeyeater	bio01, bio04, bio05, bio14, bio15, bio17	2,015	n	0	1	REMP
81	*Haliaeetus leucogaster*	white-bellied sea-eagle	bio04, bio11, bio12, bio13,bio15	30,590	r	1	0	ENM-only
60	*Hieraaetus morphnoides*	little eagle	bio01, bio04, bio07, bio12, bio17, bio18	15,629	n	0	0	ENM-only
33	*Ixobrychus flavicollis*	black bittern	bio04, bio10, bio11, bio12, bio14, bio15	1,518	c	1	0	REMP
79	*Lathamus discolor*	swift parrot	Bio01, bio04, bio07, bio13, bio15, clay	6,570	n	0	1	ENM-only
64	*Lophochroa leadbeateri*	major mitchell's cockatoo	bio14, bio15, bio18	3,166	c	0	1	ENM-only
57	*Melanodryas cucullata cucullata*	hooded robin (south-eastern form)	bio01, bio02, bio15, bio18	12,223	n	0	1	REMP
34	*Melithreptus gularis gularis*	black-chinned honeyeater (eastern subspecies)	bio01, bio04, bio19, clay	8,814	c	0	1	REMP
5	*Menura alberti*	alberts lyrebird	bio04, bio10	968	c	0	1	REMP
29	*Neophema pulchella*	turquoise parrot	bio01, bio05, bio11, bio17, clay	2,581	c	0	0	ENM-only
21	*Ninox connivens*	barking owl	bio04, bio12, bio15, bio17	13,993	n	0	0	ENM-only
68	*Ninox strenua*	powerful owl	bio01, bio06, bio07, clay	11,173	c	0	0	ENM-only
37	*Oxyura australis*	blue-billed duck	bio01, bio02, slit, slope	6,940	r	1	0	ENM-only
23	*Pachycephala inornata*	gilbert's whistler	Bio01, bio12, bio13, bio14, bio15, clay	3,048	n	0	1	ENM-only
12	*Pachycephala olivacea*	olive whistler	bio02, bio05, bio17, sand	3,465	c	0	0	REMP
48	*Pandion cristatus*	eastern osprey	bio05, bio07, bio10, bio11, bio14	5,927	n	1	0	ENM-only
72	*Petroica boodang*	scarlet robin	bio01, clay, slit	16,792	c	0	0	ENM-only
49	*Petroica phoenicea*	flame robin	bio01, bio06, bio13, bio15	7,821	n	0	0	REMP

PLP number	Scientific name	Common name	Covariates contributing more than 5% to model suitability scores	No. records	Condition modifier	Distance to water	Geog. mask	Phase3 method
9	*Podargus ocellatus*	marbled frogmoth	bio07, bio15, bio18, sand	170	c	0	1	REMP
27	*Polytelis swainsonii (breeding)*	superb parrot (breeding)	bio01, bio04, bio15	6,801	c	0	1	ENM-only
82	*Ptilinopus magnificus*	wompoo fruit-dove	bio03, bio04, bio05, bio07, bio12, bio15, bio18, sand	6,405	n	0	0	ENM-only
6	*Ptilinopus regina*	rose-crowned fruit-dove	bio01, bio05, bio07, bio12, bio15	3,933	c	0	0	ENM-only
22	*Stagonopleura guttata*	diamond firetail	bio01, bio03, bio04, bio11, bio14	12,278	r	0	0	ENM-only
50	*Stictonetta naevosa*	freckled duck	bio01, bio02, bio07, bio15, clay, sand, slope	3,680	c	1	0	ENM-only
8	*Tyto tenebricosa*	sooty owl	bio04, bio06, bio11, bio13, bio14, bio15	4,263	c	0	0	ENM-only
71	*Aepyprymnus rufescens*	rufous bettong	bio05, bio06, bio12, bio15, bio17, bio18	1,152	c	0	1	REMP
13	*Cercartetus nanus*	eastern pygmy possum	bio01, bio02, bio13, bio17, bio19, clay, sand, TWI	898	n	0	0	ENM-only
75	*Dasyurus maculatus*	spotted-tailed quoll	bio05, bio18, clay	8,664	n	0	0	ENM-only
35	*Macropus dorsalis*	black-striped wallaby	bio03, bio04, bio06, bio07, bio14, bio17	43,125	n	0	0	REMP
15	*Macropus parma*	parma wallaby	bio02, bio04, bio18, clay	3,922	n	0	0	ENM-only
19	*Ningaui yvonneae*	ningaui	bio01, bio06, bio13, bio14, bio15, bio17, bio18, bio19, clay	744	c	0	0	ENM-only
88	*Petauroides volans*	greater glider	bio04, bio06, bio07, bio13, clay	14,638	r	0	1	ENM-only
20	*Petaurus norfolcensis*	squirrel glider	bio13, bio15, bio19, clay	3,081	n	0	0	REMP
39	*Phascogale tapoatafa*	brush-tailed phascogale	bio02, bio03, bio04, bio07, bio12, bio15, bio18, bio19, clay	3,176	c	0	0	ENM-only
56	*Pseudomys oralis*	hastings river mouse	bio11, bio15, bio18, bio18, bio19	1,128	c	0	1	ENM-only

PLP number	Scientific name	Common name	Covariates contributing more than 5% to model suitability scores	No. records	Condition modifier	Distance to water	Geog. mask	Phase3 method
14	*Thylogale stigmatica*	red-legged pademelon	bio03, bio05, bio06, bio13, bio15, sand	442	c	0	1	ENM-only
67	*Aprasia parapulchella*	pink-tailed legless lizard	bio06, bio14, bio15, bio17, clay	1,081	n	0	1	ENM-only
3	*Coeranoscincus reticulatus*	three-toed snake-tooth skink	bio04, bio10, sand	462	c	0	1	REMP
77	*Delma impar*	striped legless lizard	bio01, bio02, bio04, bio06, bio12, bio13, bio16	1,491	n	0	1	ENM-only
86	*Harrisoniascincus zia*	rainforest cool-skink	bio04, bio10, bio15, sand	336	c	0	0	REMP
30	*Hoplocephalus bitorquatus*	pale-headed snake	bio12, bio06, bio17, bio18, bio13, silt, slope,	53	n	0	1	REMP
4	*Hoplocephalus stephensii*	stephan's banded snake	bio04, bio06, bio11, bio14, bio17	554	c	0	1	REMP
85	*Silvascincus tryoni*	tryon's skink	bio11, bio14, bio16, bio13, bio17	247	c	0	1	ENM-only
65	*Brachyurophis fasciolatus*	narrow-banded snake	bio03, bio04, bio06, bio14, bio17, clay	276	c	0	1	REMP
70	*Varanus rosenbergi*	rosenberg's goanna	bio02, bio11, bio12, bio13, bio14, bio15, clay	600	c	0	1	REMP

Table 8 Species landscape characteristics collated for 54 landscape managed species

Species for which REMP was chosen as the preferred model are indicated by an asterisk (*). All others are ENM models.

PLP no.	Scientific name	Common name	MVH (ha)	Min. home range movement (m)	Max. home range movement (m)	Min. dispersal movement (m)	Max. dispersal movement (m)
84	*Assa darlingtoni*	pouched frog*	48	8	18	575	898
52	*Heleioporus australiacus*	giant burrowing frog*	238	31	74	2875	4492
62	*Litoria littlejohni*	littlejohn's tree frog	1427	148	351	17249	26951
78	*Mixophyes balbus*	stuttering frog*	190	13	30	2300	3594
1	*Mixophyes iteratus*	giant barred frog	250	36	40	4500	5000
2	*Philoria loveridgei*	loveridge's frog*	71	13	30	862	1348
18	*Miniopterus australis*	little bent wing-bat	25000	12000	20000	200000	200000
17	*Phoniscus papuensis*	golden-tipped bat*	1000	250	1000	1400	10000
11	*Atrichornis rufescens*	rufous scrub-bird	600	250	1000	300	20000
40	*Burhinus grallarius*	bush stone-curlew	1500	1000	3000	1000	10000
51	*Callocephalon fimbriatum*	gang-gang cockatoo*	2000	100	500	10000	50000
66	*Certhionyx variegatus*	Pied Honeyeater	50	2250	3500	500000	750000
26	*Chthonicola sagittata*	speckled warbler	50	200	1250	300	7500

PLP no.	Scientific name	Common name	MVH (ha)	Min. home range movement (m)	Max. home range movement (m)	Min. dispersal movement (m)	Max. dispersal movement (m)
42	*Cinclosoma castanotum*	chestnut quail-thrush*	20	60	1250	1100	5000
38	*Climacteris picumnus victoriae*	brown treecreeper (eastern subspecies)*	40	70	1000	1500	3500
7	*Cyclopsitta diophthalma coxeni*	coxen's fig-parrot	2500	2000	5000	50000	50000
80	*Daphoenositta chrysoptera*	varied sittella	1000	1000	2000	3000	7500
10	*Dasyornis brachypterus*	eastern bristlebird	750	250	500	525	5000
24	*Glossopsitta pusilla*	little lorikeet	5000	500	2000	5000	200000
25	*Grantiella picta*	painted honeyeater*	20	200	1250	300	7500
33	*Ixobrychus flavicollis*	black bittern*	500	100	1000	1000	10000
57	*Melanodryas cucullata cucullata*	hooded robin (south-eastern form)*	300	400	600	5000	20000
34	*Melithreptus gularis gularis*	black-chinned honeyeater (eastern subspecies)*	5000	1000	2000	5000	7000
5	*Menura alberti*	albert's lyrebird*	6000	125	500	4000	7000
29	*Neophema pulchella*	turquoise parrot	5000	250	500	1000	10000
21	*Ninox connivens*	barking owl	100000	2000	4000	10000	20000

PLP no.	Scientific name	Common name	MVH (ha)	Min. home range movement (m)	Max. home range movement (m)	Min. dispersal movement (m)	Max. dispersal movement (m)
68	*Ninox strenua*	powerful owl	62395	3000	500000	45000	1000000
23	*Pachycephala inornata*	gilbert's whistler	20000	500	4000	2000	40000
12	*Pachycephala olivacea*	olive whistler*	1000	250	750	400	6400
48	*Pandion cristatus*	eastern osprey	70437	6218	8291	3228	6457
72	*Petroica boodang*	Scarlet Robin	200	300	500	10000	20000
49	*Petroica phoenicea*	flame robin*	1000	500	750	500	350000
9	*Podargus ocellatus*	marbled frogmouth*	24000	250	500	10000	20000
27	*Polytelis swainsonii*	superb parrot breeding	10000	1000	10000	2000	35000
6	*Ptilinopus regina*	rose-crowned fruit-dove	1500	5000	10000	500000	500000
22	*Stagonopleura guttata*	diamond firetail	5000	500	2000	2000	20000
8	*Tyto tenebricosa*	sooty owl	37500	500	5000	25000	75000
71	*Aepyprymnus rufescens*	rufous bettong*	500	400	1300	1200	6500
13	*Cercartetus nanus*	eastern pygmy-possum	1000	300	1000	1000	3000
75	*Dasyurus maculatus*	spotted-tailed quoll	20000	200	5000	2000	40000
35	*Macropus dorsalis*	black-striped wallaby*	5000	500	750	1500	10000

PLP no.	Scientific name	Common name	MVH (ha)	Min. home range movement (m)	Max. home range movement (m)	Min. dispersal movement (m)	Max. dispersal movement (m)
15	*Macropus parma*	parma wallaby	6000	250	750	500	6000
19	*Ningaui yvonneae*	ningaui	12500	87	217	87	1086
88	*Petauroides volans*	greater glider	1500	150	200	500	3500
20	*Petaurus norfolcensis*	squirrel glider*	10000	250	500	3000	8000
39	*Phascogale tapoatafa*	brush-tailed phascogale	1000	250	2000	1000	6000
14	*Thylogale stigmatica*	red-legged pademelon	1200	250	750	500	5000
67	*Aprasia parapulchella*	pink-tailed legless lizard	594	165	216	303	345
65	*Brachyurophis fasciolatus*	narrow-banded snake*	5000	5	500	10000	20000
3	*Coeranoscincus reticulatus*	three-toed snake-tooth skink*	547	159	209	294	334
86	*Harrisoniascincus zia*	rainforest cool-skink*	131	111	146	172	196
30	*Hoplocephalus bitorquatus*	pale-headed snake*	5000	400	400	1000	1000
4	*Hoplocephalus stephensii*	stephens' banded snake*	2853	427	561	546	620
85	*Silvascincus tryoni*	tryon's skink	250	125	164	219	249
70	*Varanus rosenbergi*	rosenberg's goanna*	3566	509	670	593	674

Appendix C – Expert review process user guide

Background information on the nature of the modelling exercise

Any model of this kind will not always reflect fine-grained details. For example, it may not pick up a small patch of suitable habitat or it may predict habitat in a small area that has no habitat. Our models are intended to reflect the landscape habitat conditions, but do not consider other drivers such as predation and disease, recent fire and current seasonal conditions. The impacts of the recent fire season are not being included in this review. We ask reviewers to approach the exercise using their knowledge of species conditions before the 2019-20 fire season and also please consider the potential for our modelled species to utilize areas in future seasons even if they are temporarily unoccupied due to drought or other threats and pressures. Once this baseline model is finalized, additional considerations can be included.

The model is meant to capture general patterns, so we are seeking comments along those lines.

If you know of other people who could contribute to the review process, please let us know.

Please do not share the review material with others.

Review process

The review process focuses on the DRAFT model representing the baseline (or current epoch).

Once the DRAFT baseline model is finalised it will be projected into future climatic conditions.

To facilitate the review process, we have prepared two on-line components.

These are:

a. An interactive StoryMap

   The StoryMap allows reviewers to view spatial outputs, including DRAFT outputs of the major steps in reaching the final product (potential occupancy). It allows you to zoom in, pan to areas of interest, and to compare related maps. The StoryMap is for viewing only; you cannot enter information.

b. A PDF map

   This is provided for reviewers to annotate, using sticky notes in Adobe Acrobat Reader (instructions on how you can annotate is attached). Use this to direct us to places in the DRAFT models in StoryMap. Attaching any comments in relevant places on the PDF of NSW.

How to make comments on the PDF map

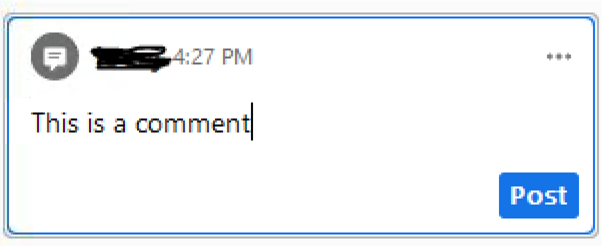
Open NSW_BND.pdf in Adobe Acrobat Reader, (email attachment).

If you don't have Adobe Acrobat Reader, it can be downloaded from here https://get.adobe.com/reader/. (Remember to untick the optional offers forMcAfee software if these are not wanted).

Once open, you can find the area you're interested in by zooming in and panning around the map using the zoom and pan tools.

Use the add sticky notes  tool to place comments on specific parts ofthe map.

Type your comment, press 'Post' once complete.



Remember all the DRAFT models aim to represent where habitat is present and where the modelled species could persist as a population when habitat patch size and connectivity are considered. They do not necessarily show where modelled species actually are present.

Please refer to the StoryMap for how site records relate to ENMs or REMP models.

General comments which refer to no specific area on the map can be given in an email.