ADAPTNRM

Implications of Climate Change for Biodiversity:

A community-level modelling approach

A GUIDE FOR USE WITH THE DATASETS AND MAPS

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Front Cover:
Image: Lake Johnston, Source: Suzanne Prober

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Summary & Key Messages

Evidence over the last decade has shown that ecological change in response to climate change is unavoidable and will be widespread and substantial.

Our ability to manage biodiversity through these changes depends on understanding what the nature of the change might be and where the potential for future persistence of biodiversity may be greatest.

The scope of the challenge of adapting biodiversity management to climate change is shaped by the magnitude and extent of future climate change across Australian landscapes and by our ability to predict the associated ecological changes. Biodiversity managers will also need to consider the interactions with other processes that threaten the resilience of biodiversity, including how future societies themselves shape the landscape. Future natural resource management (NRM) plans will then need to allow for extensive changes in biodiversity that are not entirely predictable. Plans may need to focus on supporting biodiversity through these changes, including adjusting objectives to better cater for climate change.

It is in this context that we present two parts of the story bringing biodiversity and climate change into NRM planning. The first part, this Guide and associated datasets and maps, feeds into the assessment phase of adaptation planning: a new way to view the magnitude, extent and type of changes in biodiversity is introduced. The second Guide in this series, ***Helping Biodiversity Adapt***, feeds into the strategic and implementation phases of planning, with a more specific focus on potential adaptation options.

Both Guides present new types of information about the potential for broad shifts in biodiversity in response to climate change applied to four terrestrial biological groups – vascular plants, mammals, reptiles and amphibians – for two plausible climate futures using the latest climate projection data.

Our new measures of change in biodiversity

It is challenging to develop a synthesised understanding of biodiversity change from many individual species models. This first Guide therefore introduces the concept of 'ecological similarity' for assessing the potential for broad shifts in biodiversity, as a whole, in response to climate and land use change. It uses a form of community-level modelling that considers the implications of climate change on all species simultaneously within a single integrated process. We use ecological similarity as a basis to produce four specific measures that each provide a different view of the magnitude and nature of likely change in biodiversity.

These new whole-of-biodiversity measures present a different perspective on how particular biological groups may respond to climate change and implications for how managers may plan to intervene.

In this Guide, we suggest ways in which this new information can be used to support specific tasks in planning, and encourage planners to develop their own approaches to build on these practical suggestions.

Diagram:
The five components of planning through an adaptation lens.

Biodiversity in an adaptation planning framework

Viewing biodiversity planning through an adaptation lens suggests that adaptation planning may look very different when compared with traditional approaches to planning of assets, managing or eliminating threats, or even managing resilience of systems as they are today. All components of the general planning framework introduced in our first guide, The ***NRM Adaptation Checklist*** may need to be approached differently for biodiversity planning, though our current focus is on assessment, strategic planning and implementation planning.

Below: Image: Eremaea and native bee, Source: NACC

Implications of Climate Change For Biodiversity (this module) provides tools to assist with assessment and an indication that different types of change may need different approaches in strategic planning.

Assessment

will need to incorporate assessment of potential change in biodiversity and the nature of the changes, including the consequences for community and stakeholder values and aspirations.

Strategic Planning

will need to consider that different types of changes in biodiversity may need different strategic approaches to manage, and that some current values and objectives may be impossible or impractical to maintain.

Implementation Planning

will need to consider a broad range of approaches, including new innovative actions which will need to be matched to the degree and nature of biodiversity change and may need to be adjusted over time.

Helping Biodiversity Adapt (a follow-up module) will provide guidance on strategic planning given the nature of biodiversity change, and a toolkit for considering implementation options.

Assessing the implications of climate change for biodiversity

This AdaptNRM Module introduces a series of new measures based on ecological similarity to assess the potential for change in biodiversity under climate change at scales relevant to planning. It is intended to support assessment and lead into strategic planning in NRM. In addition to this Guide, the Module includes a series of maps in poster format and data layers, available from the *CSIRO Data Access Portal*.

This Guide explains how to interpret and use this information, rather than focusing on outcomes for any specific biological group, a likely future climate, or on how global human behaviour may be expressed though a particular emission scenario.

In this Guide, we:

1. introduce a new approach to modelling/mapping change in biodiversity under climate change developed by CSIRO,
2. demonstrate the types of data, show how these can be viewed at national, regional and local scales, and explain their interpretation,
3. provide examples of how this information can be used in planning, with a particular focus on assessment and the core adaptation challenges outlined in *The NRM Adaptation Checklist*.

Our new assessment approach uses ecological similarity to estimate change in species composition between a baseline period and a future time. To demonstrate the potential for different outcomes for biodiversity, we use two CMIP5 climate models—the Model for Interdisciplinary Research on Climate produced by the Japanese research community (MIROC5) and the Canadian Earth System Model (CanESM2). For both models, we project ecological change by 2050 under the emissions scenario defined by a Representative Concentration Pathway (RCP) of 8.5 at a resolution of 250m across Australia.

Using the basic ecological similarity measure, a series of data layers were generated with different calculations and modes of comparison between baseline and future climates. Previews of the data are presented throughout this Guide using images and maps. The following outlines some key messages and examples of how the information can be interpreted and used in planning.

Potential degree of ecological change

- *Potential degree of ecological change* measures similarity between a baseline and future climate for every location within Australia: the lower the similarity, the greater the potential change in biodiversity.
- Under a high emissions scenario, our models show mainly 50-75% ecological similarity to the future across continental Australia, suggesting that at least one quarter to one half of our native species may be affected by 2050.
- There can be substantial variation within a region, which can indicate the parts of a region or the biological groups that may experience greater change.
- *Potential degree of ecological change* could be used in **climate change risk/vulnerability assessments** to better incorporate the interactions between climate exposure and sensitivity.

Disappearing ecological environments

- Disappearing ecological environments are present-day environments that may become absent from the entire continent in the future.
- Under the climate scenarios examined, very few of our more widespread ecological environments are likely to disappear completely by 2050, but pockets of disappearing environments may be found at local to sub-regional scales.
- Plants and amphibians appear to be more at risk of disappearing ecological environments and associated changes in local compositions than mammals and reptiles.
- Maps showing the trend toward disappearing ecological environments provide an opportunity to **engage with communities and stakeholders about their values into the future** and the potential need to consider adjusting aspirations.

Novel ecological environments

- Novel ecological environments are new environments that may arise in the future but which don't exist anywhere on the continent at present.
- Moderately novel ecological environments for all species groups may be expected for parts of Australia under the hotter future climate that we examined, with parts of the interior and the rangelands showing the greatest overall tendency to becoming novel.
- It will be difficult to predict what these novel ecological environments will be like or how they will need to be managed, so they may benefit from a greater focus on monitoring.
- Novel ecological environments in particular could be used to **encourage targeted cross-border collaboration** to ensure that assembling ecosystems are managed to avoid dominance by weeds (also see the AdaptNRM guide ***Weeds and Climate Change***).

Change in effective area of similar ecological environments

- The *effective area of similar ecological environments* is a measure of the total land area within a region or landscape suitable for the maintenance of its biodiversity.
- As certain ecological environments shrink in extent, due to climate change and/or land clearing, some species will be less able to persist over the long term.
- Under the scenarios examined, plants and amphibians may be facing greater overall loss in *effective area of similar ecological environments*, than mammals and reptiles. Mammals in particular are facing losses in effective area in northern Australia, whereas reptiles face such losses in the south.
- Historical land clearing has occurred in environments that are most favourable for people. The effects of climate change can be combined with those of land clearing, revealing very large losses in effective areas of ecological environments throughout Australia's intensively utilised agricultural zones.
- Change in effective area of similar ecological environments could be used to **integrate climate change with other threats** in risk/vulnerability assessments, and so derivatives of this measure are a particular focus of the second Module in this series, ***Helping Biodiversity Adapt***.

Composite ecological change

- We provide a composite measure that integrates the *potential degree of ecological change* with the *degree to which ecological environments are becoming novel or disappearing*, showing where different combinations of change may occur and how extreme that change may be.
- The different types of change vary within regions, particularly under the hotter future climate that we examined, suggesting that different strategic goals may be required within a single region and for different biological groups.
- Maps depicting different areas of *composite ecological change* can be used to acknowledge **different types of vulnerability for strategic planning.**

Empowering action

Too often, the impacts of climate change on biodiversity can seem overwhelming – leading to a long list of changes and possibilities that planners may feel unable to address comprehensively. Through this Guide and its associated maps and data layers we focus on providing an integrated picture of the implications of climate change for biodiversity, continent-wide. In doing so, we have not sacrificed quality of information or regional and local applicability. For example, we include more local topographic detail and explicit interactions between the biota and their environments in these models than has previously been available. Most importantly, we aim to express the relative amount and types of change in ways that support key strategic decisions and adaptation actions. Our approach to delivering information for planning aims to empower NRM planners, and ultimately society, to collectively facilitate the adaptation and persistence of biodiversity, even as species shift and local compositions change in a dynamic world.

What to expect in this guide

SECTION 1

This Guide introduces the concept of ecological similarity, showing the potential for broad shifts in biodiversity, as a whole, in response to climate and land use change.

Below: Image: Chowilla Foodplain, Source: Ian Overton

Our biodiversity projections were developed using a form of community-level modelling that considers the implications of climate change on all species simultaneously within a single integrated process. This complements individual species models that have been more commonly used in natural resource management planning.

This Guide is intended as a reference to explain the interpretation and use of the new types of measures we introduce. For immediate application, we also provide accompanying datasets and maps that, along with the Guide, collectively constitute the AdaptNRM Module.

This Guide also serves as a reference for future applications, as there are opportunities to produce updated maps and datasets with a wider range of alternative climate futures or biological groups.

1.1

What this guide includes

Section 2 of this Guide introduces the concept of *ecological similarity* and explains the key principles of the community-level modelling approach and how it applies to climate change.

Sections 3 to 6 cover four topics, which present different measures of ecological change, in order of increasing complexity:

- Section 3 describes the *potential degree of ecological change* at any location as a simple measure of the potential for future persistence of biodiversity.
- Section 4 outlines two concepts related to the potential for extreme ecological outcomes – where present-day environments may *disappear* from the continent in the future and where *novel* environments may arise.
- Section 5 introduces the concept of *effective area of ecological environments*, for measuring change in the capacity of future landscapes to support their original biodiversity, including interactions with past land clearing patterns.
- Section 6 presents an integrated view of three of the measures explored in previous sections, to identify different types of change and show where they coincide.

THIS MODULE

delivers a series of projections about the potential for broad shifts in biodiversity in response to climate change.

THE GUIDE PROVIDES

information and guidance for NRM planners wishing to use the biodiversity projection datasets and maps in their climate adaptation planning.

HOW TO USE THIS GUIDE

Access the maps relevant to your region using the ***CSIRO Data Access Portal*** (see Technical Note 1 for instructions) and use this Guide as a reference to explain their interpretation and potential use in planning.

Each section of the Guide provides:

- A national view of each measure for context
- An example regional view of each measure illustrating more local interpretation

PLANNING EXAMPLES
are provided in Boxes to demonstrate just a few ways in which the information might be used in the Assessment phase of regional planning.

THE SIDEBARS
provide key messages from the main text and can be used as a quick reference.

TECHNICAL NOTES
provide more detailed explanations and background information on the modelling approach.

Sections 3-6 are structured to provide a brief explanation of each measure and the methods we use to derive it, followed by example outputs that present a national view for context and a regional case study with a more specific focus.

The emphasis here is on illustration through examples, to demonstrate how to explore, use and interpret the data in regional planning, but viewing the data at a range of relevant spatial scales. More specific suggestions for how the information might be used in planning are provided in Boxes, often with more detailed mapping.

For those interested in learning more about the methods, further explanation and background information is provided in a series of Technical Notes appended with this Guide. Points of referral are given in the main text.

A quick reference guide to the measures introduced in this Guide is provided in Box 1. Each is fully described in the section where it is introduced and expanded definitions can be found in the Glossary at the end of this Guide.

BOX 1

Definitions of projected ecological similarity measures introduced in this Guide

A range of novel measures are introduced and described in this Guide. For quick reference, these measures are briefly defined below. Expanded definitions are provided in the Glossary at the end of this Guide, and fully described in the relevant section.

Projected ecological similarity:
In the context of climate change, projected ecological similarity measures how similar a single location is over two time periods in its composition. It is typically applied to a baseline (current) and future climate scenario. Ecological similarity can vary from 0 (no species in common) to 1 (all species the same).

Potential degree of ecological change:
The potential degree of ecological change is how much change in composition may occur. It is measured using the projected ecological similarity between different points in time, but at the same location. The lower the similarity between a baseline and future time, the greater the potential degree of ecological change.

Novel ecological environments:
Novel ecological environments are places where the future environment that arises is likely to have a composition that is different from any environment currently known on the continent.

Disappearing ecological environments:
Disappearing ecological environments are places where the composition in its current form is unlikely to exist anywhere on the continent in the future.

Change in effective area of similar ecological environments:
Change in effective area of similar ecological environments is the extent within a specified area to which a particular habitat may have changed in its suitability and therefore reduced or increased capacity to support its original biodiversity. For example, this may occur due to climate change and/or land clearing patterns. If there is a reduction in the effective area of similar ecological environments, we expect a corresponding loss of original biodiversity, and vice versa.

1.2
National context, regional focus

The models underpinning the information presented here were assembled nationally to provide consistent information for cross-boundary planning. Relatively fine-grained data (approximately 250m resolution) were used to allow the results to be viewed at different scales of interest.

The data and maps can be viewed nationally to provide broad context, or across groups of Natural Resource Management (NRM) regions to reveal more detail and show cross-boundary contexts. Regionally, the data can be used to explore the more local details relevant to individual NRMs.

This Guide provides examples of using views at different scales. Individual regional groups can use the data supplied via the ***Data Access Portal*** to display all the views relevant to their planning.

THE MODELS

use fine-grained data (250m resolution) so they are applicable to local and regional planning.

CROSS-REGIONAL AND NATIONAL

views are also possible to support planning in a range of contexts.

1.3
Biodiversity projection datasets and maps

Materials provided with this Guide include a series of spatial datasets and maps showing projected changes in ecological environments for four terrestrial groups of native species that are a common focus for natural resource planning:

Vascular plants
(ferns, gymnosperms and angiosperms)

Mammals

Reptiles

Amphibians

MAPS AND SPATIAL DATASETS

of the measures explained in this Guide can be accessed on the ***CSIRO Data Access Portal***.

(For a list of the maps, datasets and supporting information available on the ***CSIRO Data Access Portal***,see Technical Note 1)

THE MAPS ARE OFFERED

as a 'quick reference' to the extent and nature of the change.

The map series for each topic is provided at the national scale and for eight broad groupings of NRM regions. These maps are offered as a 'quick reference guide' to the extent and nature of projected change in biodiversity.

THE SPATIAL DATASETS

are available for spatial planners to explore the data for tailored use in planning.

The **nationally-consistent** biodiversity assessment datasets are provided as a grid of raster cells (c.250m x 250m) that can be usefully applied at resolutions approximating a 1:500,000 to 1:1,000,000 topographic map of **local to regional relevance**. In addition to the direct effects of landform and soils on differences in species compositions between locations, an important innovation is the incorporation of topographic effects (slope, aspect and shading) on climate in the estimation and downscaling of variables used in the biodiversity assessment models.

For planning regions with the capacity to use geographic information systems (GIS), planners or technicians can download the datasets and zoom into their local region, subset the data to match their planning boundaries if so desired, and variously classify, combine and colour the outputs to focus planning attention on potential local areas of interest.

1.4

Building knowledge

THIS GUIDE SERVES AS

a reference document for ongoing use with additional future datasets developed using this modelling approach.

The biological groups and future climates used in this Guide are not the only ones that have been or can be investigated using this modelling approach. The models and data are continuously updated with new and better information, or on demand. So this Guide is provided as a reference document for ongoing use. Additional or revised models will be made available through the ***CSIRO Data Access Portal*** as they are developed.

REGIONAL PLANNERS ARE ENCOURAGED

to continue to build on the interpretations and uses in planning over time.

In addition, we hope that in working through this guide, individual planners will develop a degree of familiarity with the datasets and the types of change that can be envisioned. Planners can then continue to build on the interpretations and uses in planning over time.

ADDITIONAL APPROACHES

for strategic planning and implementation planning will be presented in the follow-on Guide, ***Helping Biodiversity Adapt: supporting climate adaptation planning using a community modelling approach***.

Additional interpretations and variations on these models with more specific relevance to strategic planning and implementation planning will be included in the follow-on guide to be released in 2015, ***Helping Biodiversity Adapt: supporting climate adaptation planning using a community modelling approach***[1].

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[1] Additional variations on our community-level modelling approach are also presented in Drielsma *et al.* (2014b) '3C Modelling for Biodiversity Management Under Future Climate.'

How do we measure change in whole of biodiversity?

SECTION 2

Our modelling approach provides spatial information on the potential effects of climate change on key groups of organisms, such as plants or mammals, at a collective or 'community' level. This approach enables a 'whole of biodiversity' perspective in NRM planning.

Below: Image: Blooming Acacia in the Pilbara,
Source: Veronica Doerr

2.1
Modelling options

Estimating the effects of climate change on biodiversity can be derived through a range of modelling approaches. Most commonly, modelling is undertaken at the species level, to project changes in species distributions under future climate scenarios. These species-level models are important in planning for better-known species of particular ecological, social or economic concern. However, the sheer number of species in Australian ecosystems, including many species as yet unknown to science, limits their use in managing biological diversity as a whole.

Therefore, interest has been growing in community-level modelling approaches which focus on emergent properties of biodiversity and ecosystems.

SPECIES-BASED MODELS

are particularly useful for species of special concern. But the sheer number of species means we need a different approach to assess the implications of climate change for biodiversity, overall.

2.2
What is community-level modelling?

Community-level modelling combines data from multiple species in a single model, and produces information on spatial patterns in the distribution of biodiversity at a collective or community level.

This Guide uses a form of community-level modelling known as 'generalised dissimilarity modelling' (GDM, described in Technical Note 2). These models combine data from multiple species and locations, simultaneously, to estimate change in biodiversity composition between places or over time.

COMMUNITY-LEVEL MODELLING

allows us to estimate the amount of change in composition between two locations or two points in time.

2.3
Ecological similarity

The community-level models presented in this module use the concept of 'ecological similarity'. Ecological similarity is a measure for comparing biological composition between sites – here we use species – varying between 1 (all species are identical) and 0 (all species are different). It reflects the way biological groups respond to variation in climatic, soil and other environmental variables.

Ecological similarity can be predicted for any biological group or feature for which adequate observation data are available. It forms the basis of all of the calculations and maps described in this Guide.

THE MODELS USED

in this guide estimate 'ecological similarity' - the similarity in predicted species composition between two locations or between one location at two points in time.

THE MEASURE OF 'ECOLOGICAL SIMILARITY'

between a 1990 baseline and 2050 for all locations in Australia is the basis of most of the measures and maps in this Guide.

AREAS THAT WILL BE LESS SIMILAR

in terms of species composition in the future are likely to experience greater biodiversity change.

The term ecological similarity can refer to comparisons across space (i.e. between two locations) or across time (i.e. between time periods at one location). Similarity across time is used to project ecological responses to climate change.

To assess this, observation data for target biological groups (e.g. all mammals or all reptiles) are used along with data from a broad suite of environmental variables (including climate) to see which environmental variables best explain similarity in overall species composition across space.

The resulting statistical model can then be used to assess ecological similarity between points in ***time*** by substituting current climate data with future climate data for all climate variables in the model. We use the term 'projected ecological similarity' when comparing between a baseline and future time period. Areas that are projected to be less similar in terms of species composition in the future are likely to experience greater biodiversity change as a result of climate change.

See Technical Note 2 for more details on the calculation of ecological similarity applied to climate change.

2.4

Why these four biological groups and two climate scenarios?

THIS MODULE

includes projections of ecological similarity for four terrestrial biological groups: vascular plants, mammals, reptiles and amphibians.

We developed projections of ecological similarity for four terrestrial biological groups—vascular plants (ferns, gymnosperms and angiosperms), mammals, reptiles and amphibians. These groups met two main criteria for inclusion:

- Adequate observational data was available for modelling
- They encompass many of the elements of common interest for natural resource planning, such as vegetation communities, fauna with high societal values and many threatened species of vertebrates and plants

Together these groups also highlight the potential contrasts in response to climate change by different groups of organisms. Although, as noted below (Section 2.7), we emphasize that interactions among groups are not accounted for.

Birds are another highly valued group with excellent datasets available, but models were expected to be less reliable because observations of birds can vary across seasons. As an alternative to modelling birds as a whole, future models could attempt to define key functional groups, like those that are sedentary or reliant on local resources.

To demonstrate the potential for different outcomes for biodiversity, two ***CMIP5*** climate models—the Model for Interdisciplinary Research on Climate produced by the Japanese research community (MIROC5) and the Canadian Earth System Model (CanESM2)—were used to project ecological change by 2050 under the high emissions scenario defined by a Representative Concentration Pathway (RCP) of 8.5 which assumes a continuation of recent trends in greenhouse gas emissions. See Technical Note 3 for details and Glossary for definitions).

These are a small subset of the wide range of climate models, time frames and emission scenarios supporting the ***IPCC's 5th assessment report***. The ***CSIRO/BoM Climate Futures Framework*** guided the process of choosing the two climate models. They fall within the spectrum of 'Maximum Consensus' futures for Australia for the RCP 8.5 scenario. They represent a relatively mild warming and a hotter climate future, respectively. For simplicity, we call them the high emissions' *mild MIROC5* and *hot CanESM2* climate scenarios.

We chose to use the high emissions trajectory to demonstrate the possible outcome for biodiversity by 2050, indicative of the potential ecological response to the changing climate. The climate models selected are not necessarily the most extreme or mild for this scenario and vary in this respect regionally, across Australia. Additional analyses are possible but will depend on demand and resources.

TO FACILITATE PLANNING

for multiple futures, we used two contrasting climate scenarios. We modelled two global climate models (a *mild MIROC5* and a *hot CanESM2*) to 2050 using the high emissions RCP 8.5 scenario.

THESE TWO CLIMATE SCENARIOS

reflect a milder and a hotter likely future in the next few decades if emissions remain on their current trajectory.

2.5
Datasets used

We used data on where native species are found collated from herbaria and museums across Australia by the ***Atlas of Living Australia***. We also used best-available, high resolution, national environmental layers capturing spatial variation in the environment including soils, climate and landform. We used the latest climate change data from the CMIP5 set of climate models. These data sources are described in technical documentation for the models, accessible from the ***Data Access Portal*** and as broadly outlined in Technical Note 1.

2.6

Illustrating ecological similarity for particular locations

The concept of ecological similarity can be demonstrated for a specific location in three steps:

- First, grid cells anywhere in Australia that are ‘ecologically similar’ to the grid cell of interest (the focal cell), are identified. This similarity can vary from 0 (nothing in common) to 1 (effectively identical).
- Next, the focal cell in the future (e.g., 2050) is compared with grid cells anywhere in Australia in the present (1990 baseline), showing which areas at present have any similarity with the future ecology of the focal cell.
- Finally, the focal cell at present (1990 baseline) can be compared with grid cells anywhere in Australia in the future (e.g., 2050), showing where ecologically similar areas may be expected to emerge, and how similarity surrounding environments remain.

Box 2 illustrates the concept of ecological similarity.

Ecological similarity can be used, along with local knowledge, to infer the types of ecosystems that could be sustained by new climatic regimes at each location. Suppositions can be made about the likely mixing of species, though the analysis does not indicate which species are likely to be affected or to what degree.

The nature of the change and the consequences for biodiversity also require consideration of the potential for native species to rapidly disperse and colonise new areas. These topics, as they relate to the potential invasiveness of native and alien plant species for example, are discussed in the AdaptNRM Guide ***Weeds and Climate Change***.

The estimation of projected ecological similarity in the remaining sections of this Guide use this basic concept of ecological similarity—for which comparisons can be made across locations and between different points in time—applied simultaneously to every grid cell (i.e. >110 million pixels nationally).

Left:
Image: Margaret River vegetation
Source: South West Catchments Council
Credit: Damien Postma

BOX 2

Illustrating ecological similarity and change in the Great Western Woodlands

The Great Western Woodlands of south-western Australia contain Australia's most extensive remaining temperate eucalypt woodlands. These woodlands are globally unique in supporting trees to 20 m tall at mean annual rainfall as little as 260 mm. At the warmest, northern limits of the region, the eucalypt woodlands abut the Mulga (*Acacia*) woodlands of Australia's rangelands, along what is known as the 'Mulga line'. An ecological research station (hereafter 'Credo research woodland') has been established in old-growth Salmon gum (*Eucalyptus salmonophloia*) woodland close to the Mulga line on the Credo Proposed Conservation Reserve near Kalgoorlie. The Credo research woodland aims to characterise how the eucalypt woodlands function and how they are responding to climate change.

The projections in this example illustrate how the concept of ecological similarity can be applied to a specific location, in this case the Credo research woodland, to identify:

A) Surrounding environments that are currently ecologically similar

Current vegetation at the Credo research woodland is Salmon gum woodland with a chenopod understorey. As might be expected, the model shown below indicates ecological similarity for vascular plants for the present (1990) is highest close to the Credo research woodland. Ecologically similar areas extend several hundred kilometres to the east and west, but with a much shorter range (c. 100 km) in a north-south direction, suggesting a strong influence of temperature. Within the broad zone of similarity, fine-scale variation reflects the occurrence of Salmon gum woodlands on broad valley floors. Most areas shown as having moderate to high similarity (>0.7) currently support similar eucalypt woodlands, but some to the north-east of Kalgoorlie fall across the Mulga line where the vegetation is dominated by Casuarina and Mulga woodland. The latter likely reflects the ecologically marginal location of the Credo research woodland adjacent to the Mulga line, which is intended as an early sentinel of ecological change.

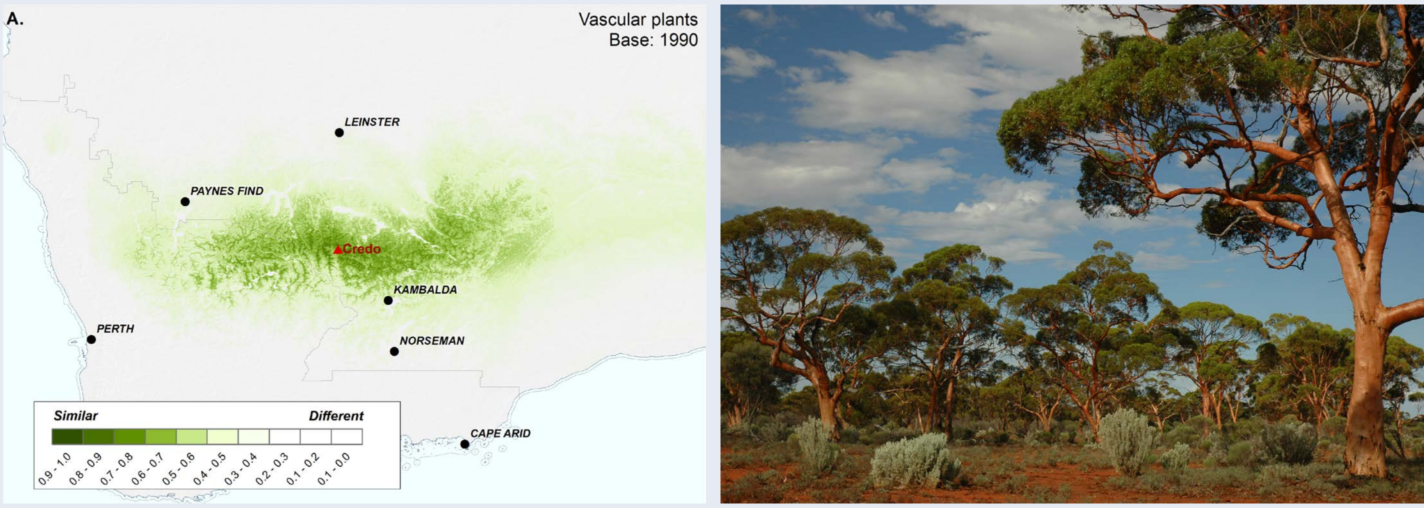


Figure A.
Predicted locations in 1990 of environments most similar to those at the Credo research woodland (red triangle) in 1990 (left); Salmon gum woodlands (right). Source: Suzanne Prober

BOX 2 (CONTINUED)

B) The current location of environments that are most similar to those expected at Credo in the future

Under the high emissions' *mild MIROC5* climate scenario, the environment at the Credo research woodland in 2050 is projected to be most similar to environments currently on the other side of the Mulga line. Vegetation in these areas typically supports Mulga (*Acacia spp.*) woodland, such as that near Payne's Find, shown in the image. This suggests substantial vegetation change can be expected at the Credo research woodland over the next few decades. Nevertheless, we cannot necessarily assume a change in dominant trees, given that only a proportion of the species are expected to change. Rather, we can expect a higher proportion of species from the Mulga woodlands to the north to be suited to future environments at the Credo research woodland.

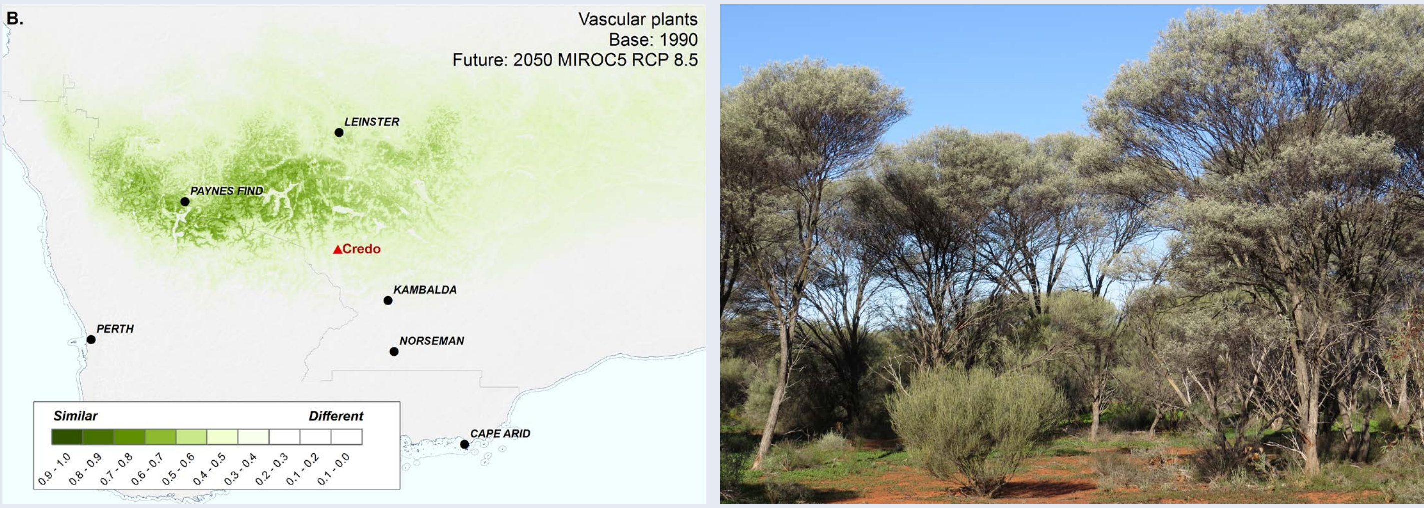


Figure B.

Location of environments of 1990 most similar to those projected under the high emissions' *mild MIROC5* scenario for the Credo research woodland (red triangle) in 2050 (left); Mulga woodlands near Payne's Find, indicating current vegetation in this type of environment (right). Source: Suzanne Prober

C) Where environments similar to those currently at Credo are likely to be found under future climate scenarios

Areas predicted to experience environments in 2050 similar to the current environments at the Credo research woodland already support eucalypt woodland, such as the Salmon gum woodland with chenopod understorey near Kambalda shown below. This suggests the ecosystems at the Credo research woodland may continue to be represented in a similar structural form in the Kambalda region under the *mild MIROC5* scenario, with potential for some taxa to move southwards if they don't already occur there.

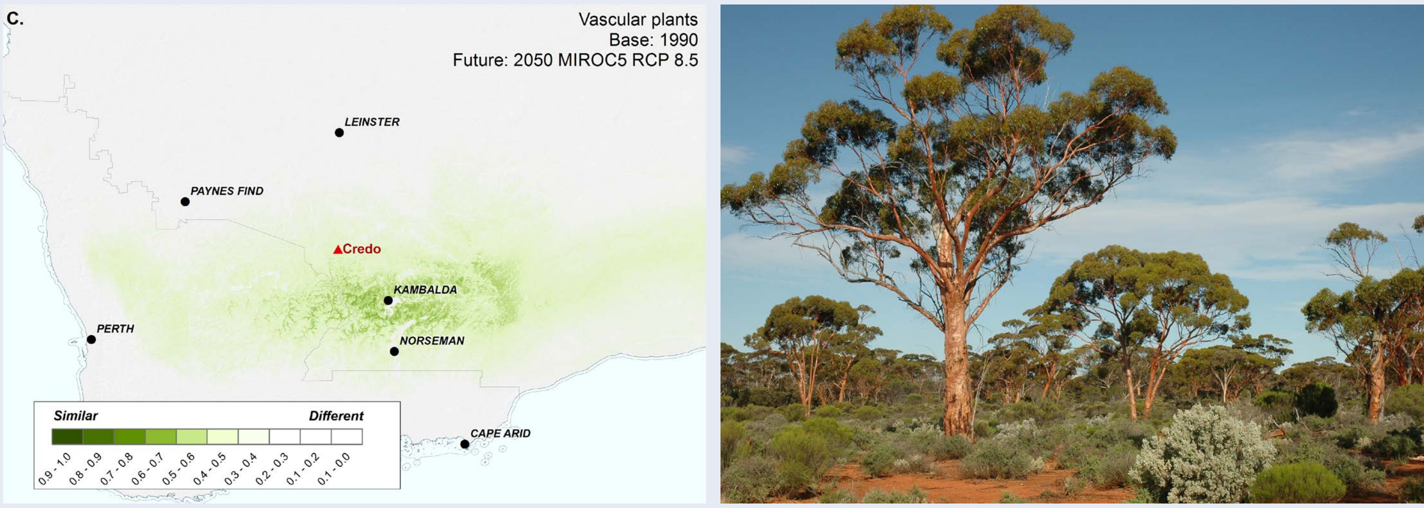


Figure C.

Projected locations of environments of 2050 under the high emissions' *mild MIROC5* climate scenario that are most similar to those at the Credo research woodland (red triangle) in 1990 (left); and Salmon gum woodlands near Kambalda, indicating current vegetation in these locations (right). Source: Suzanne Prober

2.7
Limitations to modelling and projections

The projections of ecological similarity provide one of the few tools available for planners to envisage potential futures for biological communities. When used cautiously in combination with expert local knowledge, they can help to inform climate adaptation planning, particularly during the assessment phase.

In that context, we emphasize that, as for most modelling approaches, the models presented in this module cannot be considered exact for a range of reasons:

- Different climate models and emission scenarios will produce different results and we can never be completely certain which climate future will eventuate, see Technical Note 3.
  Therefore it is sensible to cater for a range of climate futures.

- Future environments may be outside the range of the data used to fit the biodiversity model. Areas with a high degree of extrapolation into new environments for the two climate scenarios are shown in Technical Note 4.

- The environmental coverage of the biological survey data may sometimes be limited, and this affects the accuracy of the biodiversity model. Environmental coverage for each biological group is shown in Technical Note 4.

- The models don't account for factors such as the unknown capacity of organisms to adapt to change, or their functional interactions with other organisms.

Given the range of uncertainties, the projections of ecological similarity in this Guide are best viewed as an index, showing the relative potential for future persistence of biodiversity, rather than a specific estimate of the degree of change in species composition. Biodiversity managers will also need to consider the interactions with other processes that threaten the resilience of biodiversity including how future societies themselves shape the landscape in adapting to climate change.

THESE MODELS

are tools for envisaging potential futures for biodiversity that can be used in combination with other sources of information to inform planning.

THERE ARE LIMITATIONS

to any modelling, so projections of ecological similarity are best viewed as an index of the potential for future persistence of biodiversity, rather than a specific estimate of change in species composition.

How much could our biodiversity change?

SECTION 3

The projection of ecological similarity between a baseline and future climate for the same locations across Australia is the simplest indicator of the potential degree to which our biodiversity could change.

Below: Image: Common Wombat, Source: Matt Francey, courtesy of Flickr, ***Creative Commons***

3.1

Estimating the potential degree of ecological change

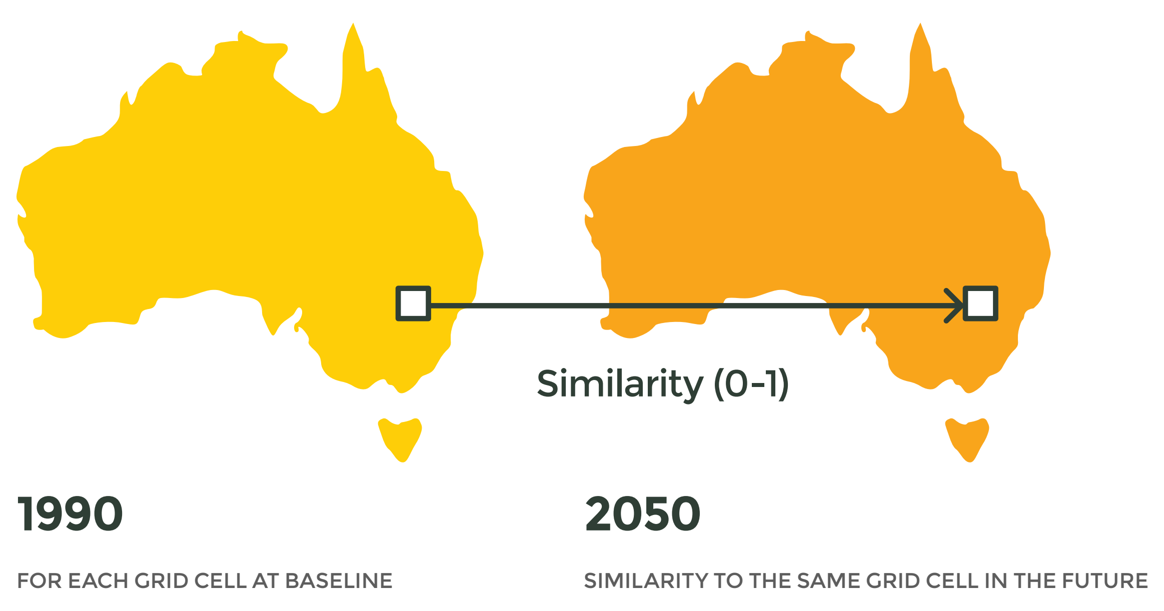
To estimate the *potential degree of ecological change* associated with future climate scenarios, we calculate the ecological similarity between the same locations at different points in time, for example between a baseline period (such as 1990) and a future time (such as 2050) (Figure 1). We do this comparison simultaneously for every location (every grid cell) within Australia.

TO ESTIMATE THE POTENTIAL degree of ecological change, we compare the ecological similarity of the same place at two different points in time.

FIGURE 1

Calculating potential degree of ecological change from ecological similarity

A schematic showing how potential degree of ecological change is calculated from ecological similarity.



These location by location projections of ecological similarity between baseline and future environments are made by:

- finding the set of baseline climate and other environmental variables that best predict current similarities in species composition across different locations in Australia (using community-level modelling, described in Technical Note 2)
- projecting the model by replacing the current climate variables with a future climate scenario (see Technical Note 2) and then,
- calculating the similarity between the baseline predicted and the future projection for each location (grid cell) in Australia.

THE LOWER THE SIMILARITY (approaching 0), the greater the potential for ecological change.

WHERE THE SIMILARITY BETWEEN the baseline and the future might be projected to be 0.2, or 20%, it can be helpful to think about this as only one in five species being able to persist.

HOWEVER, this should be viewed as an indication only, as species may be able to adapt in ways we don't yet understand.

The lower the similarity, the greater the potential for climate change to drive ecological change.

Simply put, the *potential degree of ecological change* could be interpreted as the proportion of species at a location that have the potential to persist at that location under the future climate scenario. Thus, where the similarity between the baseline and the future might be projected to be 0.2, or 20%, it can be helpful to think about this as only one in five species being able to persist. This should not be taken too literally though, because species may be able to adapt in ways we don't yet fully understand. Thus, the measure is better viewed as an index of the potential degree of change, showing where that potential is greater.

3.2

Potential degree of change – the national context

THE POTENTIAL DEGREE OF CHANGE differs among different parts of Australia.

A national overview of the *potential degree of ecological change* for vascular plants is shown in Figure 2 for the high emissions' *hot CanESM2* climate scenario. Here we describe what the measure looks like and how it is interpreted. A similar process of interpretation can be followed for the high emissions' *mild MIROC5* climate scenario using the map posters or data downloaded from the CSIRO ***Data Access Portal***.

While the measure is given in units of similarity, the spatial patterns are presented in degrees of change since the 1990 baseline period. Darker areas show parts of Australia where there is more potential for change in vascular plants species composition (i.e. lowest similarity) – where future species compositions are projected to be the most different than at present.

OVERALL, the high emissions' *mild MIROC5* climate scenario suggests that across most of Australia, only about half of present day vascular plants may have the potential to persist in their current locations by 2050.

For example, note that the highest potential for change is projected for the western coastline of south-western Australia, including the coastal sand plain region where the capital city of Perth is located. In contrast, areas like Tasmania, the southern Nullarbor Plain and parts of central Australia show the lowest potential for change, though some degree of change is still expected. In fact, across most of Australia, this model suggests less than 50% ecological similarity between vascular plants in 2050 compared to the baseline, 1990.

FIGURE 2

Potential degree of ecological change

The *potential degree of ecological change* in vascular plants between 1990 (baseline) and 2050 for the high emissions' *hot CanESM2* climate scenario. Darker colours signify lower similarity and thus higher degree of potential change. While the legend shows 10 categories, the mapped data itself is continuous.

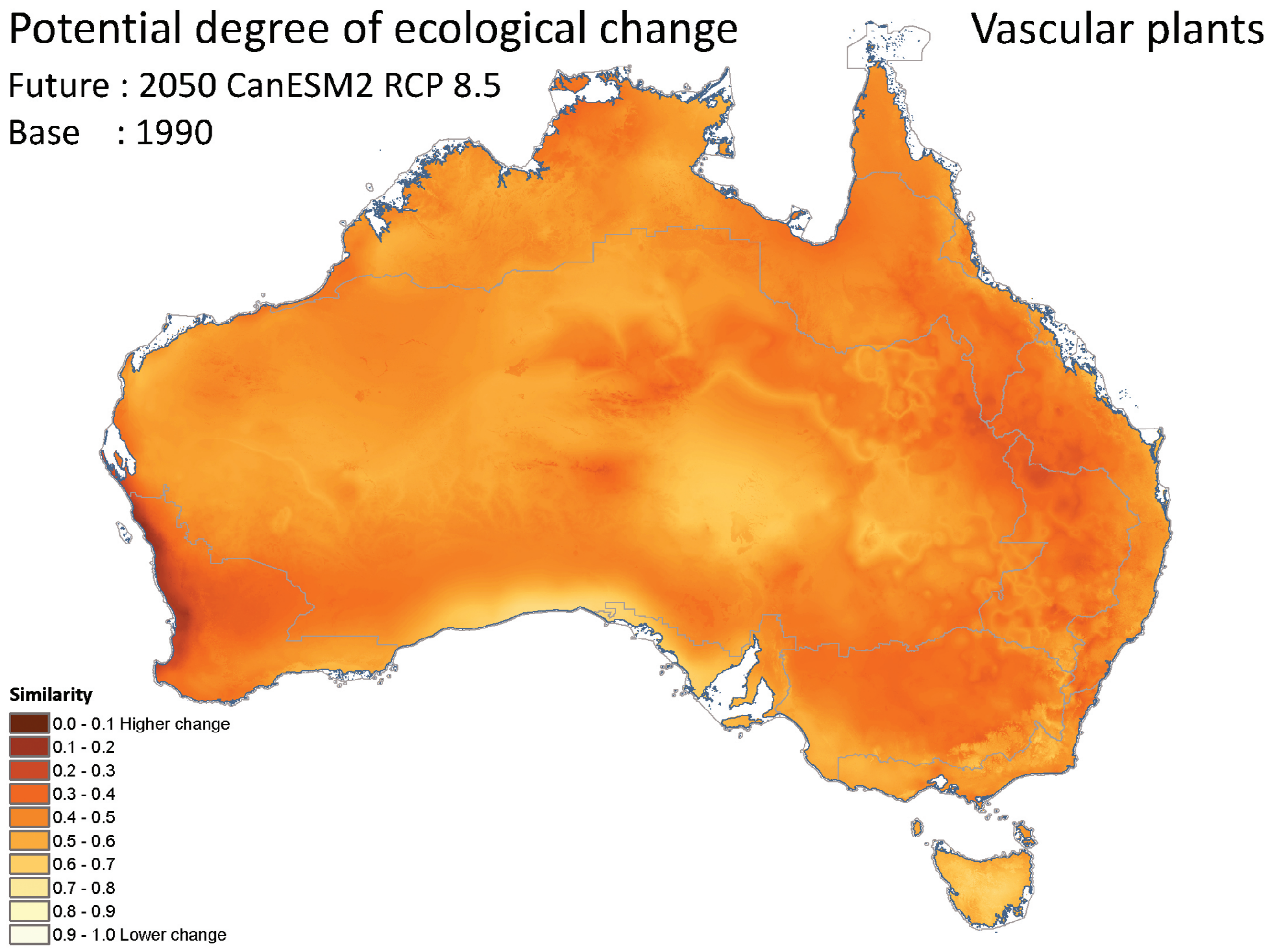


Figure 3 presents both the high emissions' *mild MIROC5* and *hot CanESM2* climate scenarios for all four biological groups. For presentation purposes, we have used just four categories (or classes) of similarity, which make it easier to do a quick visual comparison. Note that the underlying data accessed through the ***CSIRO Data Access Portal*** is continuous. Again, darker class colours show lower similarity into the future and thus greater potential for change. Not surprisingly, relative to the hot climate scenario, the results using the high emissions' *mild MIROC5* climate model show less potential for change across all biological groups.

POTENTIAL DEGREE

of ecological change also varies among different biological groups.

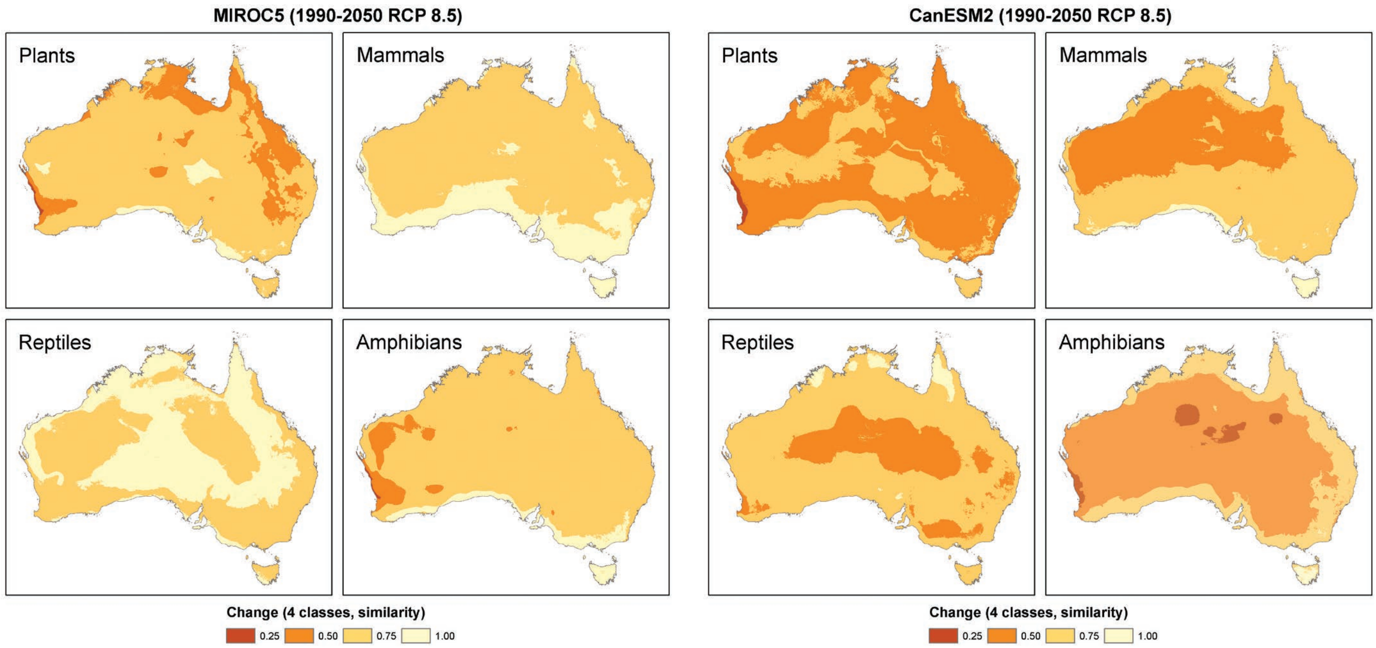
ACROSS THE FOUR SPECIES GROUPS

and two climate scenarios, our models show mainly 50-75% ecological similarity in the future, suggesting that at least one quarter to one half of these species may be affected by 2050.

FIGURE 3

Potential degree of ecological change

The *potential degree of ecological change* between 1990 (baseline) and 2050 for four biological groups and two climate scenarios. Darker colours signify less similarity and higher change. While the legend shows 4 categories for ease of visual comparison, the data itself is continuous.



3.3
Potential degree of change – a regional focus

As noted in Section 1.2 and Section 1.3, the data and maps are provided at a resolution (approximately 250m grids) that is useful for exploring the finer-grained detail relevant to individual NRM groups, particularly when using a GIS.

An example of the finer-grained detail is shown for the East Gippsland region in Figure 4. This example is for plants under the high emissions' *hot CanESM2* climate scenario, and on average suggests moderate potential for change. There is however substantial variation in the potential for change within the region. The coastal plains, major river valleys and some higher mountain ranges are projected to experience the greatest potential to change, leading to ecological similarities of only 0.2-0.5 by 2050. Some of the foothill areas by contrast, may retain an ecological similarity as high as 0.7 under this hot scenario.

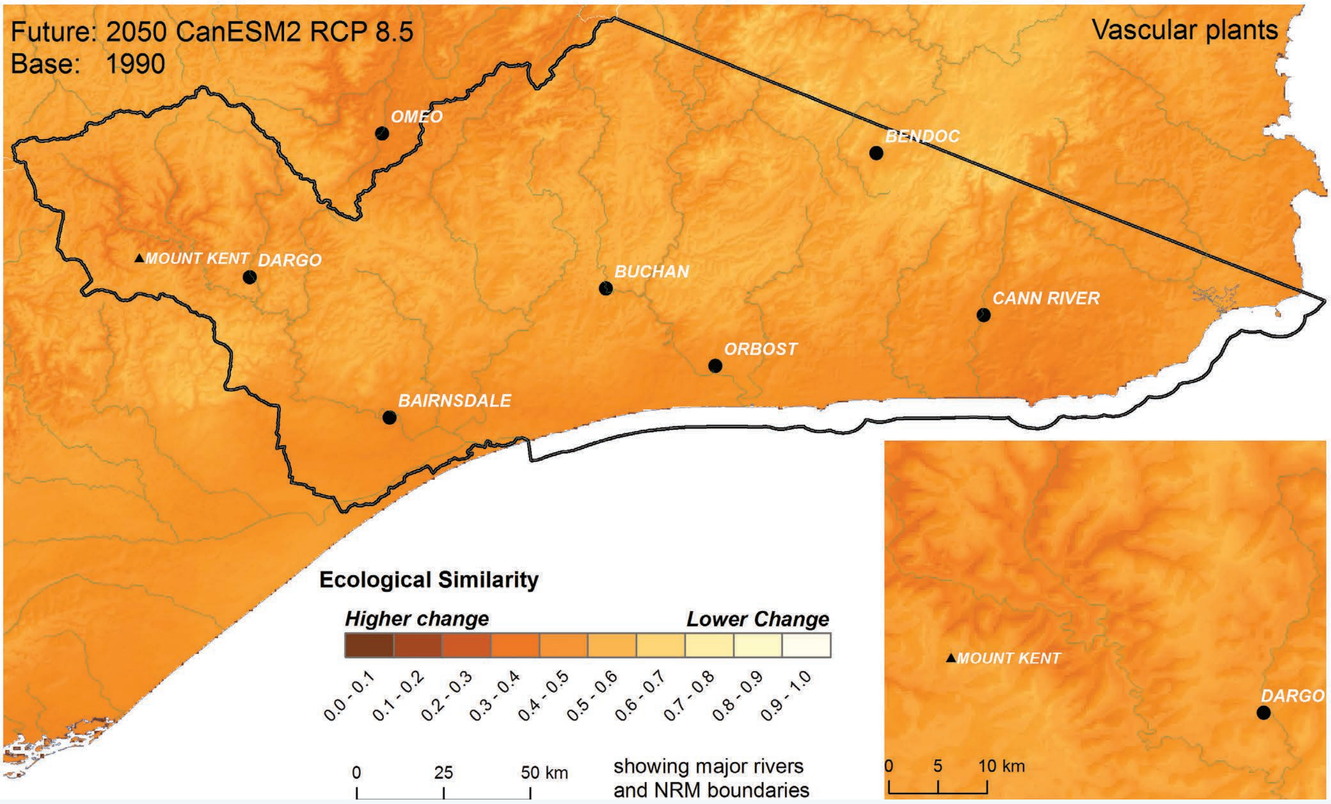
THERE CAN BE SUBSTANTIAL variation in the potential degree of ecological change within a region.

THE REGIONAL MAPS PROVIDE an indication of which parts of a region, and among which biological groups, there exists the most potential to change in biodiversity composition.

FIGURE 4

Potential degree of ecological change

The *potential degree of ecological change* in vascular plants in the East Gippsland Catchment Management Authority area, under the high emissions' *hot CanESM2* scenario.



Variation in the *potential degree of ecological change* can also be explored more locally to consider the ecological communities most vulnerable. For example, the Wonnangatta and Wongungarra River valleys north-west of Dargo are projected to be some of the most severely affected areas in East Gippsland under the high emissions' *hot CanESM2* scenario, with projected similarities of as little as 0.3. This area also supports a range of threatened species, including fauna species dependent on the 3000 ha of mature Alpine Ash (*Eucalyptus delegatensis*) stands that occur here. Species reliant on vegetation in this area could thus warrant high priority for additional conservation measures.

Box 3 provides specific ideas about formally incorporating these layers into a spatially-explicit risk or vulnerability assessment.

Box 4 provides an example of combining this information with more local knowledge in planning.

Species reliant on the Moroka-Wonnangatta-Wongungarra River valleys (the image shows the Wongungarra River) are projected to have a relatively low chance of persistence by 2050 under the high emissions' *hot CanESM2* climate scenario. Image source: The Wilderness Society. Credit: Jean-Marc Hero

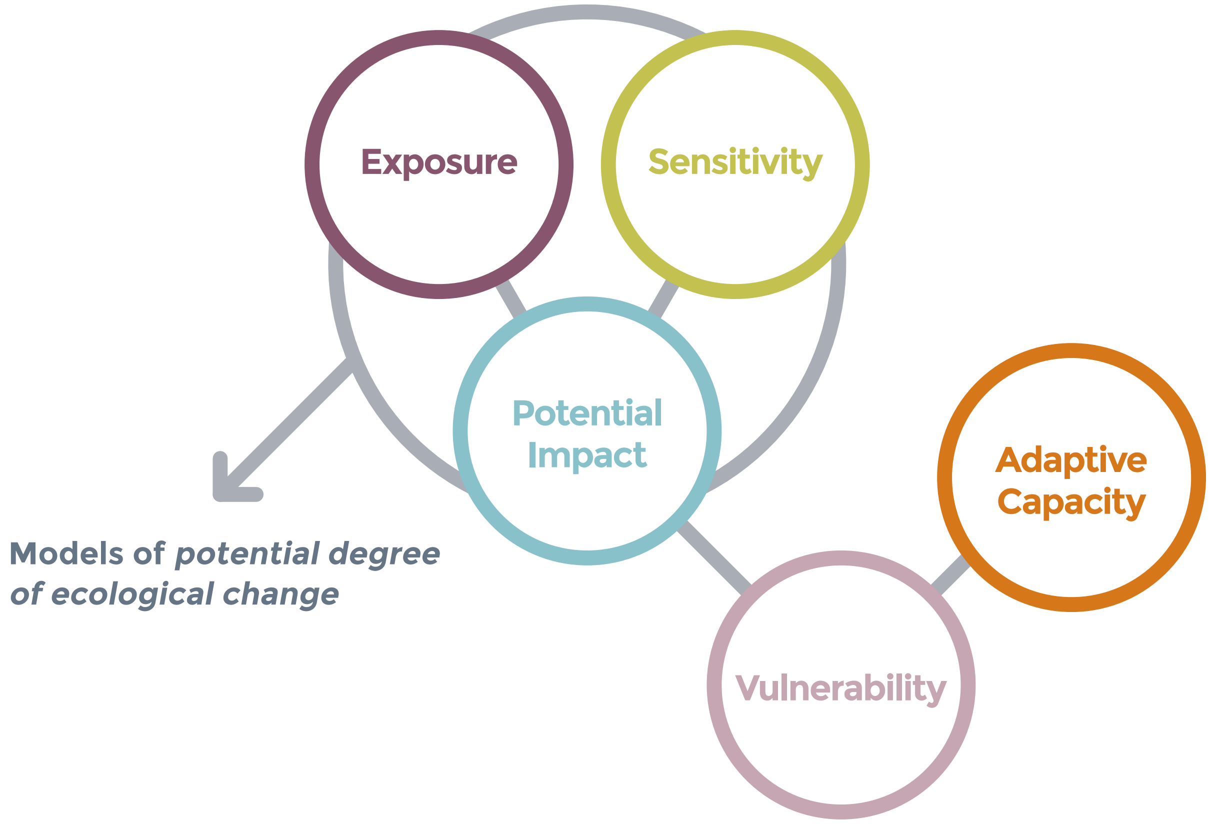
BOX 3

Planning Example

Using the *potential degree of ecological change* in vulnerability analyses

During the assessment phase of planning, Australia's regional NRM groups often undertake some form of spatial vulnerability or risk analysis – trying to identify parts of their regions that may be particularly under threat. Such assessments usually aim to integrate information on a range of different threats and vulnerabilities for a range of different assets or systems. Climate change is only one part of that bigger picture.

Our models of the *potential degree of ecological change* can be thought of as layers that integrate exposure and sensitivity to climate change, in the absence of other threats. Thus, they are not complete vulnerability assessments by themselves, but can be combined with other information in integrated assessments to give a more complete picture of differences in vulnerability across a region.



The general structure of vulnerability analyses, showing that models of *potential degree of ecological change* can be used as the 'potential impact' layer - a synthesis of climate exposure and sensitivity. Other threats may be incorporated as reductions to adaptive capacity.

For example, consultants Spatial Vision Innovations, in partnership with Natural Decisions, delivered an Impacts and Vulnerability Assessment for seven Victorian CMAs in July 2014. It represents a significant and very useful synthesis of existing information. However, due to limitations in terms of time and available data, they were only able to include exposure based on two climate variables, and the assessment of sensitivity was restricted to a categorical rating using expert opinion (very common when considering sensitivity separately from exposure).

When the assessment is next updated, the models of *potential degree of ecological change* for vascular plants presented here could substitute for the exposure and sensitivity variables for native vegetation, providing greater depth and rigour to the assessment of potential impact. This is because our models considered a broad range of climate variables and sensitivity was fully modelled based on the suite of environmental variables, including climate, that influence species compositions. Our models of fauna groups could also be added as additional assets in the analysis if desired.

BOX 4

Planning Example
Combining models with local knowledge

The wheatbelt of Western Australia is an area that our vascular plant model suggests will experience a higher potential degree of change, with around 50% of species affected by 2050 even under the milder of our climate scenarios. Local, species-specific knowledge can be used to help confirm these model results. The eastern-most population of Jarrah *(Eucalyptus marginata)*, at Jilakin Rock in the wheatbelt of Western Australia (Shire of Kulin), may be one of the first examples of vegetation change associated with climate stress. This isolated population declined from 74 live (and 55 dead) trees in 1981 to 14 live trees remaining in 2012 (Whitford et al. 2008; Whitford 2012; Peter White, Department of Parks and Wildlife WA, pers. comm.). It has not been possible to attribute the deaths to anything other than prevailing dry conditions (both declining rainfall and a shift in the seasonal distribution of rainfall). Thus, this population may be an early signal of the high potential degree of change in vascular plant species compositions in this region.

However, local knowledge may also supplement model results. Although our models incorporate topographic information at relatively high spatial resolutions (approx 250m grids), they do not include finer-scale microclimatic effects. Local knowledge and experimental evidence suggest that granite rock environments provide moisture buffering, enabling the persistence of some species in places normally considered too dry. In this case, expert knowledge about local fine-scale variation may need to be incorporated into vulnerability assessments, or factored in during more detailed implementation planning.

Above.
The eastern-most population of Jarrah (*Eucalyptus marginata*), at Jilakin Rock in the wheatbelt of Western Australia showing tree deaths, but also pockets of survival in certain microclimates. Image source: Suzanne Prober.

Sources

Whitford K, White P, McCaw L, Durell G, Whitford E (2008). Deaths of jarrah in 2008 at Jilakin Rock: an outlying population of jarrah: a report of initial observations. Unpublished report, Department of Environment and Conservation, Kensington, WA.

Whitford KR (2012) Jilakin jarrah. Western Wildlife: Newsletter of the Land for Wildlife Scheme 16(3), 12–13.

How extreme could the ecological changes be?

SECTION 4

As the climate continues to change, some familiar Australian environments may no longer exist on the continent. On the other hand, some future environments are likely to lie outside the range of our current experience. These represent contrasting ecological extremes for managing biodiversity under climate change that do not always coincide.

Below: Image: Devonian Reef, Source: Suzanne Prober

Here we use the term ‘disappearing’ to refer to present-day environments that are projected to become rare or absent at some future time. We use the contrasting term ‘novel’ for future environments that potentially have no present-day analogues. For example, assuming continuing high emissions, the coolest environments of our highest mountain-tops are likely to disappear (disappearing), and our hottest desert environments may become even hotter (novel).

Modelling disappearing and novel environments using our community-level approach allows us to go beyond past methods based only on climate. In doing so, we account for cases where a small change in temperature, for example, might result in a large change in biodiversity.

PRESENT DAY

ecological environments that are projected to no longer exist in the future anywhere in Australia are termed ‘disappearing’.

FUTURE ECOLOGICAL

environments for which there are no present analogues anywhere in Australia are termed ‘novel’.

4.1

Estimating disappearing ecological environments

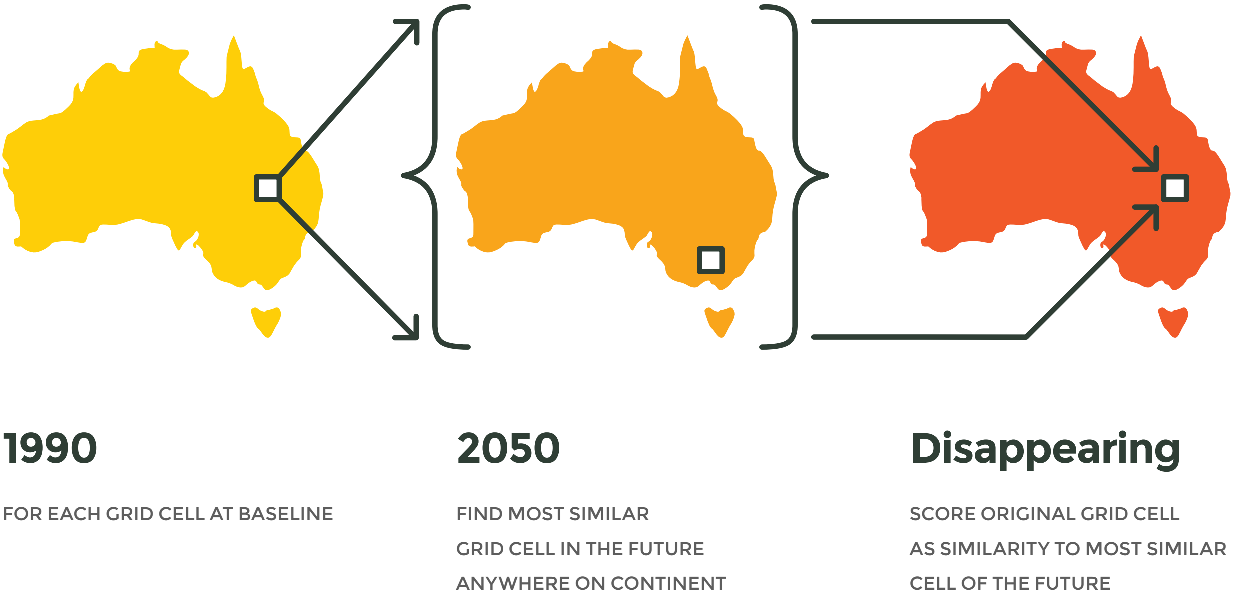
Disappearing ecological environments are calculated as the estimated ecological similarity between a location in the present (baseline) and its most similar location anywhere on the Australian continent in the future, as outlined in Figure 6. The calculation is applied to each location across the continent. The resulting index shows the *degree to which ecological environments are tending to disappear.* We use this terminology to convey the continuous nature of the measure.

When calculated this way, areas with projected ecological similarity scores approaching zero presently support ecological environments that may not exist in the future anywhere on the Australian continent – they will have disappeared. Higher scores signify some level of similarity in the future with present-day ecological environments.

FIGURE 5

Disappearing ecological environments

A schematic showing how the *degree to which ecological environments are tending to disappear* is mapped. Disappearing ecological environments are calculated by comparing a grid cell in the present (e.g., 1990 baseline climates) with all possible most similar cells in the future (e.g., 2050 climate scenario).



UNDER OUR TWO CLIMATE SCENARIOS, very few ecological environments are likely to disappear completely by 2050.

HOWEVER under the high emissions' *hot CanESM2* scenario, plants and amphibians appear more at risk of change in local compositions than the other biological groups.

4.2
Disappearing environments – the national context

A national overview of the degree to which ecological environments are tending to disappear for reptiles is shown in Figure 6 for the high emissions' *mild MIROC5* climate scenario.

This climate scenario presents a relatively positive picture for reptiles - few areas are projected to disappear completely from the continent. Rather, most 1990 environments will be represented by moderately or quite similar environments somewhere on the continent in 2050, from the perspective of reptile habitat.

A quick visual comparison of the four biological groups and two climate scenarios shows which groups and locations are likely to be most and least tending to disappear by 2050 (Figure 7). Plants and amphibians show more places of potential concern under the high emissions' *hot CanESM2* scenario, than the other two groups.

FIGURE 6

Disappearing ecological environments

The *degree to which ecological environments are tending to disappear* across Australia for reptiles by 2050, under the high emissions' *mild MIROC5* climate scenario. Darker colours signify greater tendency to disappear. While the legend shows 10 categories, the mapped data itself is continuous.

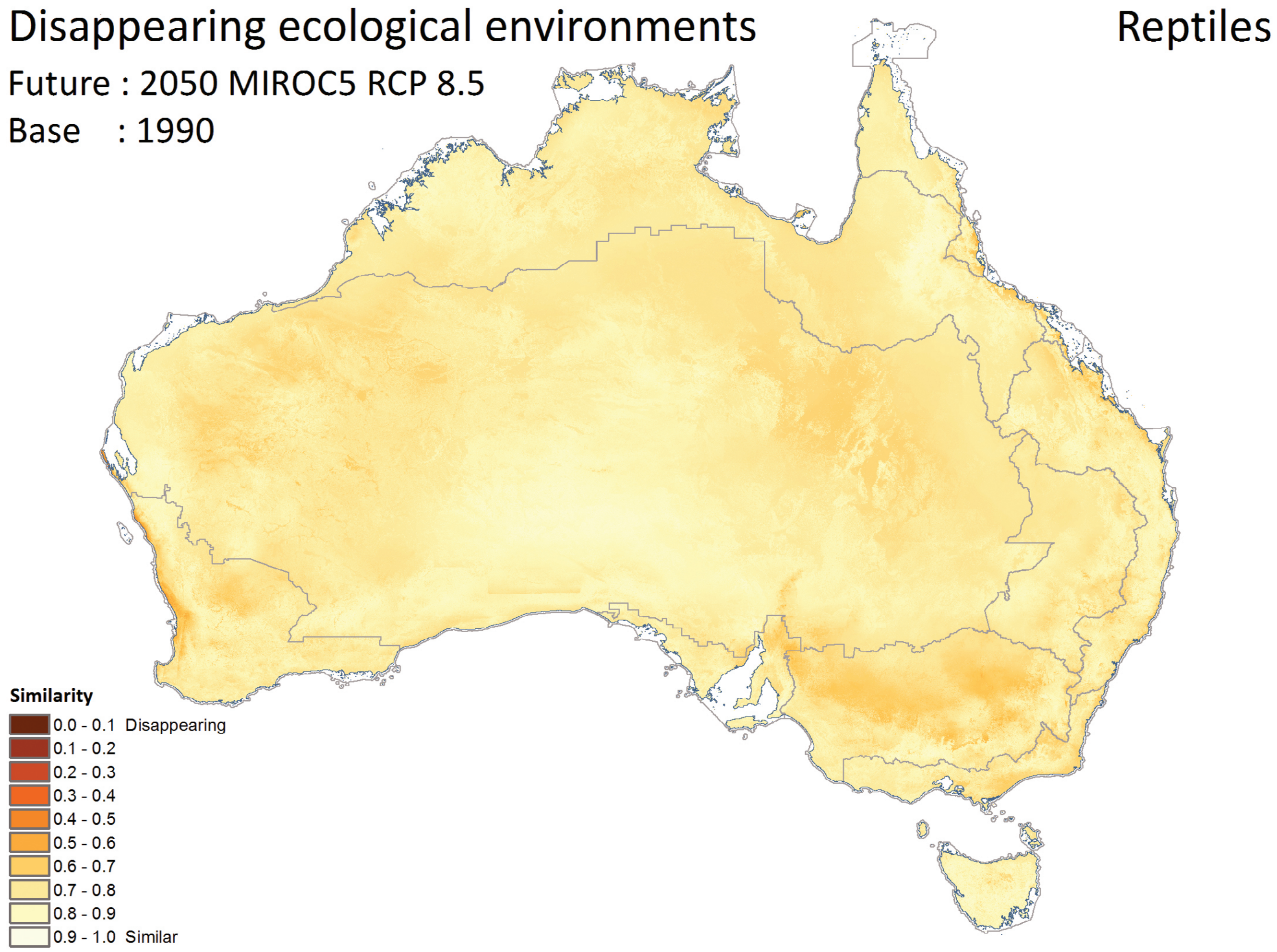
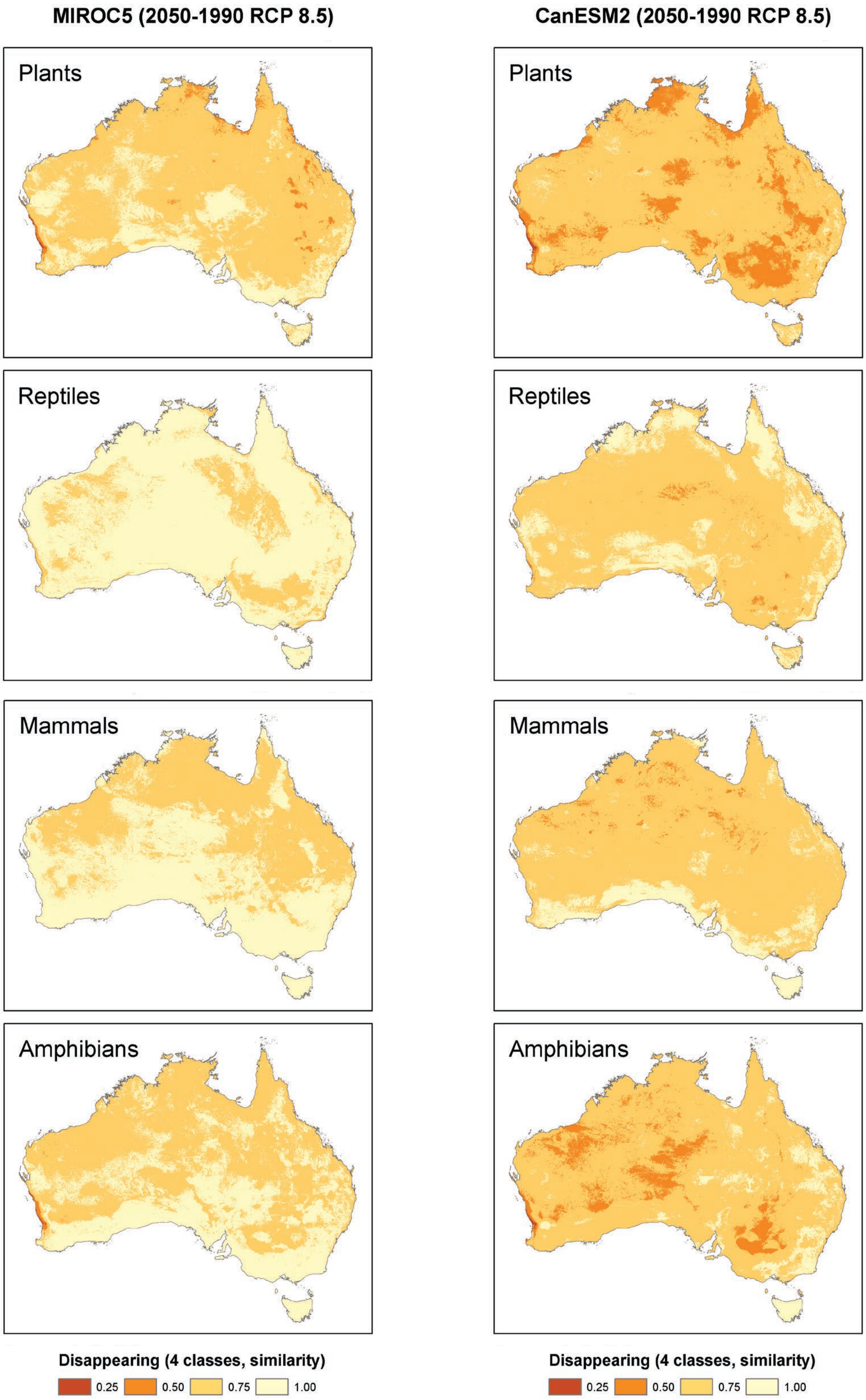


FIGURE 7

Disappearing ecological environments

The *degree to which ecological environments are tending to disappear* between 1990 (baseline) and 2050 (future) for four biological groups and two climate change scenarios. Darker colours signify greater tendency to disappear. While the legend shows four categories for ease of visual comparison, the data itself is continuous.



Right: Image: Southern Bell Frog, Source: Callie Nickolai, courtesy of Flickr, *Creative Commons*

4.3
Disappearing environments – a regional focus

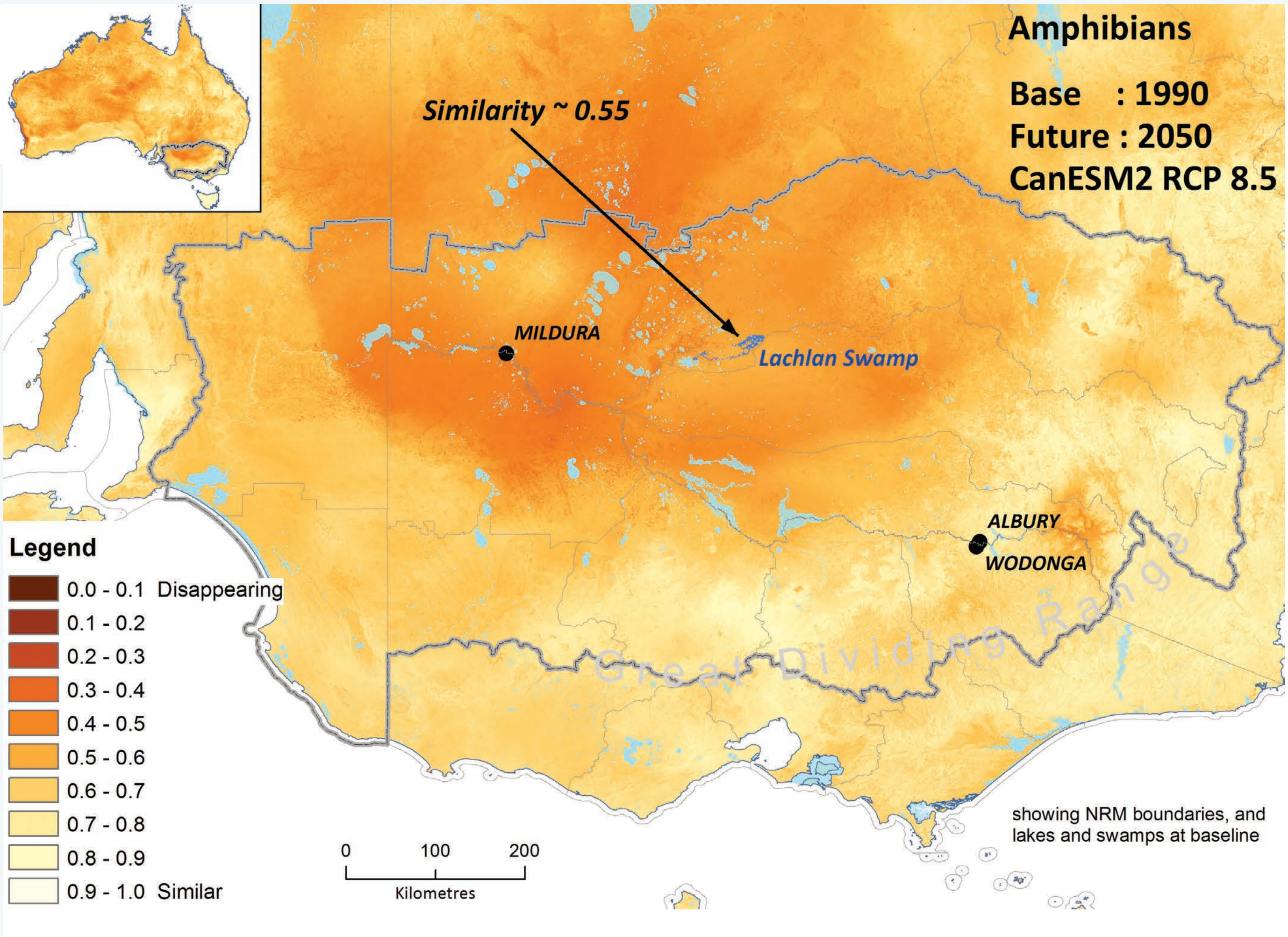
An example regional view for amphibians is shown for the regions associated with the Murray Basin under the high emissions' *hot CanESM2* climate scenario (Figure 8). It suggests that present-day amphibian environments found along the Great Dividing Range are least at risk of disappearing (indicated by paler colours in Figure 8).

Similar environments will be found somewhere on the Australian continent in 2050. The projection does not specify where the similar counterparts are likely to be located – they will be somewhere on the continent. Further analysis would be needed to locate them.

FIGURE 8

Disappearing ecological environments

Gradients in the *degree to which ecological environments are tending to disappear* for Australian amphibians under the high emissions' *hot CanESM2* climate scenario by 2050, within regions broadly associated with the Murray Basin. Darker colours signify greater tendency to disappear. While the legend shows 10 categories, the mapped data itself is continuous.



Right: Image: Aerial of lakes, Source: Mallee CMA

A number of rare and threatened amphibians currently persist around the Lachlan Lakes system. For example, the Southern bell-frog (*Litoria raniformis*) was recently re-discovered in the lower Lachlan riverine environment. This species requires areas of permanent water throughout the year. Under a high emissions' future by 2050, these environments are projected to be moderately disappearing from the perspective of amphibians, with a similarity to present-day environments of around 55%. Amphibian communities in these areas are therefore expected to undergo some degree of change even if individual species are able to migrate to more suitable environments.

Suggestions for how information about disappearing ecological environments could be used in the assessment phase of planning are provided in Box 5, with reference to vascular plants in the wet tropics. This planning example is followed by Box 6, discussing how the disappearing measure could be used to plan for uncertainty about future climates.

POCKETS OF MODERATELY DISAPPEARING ECOLOGICAL ENVIRONMENTS may be found at local to sub-regional scales – fine-scale detail that doesn't clearly appear in the national maps but becomes evident in the regional views.

BOX 5

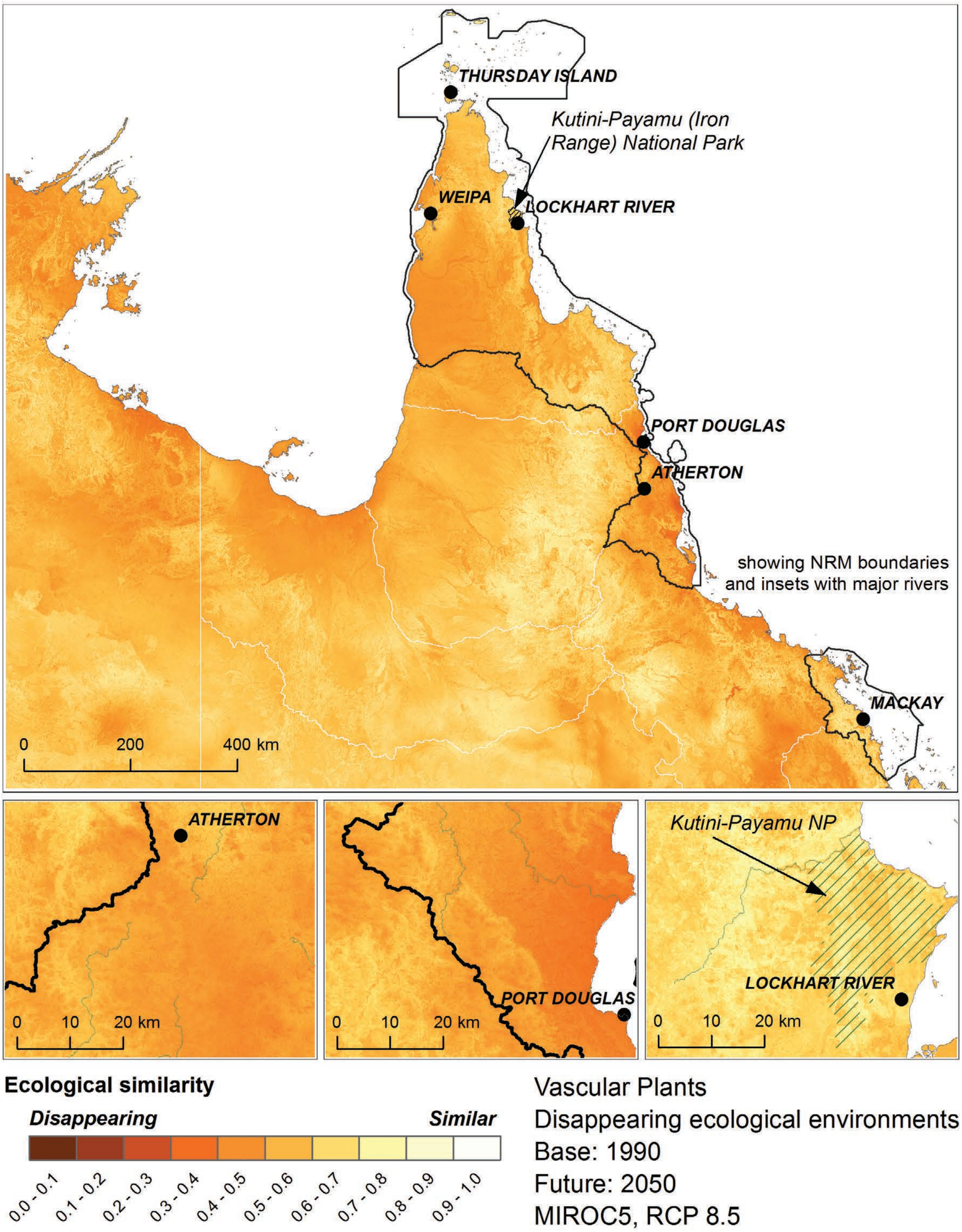
Planning Example
Engaging the community about future values

Maps of disappearing environments may provide an ideal way to engage key stakeholders, including community members, in discussions of whether current assets or 'special places' of a region will still be viewed as valuable in the future. Focusing on what the community values has become a common foundation of regional NRM planning in Australia, but is currently done in a way that tends to assume that assets like vegetation communities will remain where they currently are. Maps of disappearing environments can highlight where existing special places may be at risk of disappearing, at least in terms of their current species composition. This realisation can be used to explore more deeply why those places are currently highly valued by the community and thus whether their disappearing nature requires special attention in planning. Engaging the community in this process can also help build their capacity to adapt to the future, a core challenge of climate adaptation planning as highlighted in ***The NRM Adaptation Checklist***.

For example, the model of disappearing environments for vascular plants in northern Queensland under the high emissions' *mild MIROC5* climate scenario (the figure below) shows that areas around Port Douglas and areas west and south of Atherton, extending toward the coast around and south of Mission Beach, are all at reasonably high risk of disappearing by 2050. This means that not only is the vegetation composition in these areas likely to be quite different than it is today, but what we currently see in these areas may no longer exist in its current form anywhere in Australia.

BOX 5 (CONTINUED)

These areas are currently all important ecotourism destinations. Will their tourist value decrease as plant composition changes, potentially reducing their ability to support iconic fauna such as cassowaries and tree kangaroos? Or is the experience of nature in general more what tourists are seeking? Distinguishing between these different values associated with the biodiversity of these regions may help determine whether these areas will remain as 'special places' in the future or whether the planning focus might be shifted elsewhere.



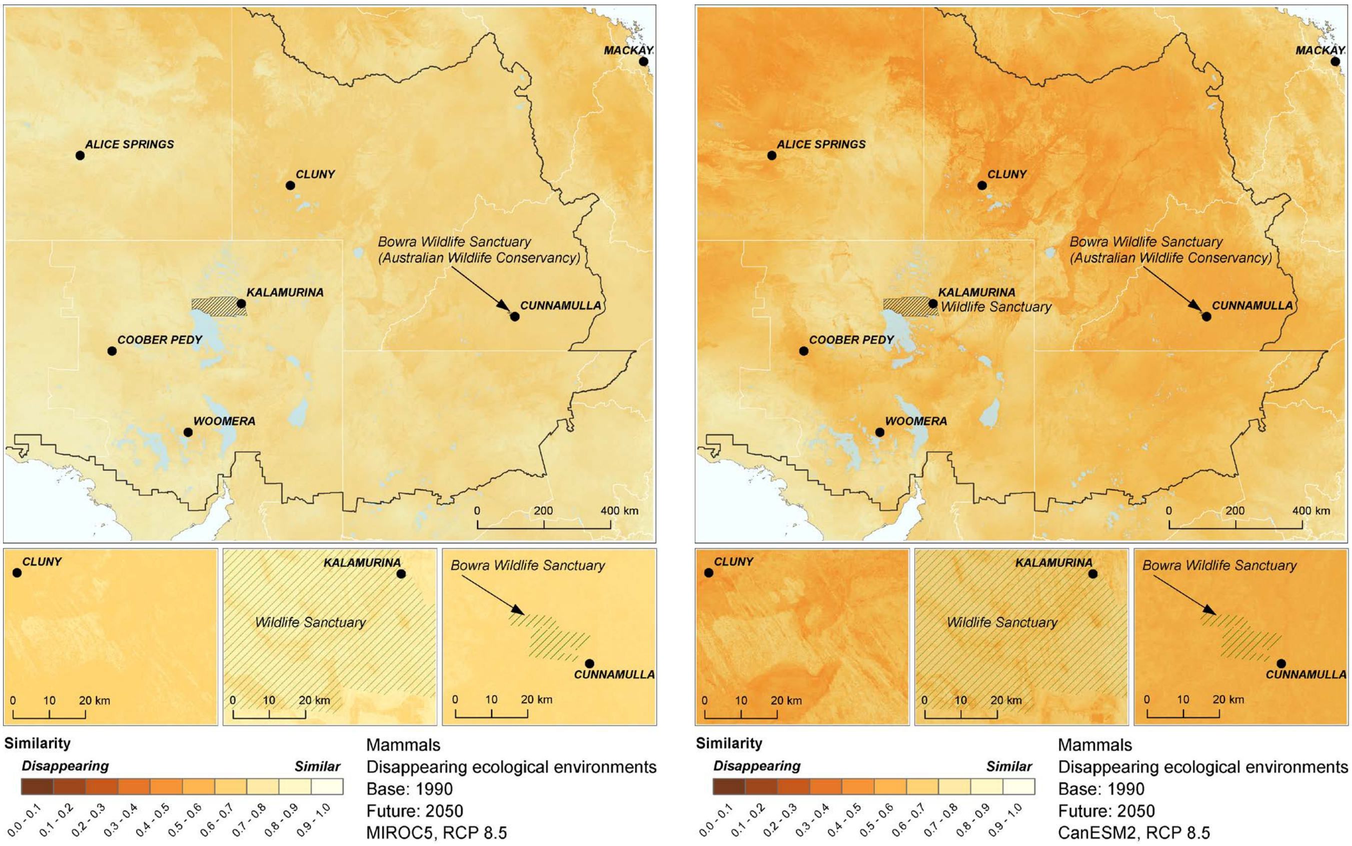
The degree to which ecological environments are tending to disappear in northern Queensland for plants by 2050 under the high emissions' mild MIROC5 climate scenario. Darker colours indicate greater tendency to disappear.

BOX 6

Planning Example
Planning for multiple futures

As highlighted in ***The NRM Adaptation Checklist***, one of the core challenges of NRM planning under climate change involves planning for multiple futures. As we can't know precisely what future climates will arise, decisions made now that may have long-term consequences need to be ones that are likely to be effective under a range of possible future climates. That is why two contrasting climate futures have been modelled for all the measures presented in this Module.

While maps based on different climate scenarios may seem strikingly different, robust decisions can still be made by focusing on where differences between climate scenarios primarily occur in terms of magnitude, but spatial variation appears similar across scenarios. For example, the images below show regional variation in disappearing environments for mammals in the eastern rangelands under two climate futures. While there is greater tendency for environments supporting mammals to disappear under the *hot CanESM2* scenario compared to the *mild MIROC5* scenario, the ***patterns*** of regional variation are similar under both climate scenarios. In general, the southern Lake Eyre Basin region and associated deserts (including the Australian Wildlife Conservancy's Kalamurina Sanctuary) are less likely to contain mammal environments that will disappear compared to the northern Basin and western Queensland more broadly (including the Australian Wildlife Conservancy's Bowra Sanctuary). Thus, both climate scenarios suggest that efforts to maintain and restore historical rangeland mammal populations (a key aim of the Australian Wildlife Conservancy) may be more readily achievable in the southern Lake Eyre Basin than in the northern Basin, where different strategic goals and management approaches may be required.



The *degree to which ecological environments are tending to disappear* in the eastern rangelands for mammals by 2050, under the high emissions' *mild MIROC5* climate scenario (left) and the *hot CanESM2* climate scenario (right). Darker colours signify greater tendency to disappear.

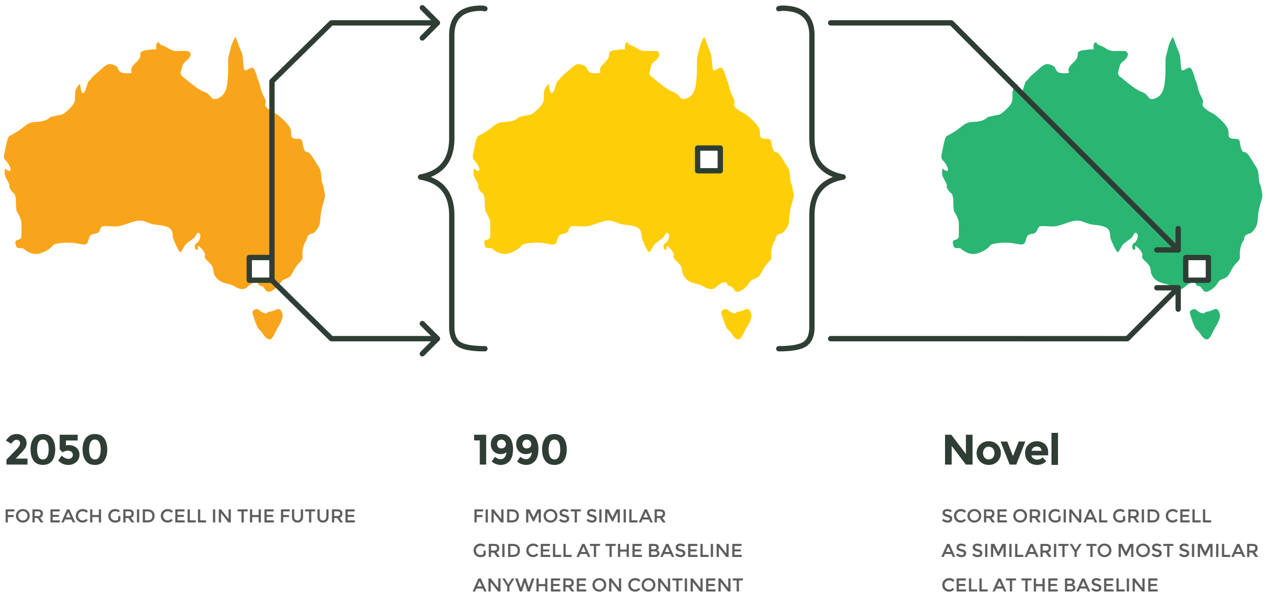
4.4
Estimating novel ecological environments

Novel ecological environments are defined by looking back from each location in the future to find the most similar location anywhere in Australia in the baseline period (Figure 9). The resulting index shows the *degree to which ecological environments are becoming novel*. Locations with future environments showing a low similarity even to their most similar location in the present are indicative of novel ecological environments. This reverses the calculation for disappearing ecological environments (shown in Figure 5).

FIGURE 9

Novel ecological environments

A schematic showing how the *degree to which ecological environments are becoming novel* is mapped. Novel ecological environments are calculated by comparing a grid cell in the future (e.g., 2050) with all possible most similar cells in the present (e.g., 1990 baseline climates).



4.5
Novel environments – the national context

VERY FEW ECOLOGICAL ENVIRONMENTS

are expected to become completely novel under the high emissions' *mild MIROC5* scenario.

HOWEVER

moderately novel environments for all species groups may be expected for parts of Australia under the high emissions' *hot CanESM2* scenario, with parts of the interior and rangelands showing the greatest tendency toward becoming novel.

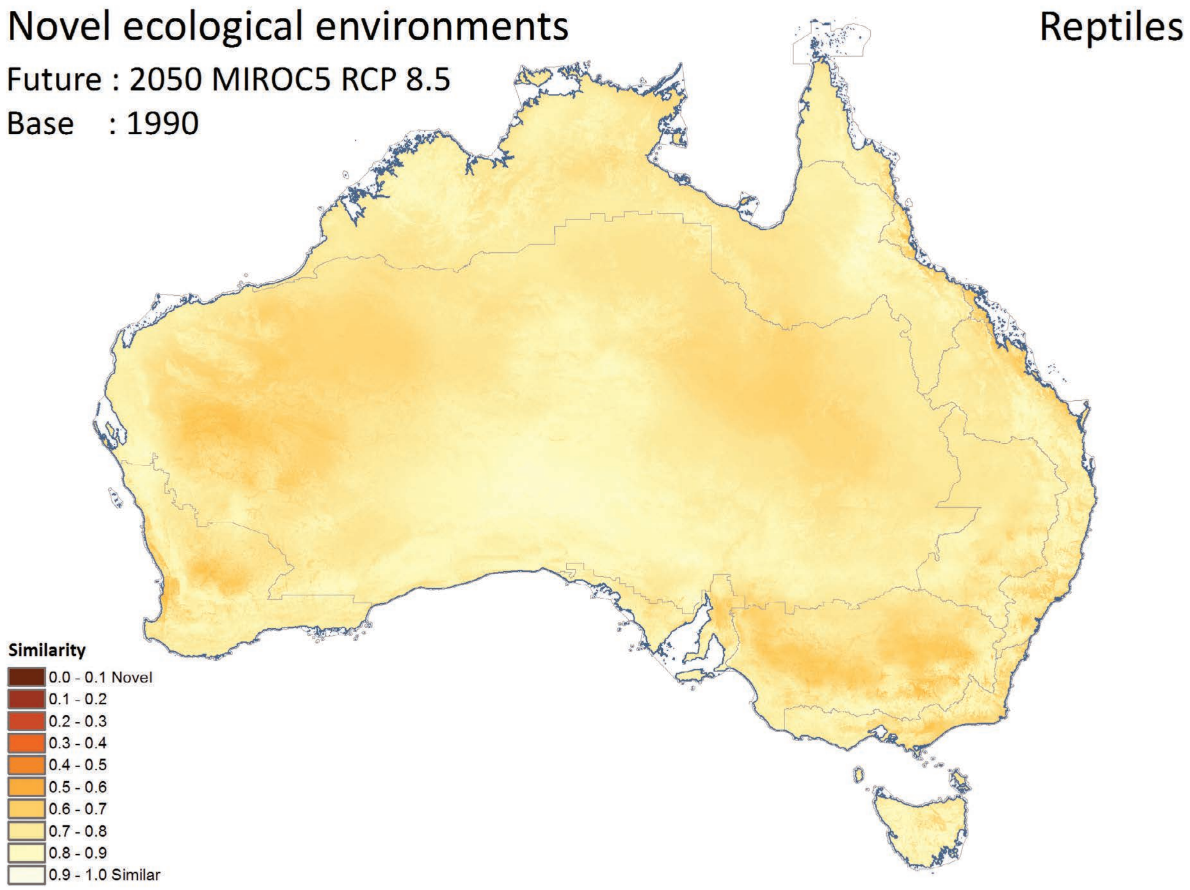
As for disappearing environments, the outcome of the high emissions' *mild MIROC5* climate scenario for reptiles appears relatively positive (Figure 10). Few areas are projected to have highly novel species compositions by 2050. Rather, suitable environments for reptiles developing by 2050 will be at least moderately similar to ecological environments that exist at present, somewhere on the continent.

A quick visual comparison of the four biological groups and two climate scenarios shows which groups and locations are most likely to become novel by 2050 (Figure 11). While few completely novel ecological environments appear to arise under the high emissions' *mild MIROC5* scenario, the *hot CanESM2* scenario suggests that moderately novel environments, and therefore species compositions, are likely to arise for all four species groups, with parts of the Australian interior and rangelands showing the greatest tendency toward becoming novel.

FIGURE 10

Novel ecological environments

The *degree to which ecological environments are becoming novel* across Australia for reptiles by 2050, under the high emissions' *mild MIROC5* climate scenario. Darker colours signify highly novel areas. While the legend shows 10 categories, the mapped data itself is continuous.

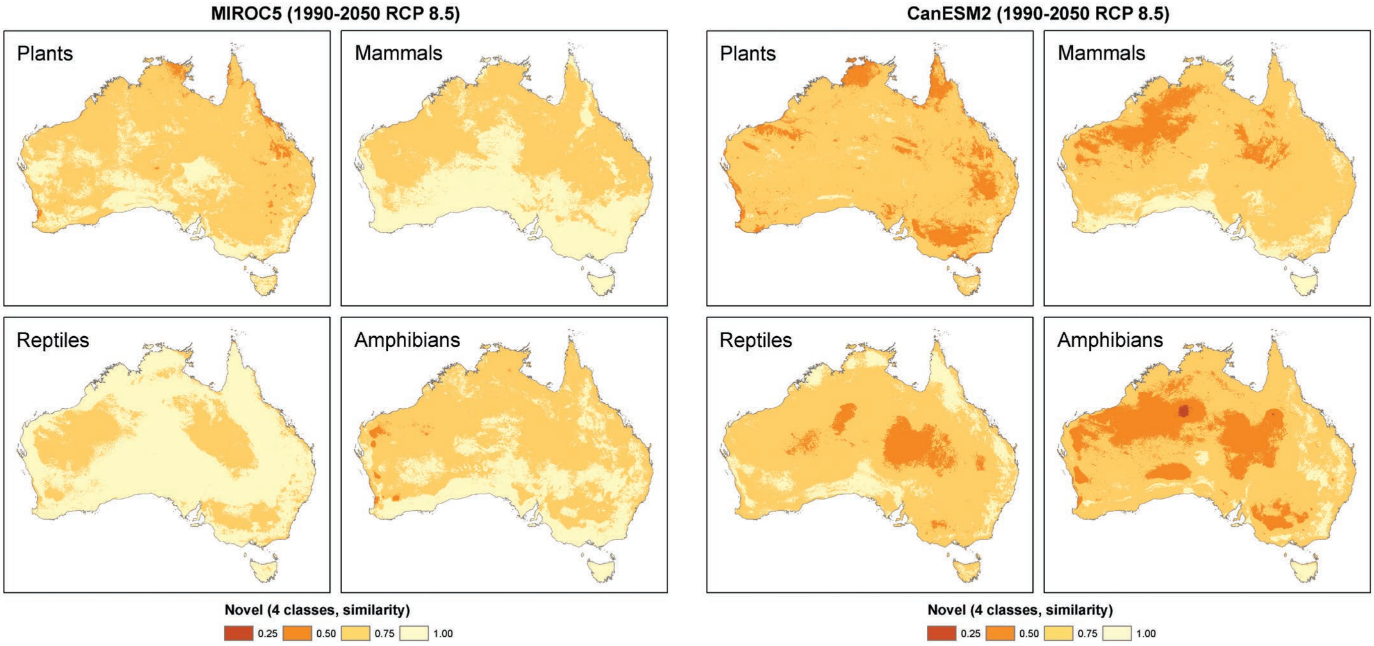


Below: *Image: Common tree snake, Source: Steven Mallett*

FIGURE 11

Novel ecological environments

The *degree to which ecological environments are becoming novel* between 1990 (baseline) and 2050 (future) for four biological groups and two climate change scenarios. Darker colours signify highly novel areas. While the legend shows four categories for ease of visual comparison, the data itself is continuous.



4.6

Novel environments – a regional focus

Here we show the novel counterpart for amphibians under the high emissions' *hot CanESM2* climate scenario in the regions associated with the Murray Basin (Figure 12). Comparison with disappearing amphibian environments (Figure 8) reveals that the novel and disappearing measures do not always coincide.

As for the disappearing measure, future amphibian environments along the Great Dividing Range will closely resemble those presently found somewhere in Australia (lighter colours in Figure 12). Elsewhere, the novel environments in 2050 are projected to have only moderately similar counterparts to the present (darker colours in the map).

For example, the projected degree to which amphibian environments are becoming novel across the mallee region of western Victoria is estimated to be 50-75%. The best counterparts for some amphibian environments by 2050 may be no more than 50% similar.

These inland areas are where novel amphibian communities may assemble and be unlike what we know anywhere in Australia today. Significant change can be expected, but some of Australia's native species may still persist in such environments, as their environmental tolerances might not be reflected by their current range, and local microclimates may further support survival.

POCKETS

of moderately novel ecological environments may be found at regional scales.

IT WILL BE DIFFICULT

to predict what these novel ecological environments will be like since native species may have unknown capacities to adapt.

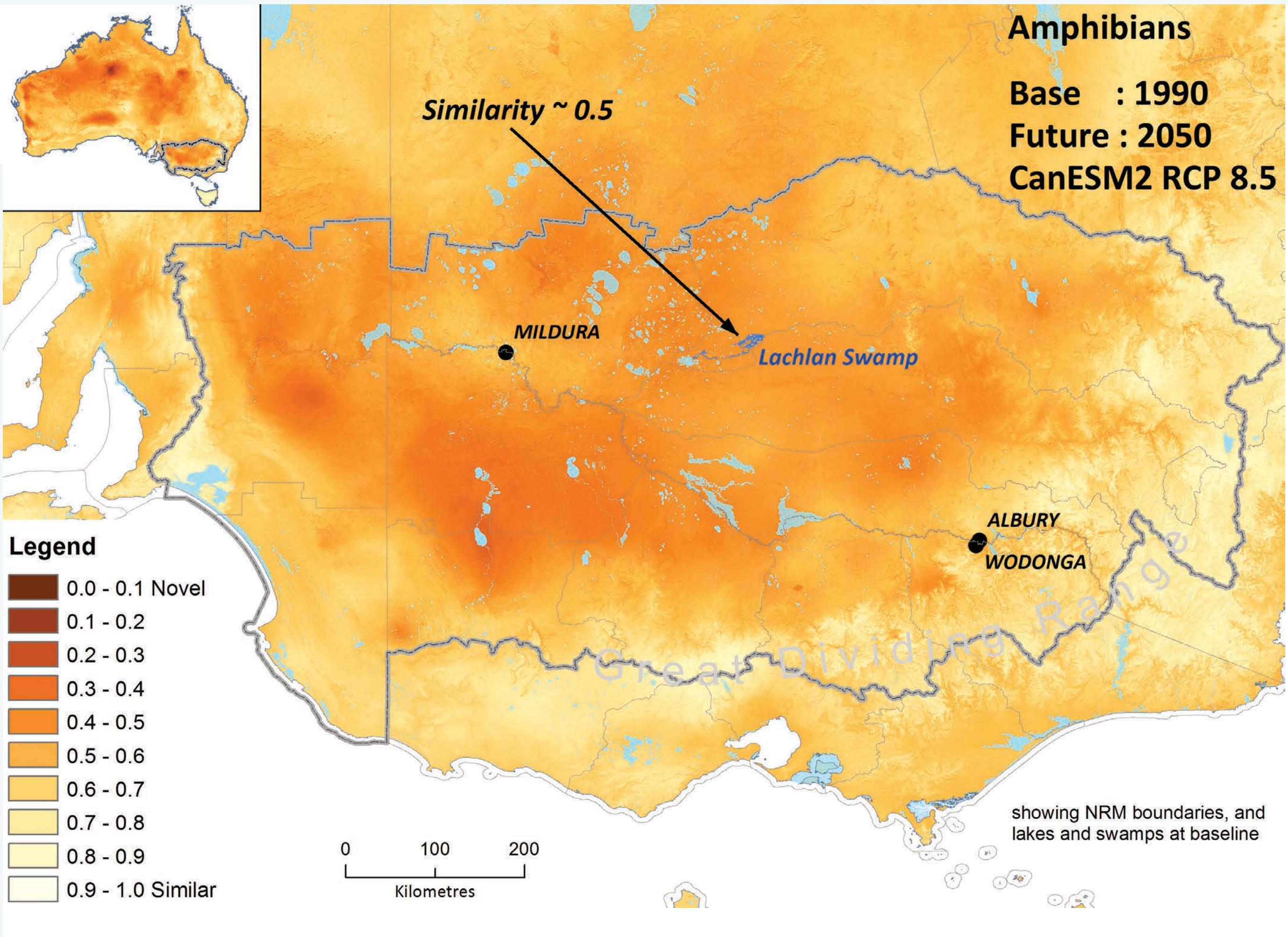
Below:
Image: Valley field, Source: Terrain NRM

A suggestion for how information about novel environments could be used to identify key areas of cross-border collaboration is presented in Box 7. A further example in Box 8 discusses how information across the four species groups could be used to reduce the common practice of using vegetation as an umbrella to plan for most species.

FIGURE 12

Novel ecological environments

Gradients in the *degree to which ecological environments are becoming novel* for Australian amphibians under the high emissions' *hot CanESM2* climate scenario by 2050, within regions broadly associated with the Murray Basin.



Below: Image: Scarlet-sided Pobblebonk, Source: Steven Mallett

BOX 7

Planning Example
Identifying key areas for cross-border collaboration

Information on where novel environments are likely to arise could highlight where cross-border collaboration might be most useful in planning – a key aspect of climate-adapted planning as highlighted in ***The NRM Adaptation Checklist***. For example, our regional focus example (Figure 12) suggests that the amphibian community of the ephemeral lakes and creeks of western Victoria may be under pressure to change such that the future community won't be much like any amphibian community known today in Australia.

For a novel community to assemble, species that don't currently live there may need to move into the region. As most amphibians are dependent on hydrological connectivity to move through the landscape, ephemeral flows through the mallee region may be critical to ensuring a new amphibian community can arise and amphibians won't be lost from the region. Planning for such flows could require collaboration among Mallee, Wimmera, and North Central CMAs, and they may benefit from presenting this cross-border perspective when interacting with existing collaborative water resource planning efforts.

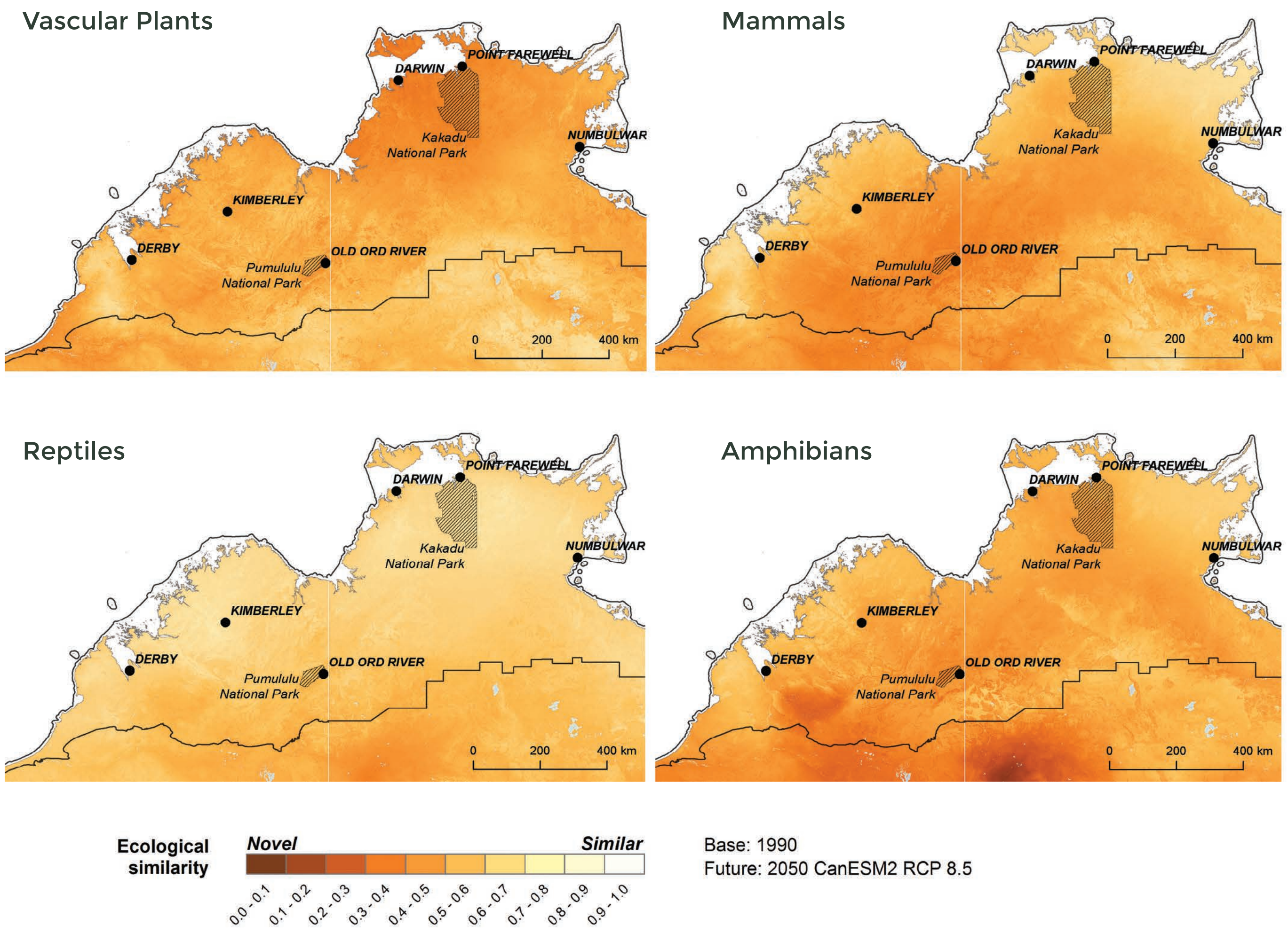
Similarly, the AdaptNRM Module on ***Weeds and Climate Change*** highlighted that where novel environments arise, there may be greater risk that the new communities will be composed of or dominated by invasive plant species. Thus, Mallee, Wimmera, and North Central CMAs could also collaborate on a simple monitoring program to try to detect new amphibians coming into the region and assess whether they are acting invasively. Such collaborative monitoring could be particularly cost-effective.

BOX 8

Planning Example
Reducing dependence on vegetation as an umbrella

In planning for biodiversity at most scales, there is considerable reliance on vegetation as an umbrella for other species. For example, a great deal of planning is based on vegetation types (e.g. improving the extent of communities like Box-Gum Grassy Woodlands) with an assumption that associated fauna species will also benefit. While that assumption has been questioned in the past, our community-level models of broad shifts in different species groups particularly highlight that vegetation is not necessarily a good indicator of the likely response of other groups under climate change.

For example, the figure below shows the tendency for novel environments to arise in the north west of Australia under the high emissions' *hot CanESM2* climate scenario for all four biological groups. There is a tendency for vascular plant environments to become most novel around Kakadu National Park. Yet mammal environments will be most novel throughout the Kimberley, amphibian environments will be most novel southeast of Derby, and reptile environments will be relatively similar to those seen today. Collectively, these maps suggest that different species groups will experience changing climates differently. Thus, fauna groups (and not just threatened fauna species) may need to be included much more comprehensively in assessment and planning. The community-level models provided with this Module present an opportunity to begin doing just that, at least for mammals, reptiles and amphibians.



Base: 1990
Future: 2050 CanESM2 RCP 8.5

The degree to which ecological environments are becoming novel by 2050 in parts of northern Australia for all four species groups under the high emissions' *hot CanESM2* climate scenario. Darker colours signify greater tendency to become novel.

4.7

Disappearing and novel environments – related but not the same

DISAPPEARING AND NOVEL ecological environments often coincide, but not always, because they are different concepts.

It is apparent from the two national context maps (Figure 6 and Figure 10) and regional examples (Figure 8 and Figure 12) that areas with a high tendency to disappear can coincide with areas with a high tendency for becoming novel. This occurs particularly in areas where the *potential degree of ecological change* itself is highest. In such cases, locations where the ecological environments are almost completely disappearing are also places projected to become highly novel.

Yet disappearing and novel ecological environments are different concepts and do not always go hand-in-hand. So areas with a high tendency to be disappearing do not always coincide with areas with a high tendency for becoming novel.

SOMETIMES DISAPPEARING ecological environments will be replaced by similar environments that already exist somewhere in Australia today.

Examining both disappearing and novel environments for amphibians in the lower Murray Basin (Figure 8 and Figure 12) reveals that some areas, such as the catchment around Mildura, may support environments that are tending to disappear but what replaces them won't be particularly novel. These areas are expected to change but may become more similar to other amphibian environments that already exist somewhere else – i.e., they will not be novel.

SOMETIMES NOVEL ecological environments will arise where environments present today will simply be supported elsewhere in Australia.

In contrast, the ephemeral lakes and creek beds in the Wimmera catchment show little tendency to disappear from the perspective of amphibians but are likely to become reasonably novel. The amphibian environments currently found in these areas will likely still exist in the future but may be found elsewhere in Australia – they will not disappear. But the environments in these areas themselves may become novel for amphibians. An integrated framework for interpreting these complex interacting patterns is presented with examples in Section 6.

How much change will occur in the capacity of future landscapes to support biodiversity?

SECTION 5

The future capacity of Australia to support the biodiversity of any landscape depends on the change in amount of suitable habitat, and on the condition of that habitat.

Below: Image: Aerial valley,
Source: North East CMA, Credit: Alison Skinner

Here we present a measure that shows the interplay between climate change and clearing patterns. It can be thought of as the proportion of habitat remaining in the future.

5.1

Effective area of similar ecological environments

The effective area of similar ecological environments is a measure of the total land area within a region or landscape that supports a species composition similar to a given location within that landscape. For example, a location that supports an ecological environment (akin to suitable habitat) that is common in the landscape will have a high score for effective area, whereas a location that supports a rare habitat will have a low score; because rare habitat is limited in extent by definition.

We use this concept to ask several questions:

- How does the *effective area of similar ecological environments* change under scenarios of climate change? If the projected area is less than in the baseline period, this indicates an expected loss in capacity to support all of the species at a particular location.
- How does land clearing influence the effective area of similar ecological environments, and how does this interact with climate change?

To address these questions, we measure the *change in effective area of similar ecological environments*. This indicates the extent to which the typical species within a particular habitat may find themselves with less suitable habitat as a result of climate change and/or clearing patterns. If there is a loss of capacity due to a reduction in the *effective area of similar ecological environments*, we expect a corresponding loss of original biodiversity.

THE EFFECTIVE AREA

of similar ecological environments is a measure of the total land area within a region or landscape that supports a species composition similar to a given location within that landscape.

A RARE HABITAT

will have a low score because rare habitat is limited in extent, by definition.

EFFECTIVE AREA OF SIMILAR ECOLOGICAL ENVIRONMENTS

may change under climate change, with expected loss or gain in the capacity of future environments to support biodiversity.

LAND CLEARING

may have already reduced the capacity of these areas to support their local biodiversity.

CHANGE IN EFFECTIVE AREA

of similar ecological environments can be explored under climate and land cover scenarios, or both simultaneously.

change in effective area

=

future effective area

÷

baseline effective area

5.2
Estimating change in effective area of similar ecological environments

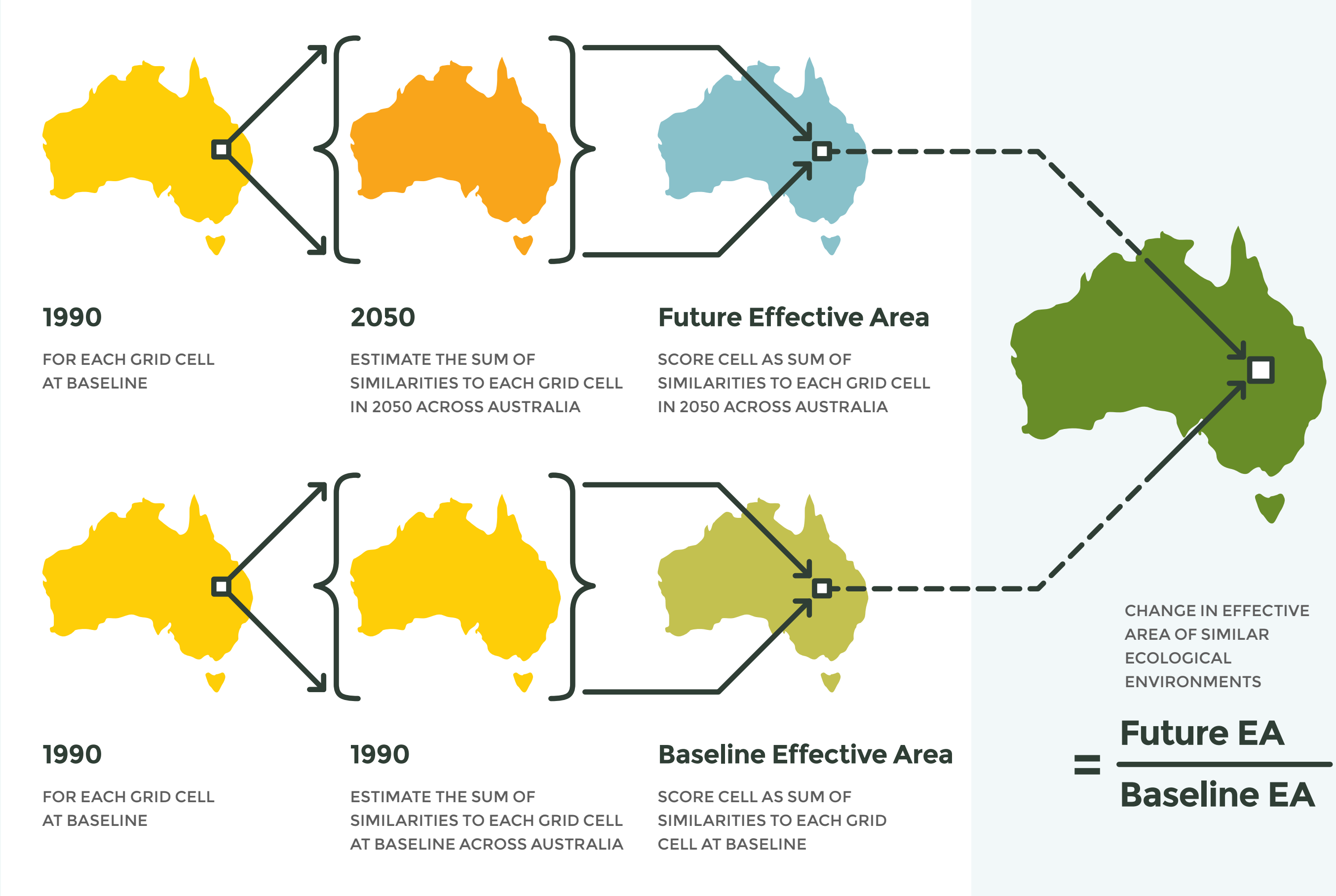
Change in effective area of similar ecological environments is calculated by dividing the effective area of ecological environments under a scenario by its potential or original effective area (Figure 13). The scenario could relate to climate change and/or to clearing of natural areas. The calculation uses two measures for each location:

1. The present-day, or baseline potential effective area of ecological environments. This 'potential' represents the original biodiversity at each location and assumes the whole landscape is ecologically intact.
2. The effective area of ecological environments under a scenario. This may be:
   - a climate scenario – showing the change in area of similar environments due to climate change alone;
   - a land cover scenario – showing the change in area of similar environments due to clearing of natural areas alone; or
   - both – showing the interaction of land cover and climate change.

FIGURE 13

Change in effective area of similar ecological environments

Change in effective area of similar ecological environments is a proportion, derived from two separate calculations.



5.3

Change in effective area of environments – the national context

The national pattern of *change in effective area of similar ecological environments* for mammals by 2050 is illustrated in Figure 14, without accounting for land use. The general outlook under the high emissions' *mild MIROC5* climate scenario is moderate, with higher projected losses (i.e., reduced capacity to support all the original mammal species) in parts of northern Australia (darker shading), and projected lesser reduction in capacity (lighter shading) along the southern edges of the continent and in Tasmania.

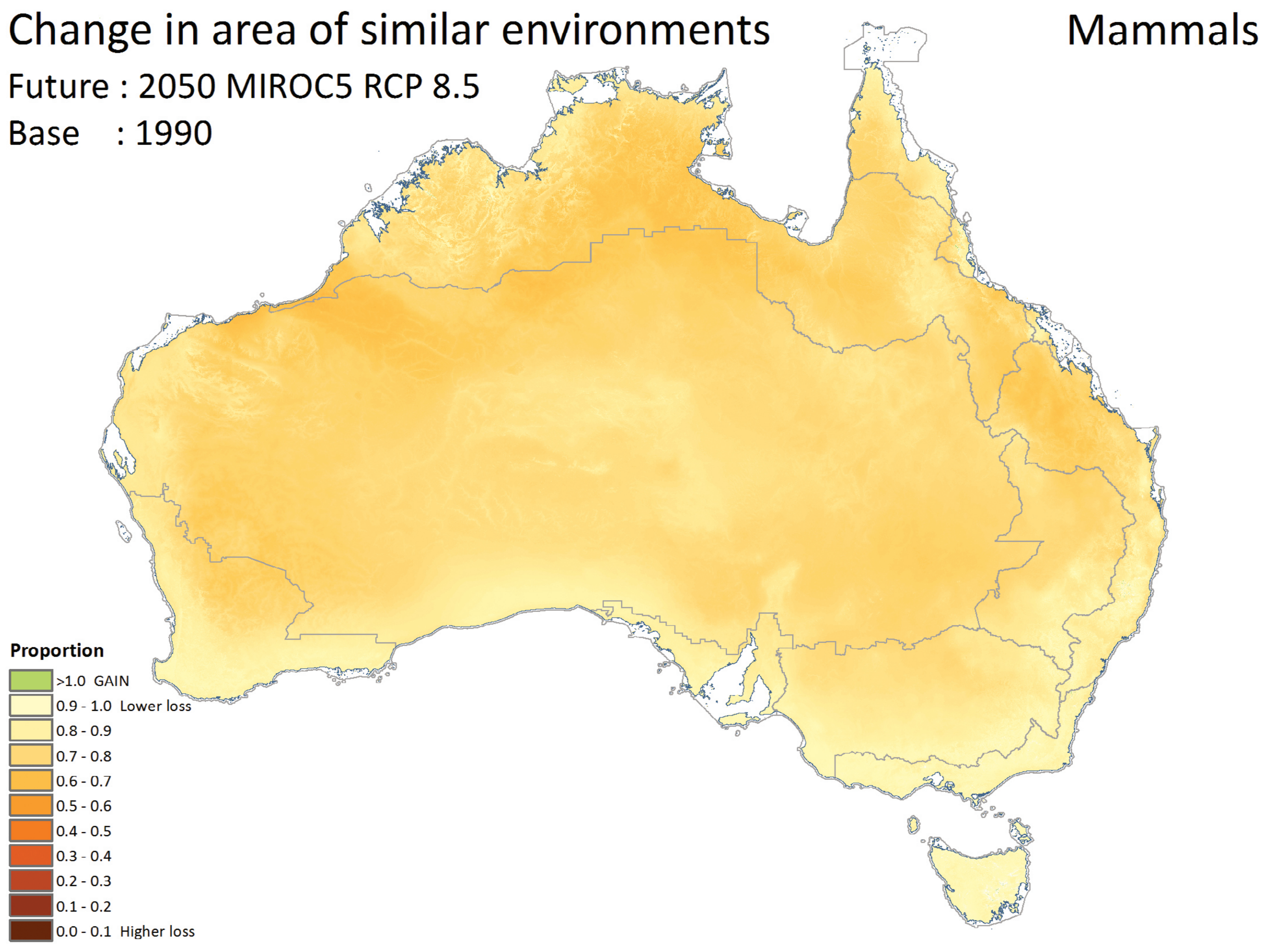
CHANGE IN EFFECTIVE AREA

of similar mammal environments by 2050 suggests that climate change alone could exacerbate recent northern mammal declines.

FIGURE 14

Change in effective area of similar ecological environments

Change in effective area of similar ecological environments for mammals by 2050 using the high emissions' *mild MIROC5* climate scenario and assuming intact habitats. Darker colours signify lower proportion of similar habitat remaining by 2050; lighter colours signify less change and, in some cases, a gain in effective area (green). While the legend shows 10 categories, the mapped data itself is continuous.



Small mammals have already suffered substantial decline in Australia since European settlement and the associated introductions of feral predators. But these existing losses are not taken into account in this analysis. The relatively *mild MIROC5* scenario shown in Figure 14, while variable, suggests that climate change alone could exacerbate recent northern mammal declines by 2050.

Because each biological group responds differently to climate change, different outcomes can be expected for the other groups. Figure 15 provides a quick visual comparison of change in effective area projections for plants, mammals, reptiles and amphibians for the two climate scenarios. Consistent with the other measures (Sections 3 and 4), more change overall is suggested for plants and amphibians.

This analysis indicates the extent to which the current ecological environment of each location within Australia is likely to diminish or increase in its capacity to support its original biodiversity. It highlights that even if change occurs locally (see Section 3), in some places this change will be buffered by a shift in similar ecological environments to new locations.

However, the analysis does not show where those environments will be in the future. Further analysis would be needed to locate them, like the illustration given for the Great Western Woodlands (Section 2.6). Consideration of ecological processes such as dispersal limitation will need to be incorporated into the interpretation of potential biodiversity response. More information will be available in the follow-on Guide, ***Helping Biodiversity Adapt***.

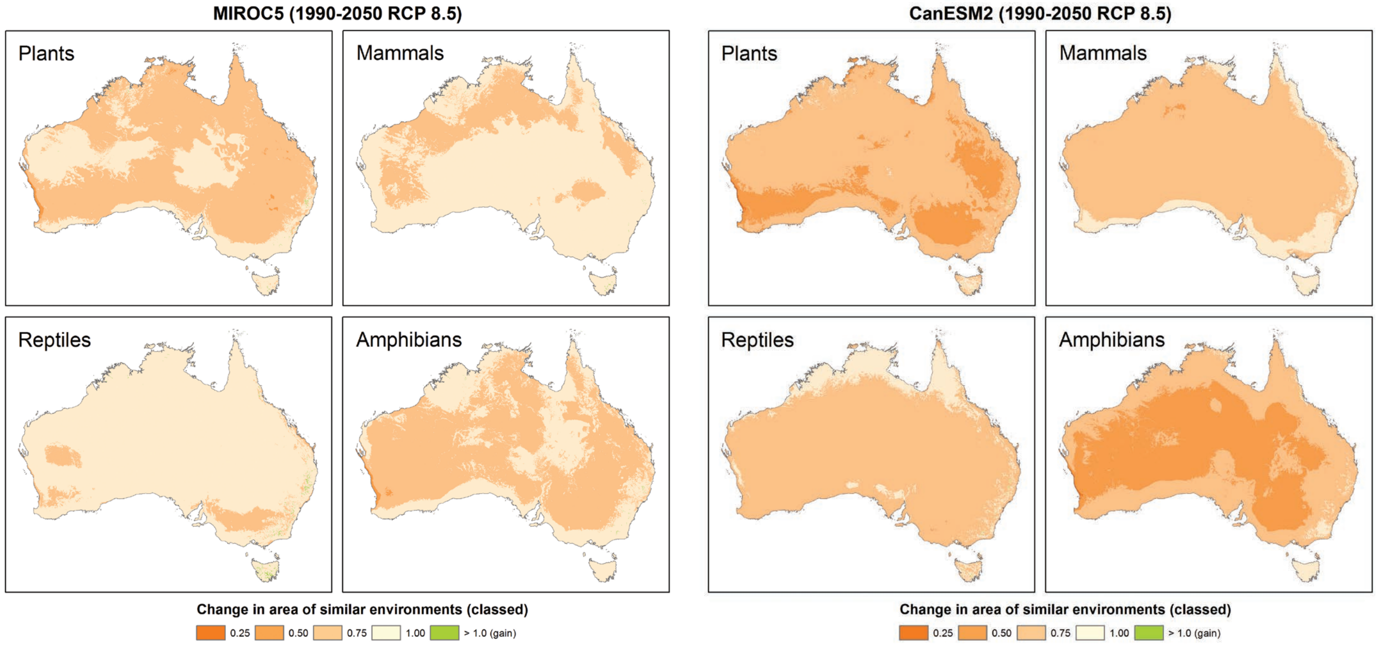
CONSISTENT WITH THE OTHER MEASURES, greater reductions in *effective area of similar ecological environments* by 2050 are suggested for plants and amphibians compared to the other species groups.

DECREASES in the area of similar ecological environments for mammals may particularly occur in northern Australia, while decreases for reptiles may particularly occur in the south.

FIGURE 15

Change in effective area of similar ecological environments

Change in effective area of similar ecological environments between 1990 (baseline) and 2050 for four biological groups and two climate scenarios, not accounting for land use. Darker browns signify higher levels of change. Occasionally, there is net area increase (green class). While the legend shows four categories for ease of visual comparison, the data itself is continuous.



5.4

Land clearing and climate change – the national context

An important additional consideration in evaluating *change in effective area of similar ecological environments* is the effect of past land use practices on habitat availability. The biodiversity projections discussed so far assume an intact landscape where natural habitat is available everywhere. Consequently, these projections are overly optimistic for intensively- or moderately-used landscapes, where wildlife habitat has been removed, degraded or fragmented.

The comparable projection of *change in effective area of similar ecological environments* for mammals under the high emissions' *mild MIROC5* scenario is shown in Figure 16, incorporating contemporary land clearing patterns. This integrated measure accounts for past land use by excluding cleared areas as potentially available habitat both in the present and the future. Not surprisingly, accounting for clearing leads to a much more severe outlook for the intensively utilised agricultural zones of southern and eastern Australia, including parts of Tasmania.

The present-day influence of clearing without the added effect of climate change is shown in Figure 17. In the less intensively utilised zones across Australia, the projections remain similar (compare Figure 16 with Figure 14).

A quick visual comparison of differences between the biological groups is given in Figure 18, for the effects of land clearing only, and in Figure 19, for the effects of climate change and land clearing. These are useful in deciding where to focus attention for a more detailed examination.

EFFECTIVE AREA OF SIMILAR ENVIRONMENTS

can also change due to past land use practices.

WHEN THE INTERACTION

between climate change and existing land clearing is taken into account, the reduction in effective area of similar ecological environments for the more intensively utilised regions of Australia is much more severe.

FIGURE 16

Change in effective area of similar ecological environments

Change in effective area of similar ecological environments for mammals by 2050 using the high emissions' *mild MIROC5* climate scenario with contemporary land clearing patterns. Darker colours signify lower areal proportion of similar habitat remaining by 2050; lighter colours signify less change and, in some cases, a gain in effective area (green). While the legend shows 10 categories, the mapped data itself is continuous.

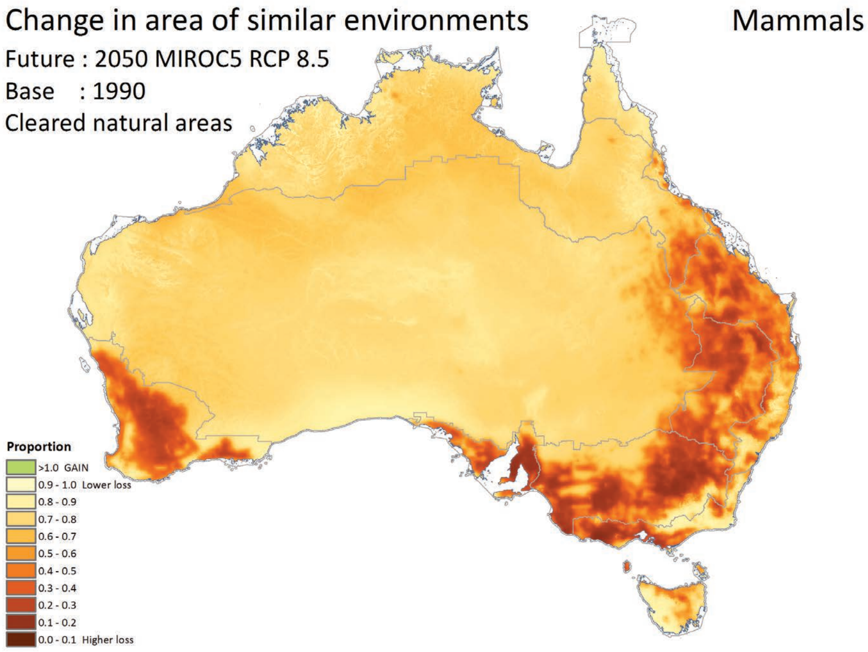


FIGURE 17

Change in effective area of similar ecological environments

Present-day *change in effective area of similar ecological environments* for mammals showing the effect of contemporary land clearing patterns only. Darker colours signify lower areal proportion of similar habitat currently remaining; and lighter colours signify less change. While the legend shows 10 categories, the mapped data itself is continuous.

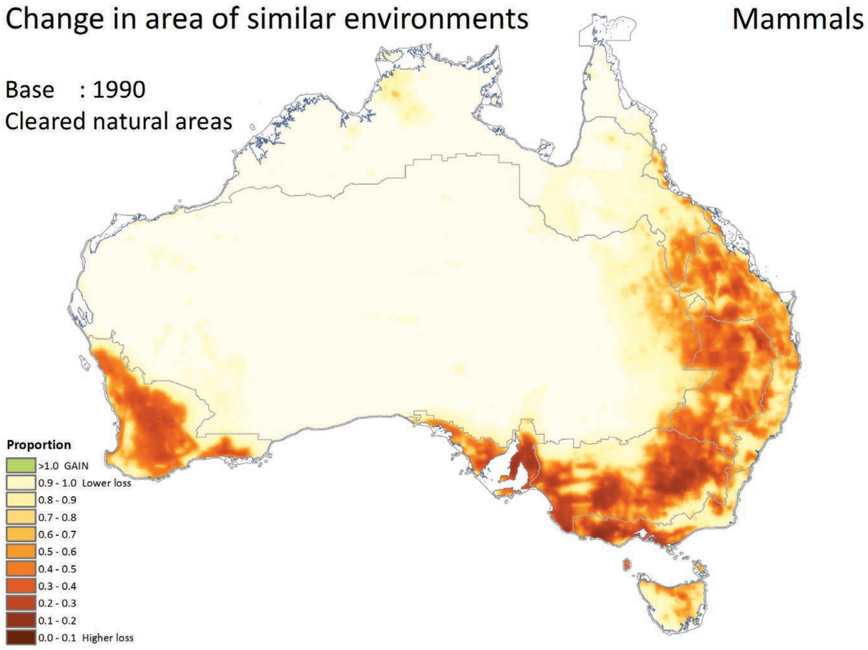


FIGURE 18

Change in effective area of similar ecological environments

Present-day *change in effective area of similar ecological environments* in categories of similarity for the baseline of 1990. Darker browns signify higher levels of change and lighter browns signify less change in effective area. While the legend shows four categories for ease of visual comparison, the data itself is continuous.

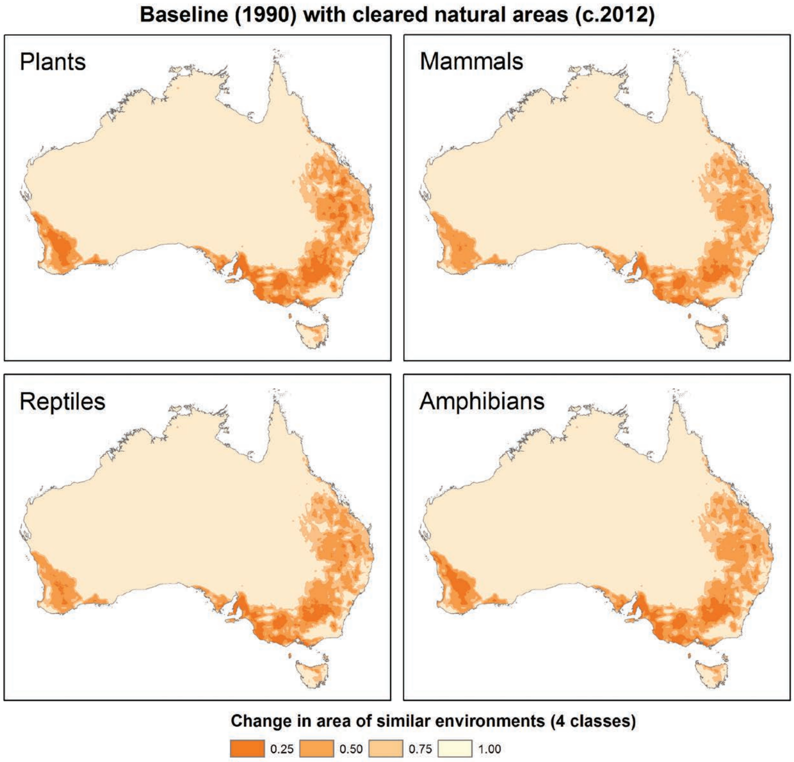
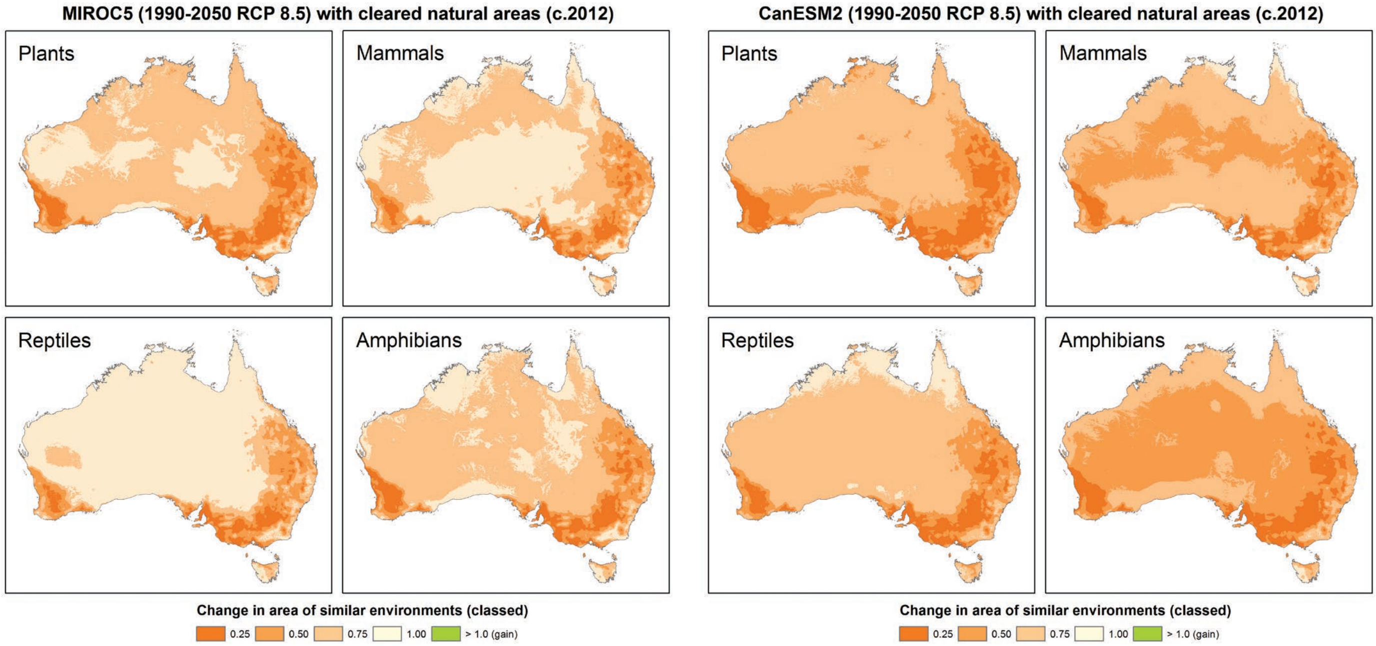


FIGURE 19

Change in effective area of similar ecological environments

Change in effective area of similar ecological environments between 1990 (baseline) and 2050 for four biological groups and two climate scenarios with cleared natural areas. Darker browns signify higher levels of change and lighter browns signify less change in effective area. Occasionally, there is net area increase (green class). While the legend shows four categories for ease of visual comparison, the data itself is continuous.



5.5

Change in effective area of similar environments – a regional focus

Taking a more regional look at the *change in effective area of similar ecological environments* for reptiles in Tasmania, the high emissions' *mild MIROC5* scenario suggests considerable local variability in the degree of gain or loss of reptile environments (Figure 20).

Some ecological environments, particularly the broad river valleys in the southeast, are showing an increase in the area of suitable habitat (green shading), which is an uncommon projection for most parts of Australia and suggests high buffering capacity.

CALCULATIONS

of change in effective area of similar ecological environments focus on changes in the amount of habitat available to support present-day species compositions over the long term.

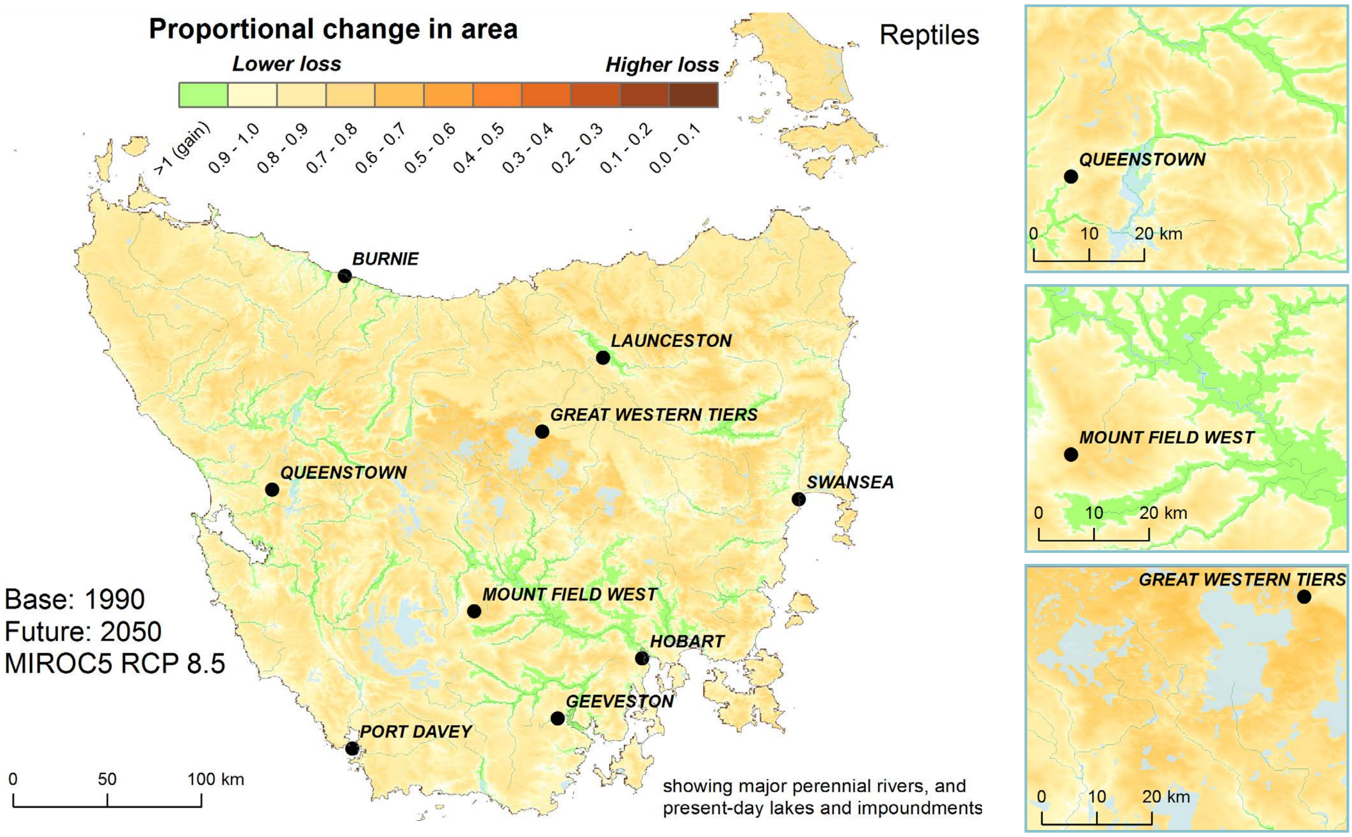
THESE MEASURES

can be used to investigate interactions between climate change and land clearing to highlight habitats most at risk of change or identify parts of the landscape with high potential buffering capacity.

FIGURE 20

Change in effective area of similar ecological environments

Change in effective area of similar ecological environments for reptiles in Tasmania by 2050, using the high emissions' *mild MIROC5* climate scenario, not accounting for past land clearing. Analysis based on the Australian continent.



showing major perennial rivers, and present-day lakes and impoundments

Right: Image: The Northern snow skink, (*Niveoscincus microlepidotus*) is a Tasmanian endemic. Its typical habitat is expected to decline, Source: Nuytsia@Tas, courtesy of Flickr, ***Creative Commons***

As might be expected, the most severely affected locations appear to be mountain tops and plateaus, particularly the Central Plateau. Those environments show the greatest loss in capacity to support their original biodiversity as the prevailing climate warms.

However, accounting for the effects of historical clearing, we find that much of the buffering potential in the state has already been lost (Figure 21). Land clearing interacts with climate change leading to a more substantial reduction in *effective area of similar ecological environments* for reptiles throughout the northern and midland agricultural regions (shown by the substantially darker colours between Burnie, Launceston and Hobart).

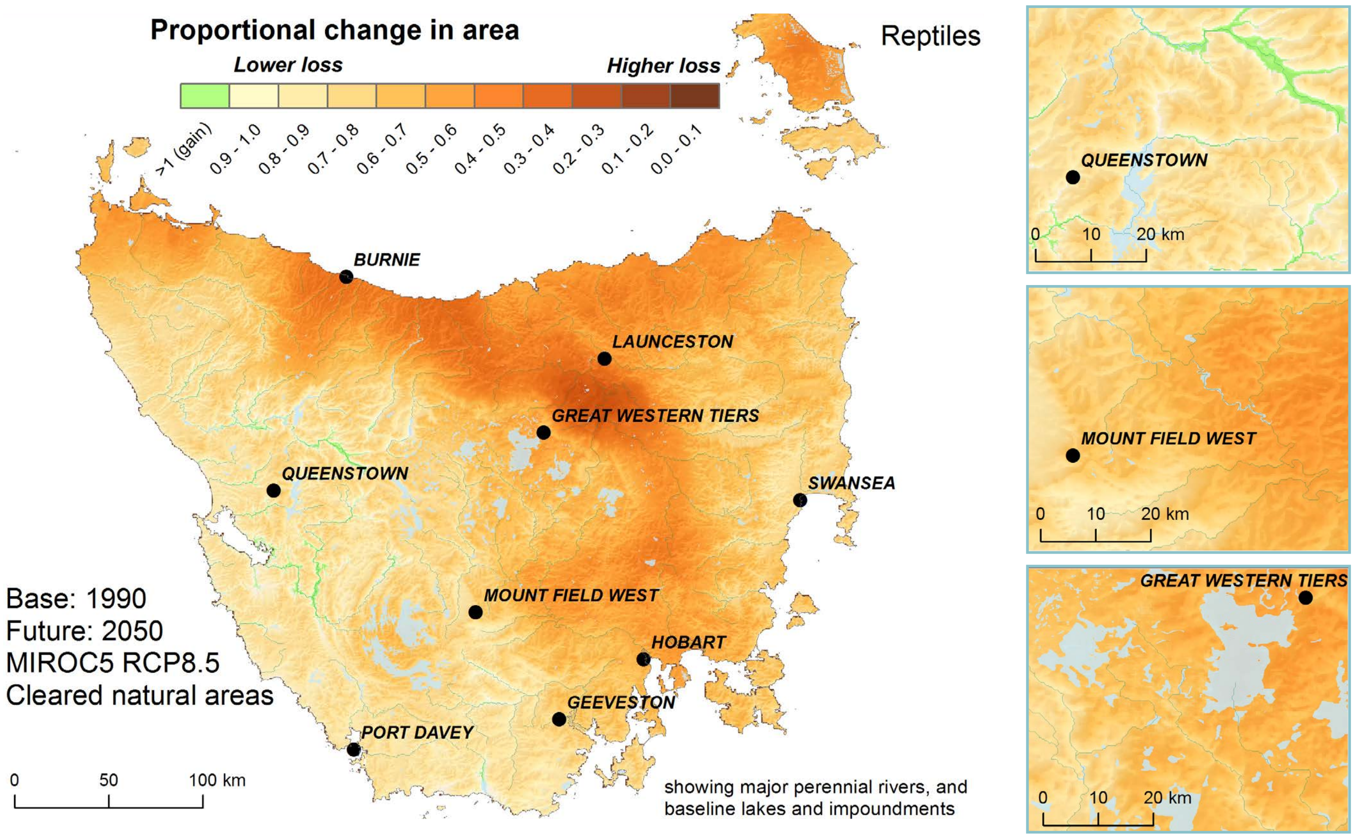
The contrasts between Figure 20 and Figure 21 highlight the significant loss in ecological resilience associated with intensively-used landscapes. In the follow-on Guide, ***Helping Biodiversity Adapt***, this analysis is extended to estimate the benefits of revegetation activities.

A suggestion for how to use change in effective area of similar ecological environments to consider climate change in the context of other threats in the landscape, is provided in Box 9.

FIGURE 21

Change in effective area of similar ecological environments

Change in effective area of similar ecological environments for reptiles in Tasmania by 2050, using the high emissions' *mild MIROC5* climate scenario, and including the effects of past land clearing. Analysis based on the Australian continent.



Below: Image: 'Egg and bacon' flowers, Source: Veronica Doerr

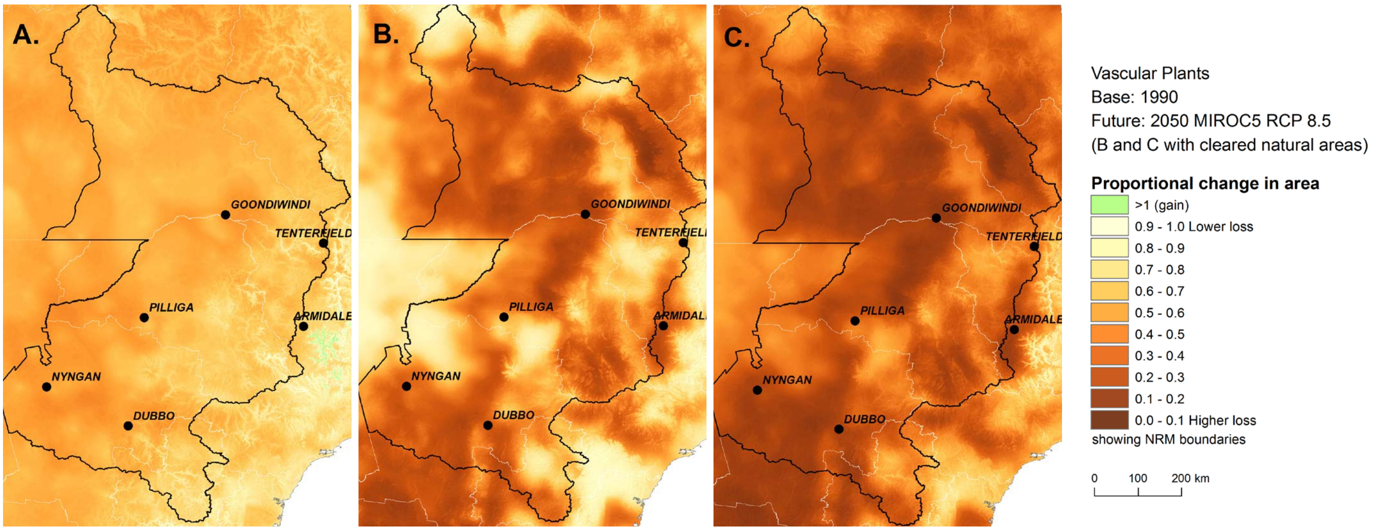
BOX 9

Planning Example
Climate change in the context of other threats

Climate impacts are commonly viewed as one more threat to biodiversity persistence on top of many others in the landscape. But it is often unclear the degree to which climate change will interact with existing threats and exacerbate the rate of biodiversity decline, or whether management of existing threats is simply more important than managing climate impacts. While other threats are usually added into a vulnerability or risk analysis as reductions to adaptive capacity (see Planning example – Using the *potential degree of ecological change* in vulnerability analyses), the *change in effective area of similar environments* allows planners to incorporate interactions as well.

For example, darker colours in Figure C below show areas that currently support vascular plant environments that will lose (and have already lost) substantial amounts of effective area due to both past land clearing and the effects of climate change. This interaction is somewhat different than the effects of climate change only (Figure A) or just past land clearing (Figure B). Figure C could be used in a vulnerability analysis to incorporate interactions between climate change and land clearing, with other existing threats added as further reductions in regional adaptive capacity for plants.

Finally, drilling into more regional detail in these maps can reveal sub-regions where the consequences of climate change are actually greater than those of past land clearing (darker colours in Figure A than in Figure B). This is the case for much of the rangelands but also for sub-regions northeast of Nyngan, the Pilliga, as well as the northwest slopes of New South Wales. These areas highlight that for some parts of a region, a special focus on adaptation planning aside from just managing current threats may be warranted.



Change in effective area of similar ecological environments for vascular plants by 2050 in north-eastern New South Wales and south-eastern Queensland under the high emissions' *mild MIROC5* climate scenario. Darker colours signify areas greater loss of effective area. **A)** loss of effective area due to climate change, **B)** effective area already lost to date due to past land clearing, **C)** the combined effects of past land clearing and climate change.

Synthesis – where can we expect different types of change to occur?

SECTION 6

Measures of the potential degree of change and of disappearing and novel environments can be combined to show not only where change might be greatest, but also something about the nature of the change to recognise different types of vulnerability.

Below: Image: Fitzroy River, Source: Fitzroy NRM

Earlier sections of this Guide showed how projected ecological similarity can be used to derive different measures of biodiversity change in response to climate change.

Starting with the simplest measure, the *potential degree of ecological change* for each location (Section 3), we then introduced the more complex but related measures: the *degree to which ecological environments are becoming novel or tending to disappear* (Section 4).

Here we show how these three related measures can be combined to highlight areas where different approaches to adaptation might be applicable.

POTENTIAL DEGREE OF ECOLOGICAL CHANGE, DISAPPEARING ECOLOGICAL ENVIRONMENTS AND NOVEL ECOLOGICAL ENVIRONMENTS ARE RELATED MEASURES.

THEY CAN BE COMBINED

to focus attention on areas where the most change is expected to occur.

THEY CAN ALSO HIGHLIGHT

where different types of change may suggest different approaches to adaptation.

6.1
Estimating composite ecological change

To create a composite view, we assigned each of the three component measures to a colour band: local similarity (from *potential degree of ecological change*) as shades of green, novel environments as shades of blue, and disappearing environments as shades of red (Figure 22). The three layers can then be mapped simultaneously, showing the varying degrees of similar, novel and disappearing ecological environments and their combinations. This provides a way to simultaneously express the degree and nature of the ecological change that can be expected.

FIGURE 22

Composite ecological change

A diagram showing the possible colour combinations arising from the three component measures using RGB scaling in the visible colour spectrum: local similarity as shades of green, novel as shades of blue, and disappearing as shades of red (top). The five broad types of change that result from this composite view (bottom).

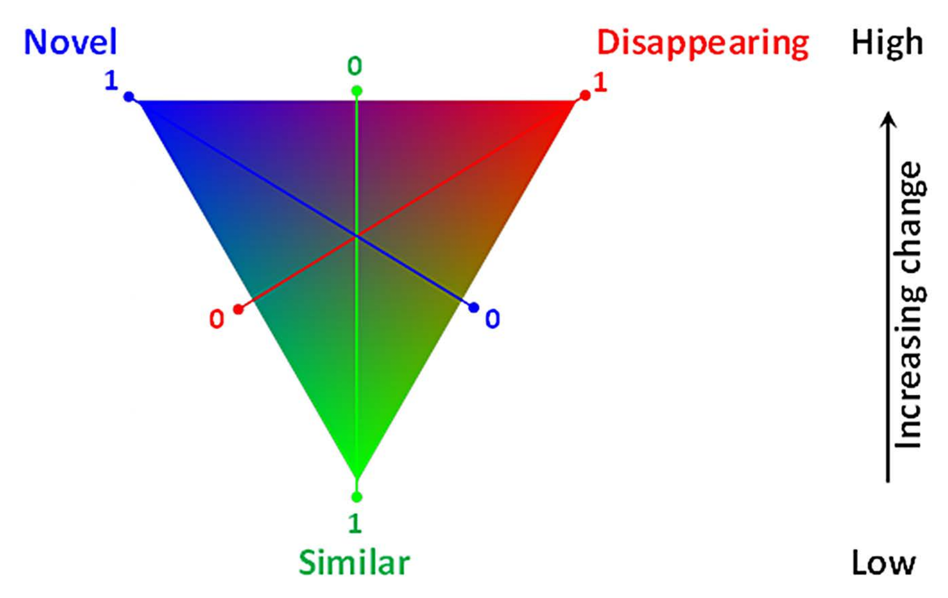
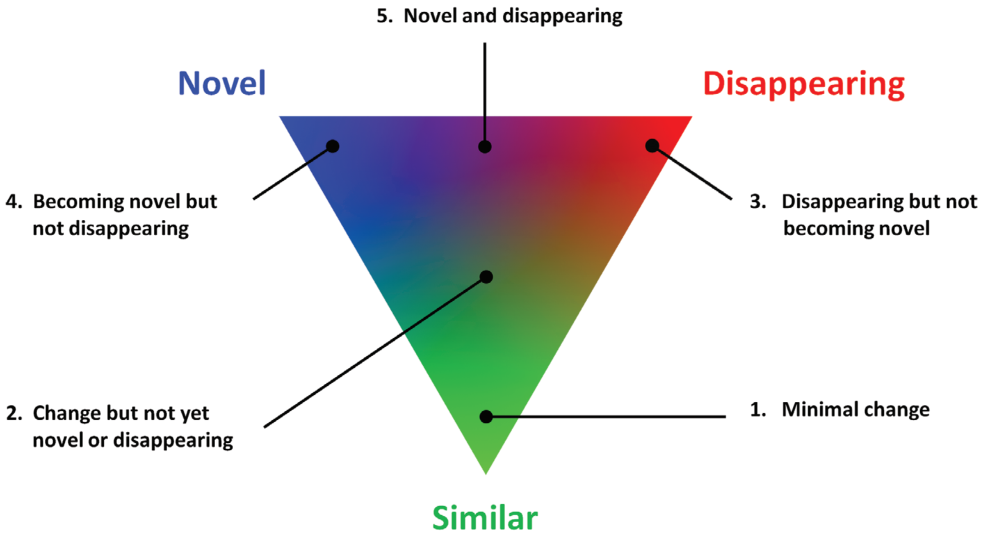


FIGURE 22 (CONTINUED)



Wherever the potential degree of ecological change is scored low, environments can neither be novel nor disappearing and minimal change is expected. But when the potential degree of ecological change is scored high, a variety of possible types of change can occur depending on whether scores for novel or disappearing environments are also high. Our composite colour-based index highlights five general types of change with different possible consequences for biodiversity where different approaches to adaptation might be applicable.

1. Minimal change (green colours) - Local environments are neither becoming novel nor tending to disappear because ecological similarity remains relatively high.

2. Change but not novel or disappearing (olive and orange colours) - The potential for local change is high but future environments have current analogues and current environments will still be present somewhere on the continent in the future.

3. Disappearing but not becoming novel (red colours) – Future local environments have current analogues (and these could be anywhere across the Australian continent), but the species of current environments may have nowhere to go (their ecological environments are disappearing).

4. Becoming novel but not disappearing (blue colours) - Future local environments will be unprecedented (not previously represented anywhere across the Australian continent), but species of current environments will still have suitable environments available elsewhere on the continent.

5. Both novel and disappearing (purple and pink colours) – Future local environments are unprecedented (not previously represented anywhere across the Australian continent), and the species of current environments have nowhere to go (their ecological environments are disappearing).

While, for simplicity, we describe these cases using the contrasting classes ‘high’ or ‘low’, the actual measure is continuous.

THERE ARE FIVE BROAD TYPES OF CHANGE:

1. MINIMAL CHANGE
2. CHANGE BUT NOT NOVEL OR DISAPPEARING
3. DISAPPEARING BUT NOT BECOMING NOVEL
4. BECOMING NOVEL BUT NOT DISAPPEARING
5. BOTH NOVEL AND DISAPPEARING

6.2

Composite ecological change – the national context

From a national perspective, the *composite ecological change* measure reveals the different spatial patterns and types of change. For example, Figure 23 shows areas of local detail among relatively subdued patterns of ecological change for reptiles under the high emissions' *hot CanESM2* climate scenario.

The bright green areas signify regions of less change. Those ecological environments are expected to be within the current adaptive range of the reptile fauna at present (change type 1 in Section 6.1).

The emerging reddish areas in the centre of the continent signify regions where similar ecological environments for reptiles are disappearing. The future environments that will occupy these locations have contemporary analogues so they will not be novel, but the current environments these locations support are projected to disappear in the future and so those reptile species may have nowhere to go (change type 3 in Section 6.1).

By contrast, the blue areas signify regions where the future local environment for reptiles is unprecedented in type (no contemporary analogues). The ecological environment currently supported in that area will exist in the future, just elsewhere on the continent, so current reptile assemblages essentially have somewhere to go (change type 4 in Section 6.1). However, their ability to get there is not incorporated into this analysis.

Various colour blends indicate departures from the contemporary ecological environment. Shades of blue-green (e.g. olive and teal colours) and red-green (orange and brown colours) are variously places where there will be moderate levels of change, but similar environments broadly exist elsewhere and reptiles generally have somewhere to assemble (change type 2 in Section 6.1).

The pink and purple colours signify regions that increasingly contain places where the future local ecological environments are unprecedented in nature (novel assemblages), and the present array of reptile species have nowhere to go (disappearing assemblages) (change type 5 in Section 6.1).

Similar views and interpretation of *composite ecological change* can be applied to the other biological groups and under different climate scenarios (Figure 24). Notably the patterns are different for the different biological groups with varying contrasts between the mild and hotter climate scenarios.

Left:
Image: Goanna
Source: Megan Jones

FIGURE 23

Composite ecological change

Patterns of *composite ecological change* for reptiles under the high emissions' *hot CanESM2* climate scenario. This image combines three datasets: the *potential degree of ecological change and the degree to which ecological environments are becoming novel and tending to disappear.*

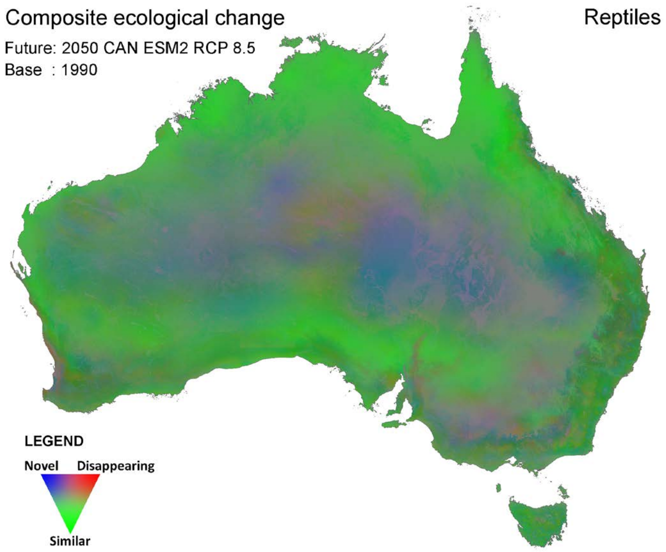
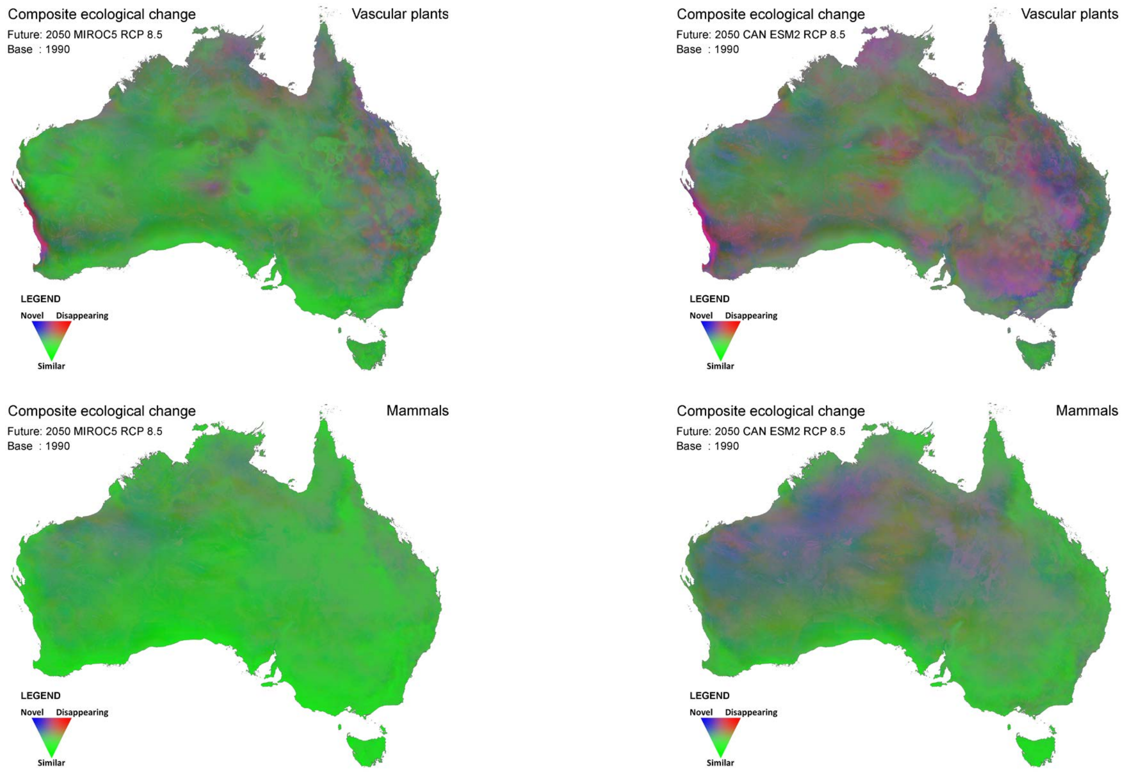


FIGURE 24

Composite ecological change

Broad comparison of *composite ecological change* patterns for two biological groups and two climate scenarios as an example. All four groups can be viewed via the map posters or data sets. Each image combines three datasets: the *potential degree of ecological change and the degree to which ecological environments are becoming novel or tending to disappear.*



6.3

Composite ecological change – a regional focus

Further insights into the types of vulnerability that might be experienced by local biodiversity are revealed on closer examination. Figure 25, for example, shows varying patterns in the types of change that may be experienced by vascular plants under the high emissions' *mild MIROC5* climate scenario in the Hunter Valley, New South Wales.

The bluer colours associated with the valley between Singleton and Muswellbrook suggest novel types of vascular plant environments may emerge. This region portrays a degree of dynamism for plants in the future. While novel environments may be emerging (the bluish areas), current environments in those locations are also tending to disappear from the Australian continent in the future (the pinker areas).

The reddish areas around the township of Cassilis signify disappearing types of environments where some vascular plant species may be at risk of extinction if these trends continue to deeper red. Areas surrounding the valley, particularly along the Great Dividing Range, appear buffered (green colours) and are projected to remain more similar to current environments under this climate scenario.

An example of how these different types of vulnerability could help in identifying focal areas for strategic planning is introduced in Box 10.

TYPES OF CHANGE

can vary within a region, and show quite complex patterns, such as the potential high degree of dynamism in plants projected for the Hunter Valley.

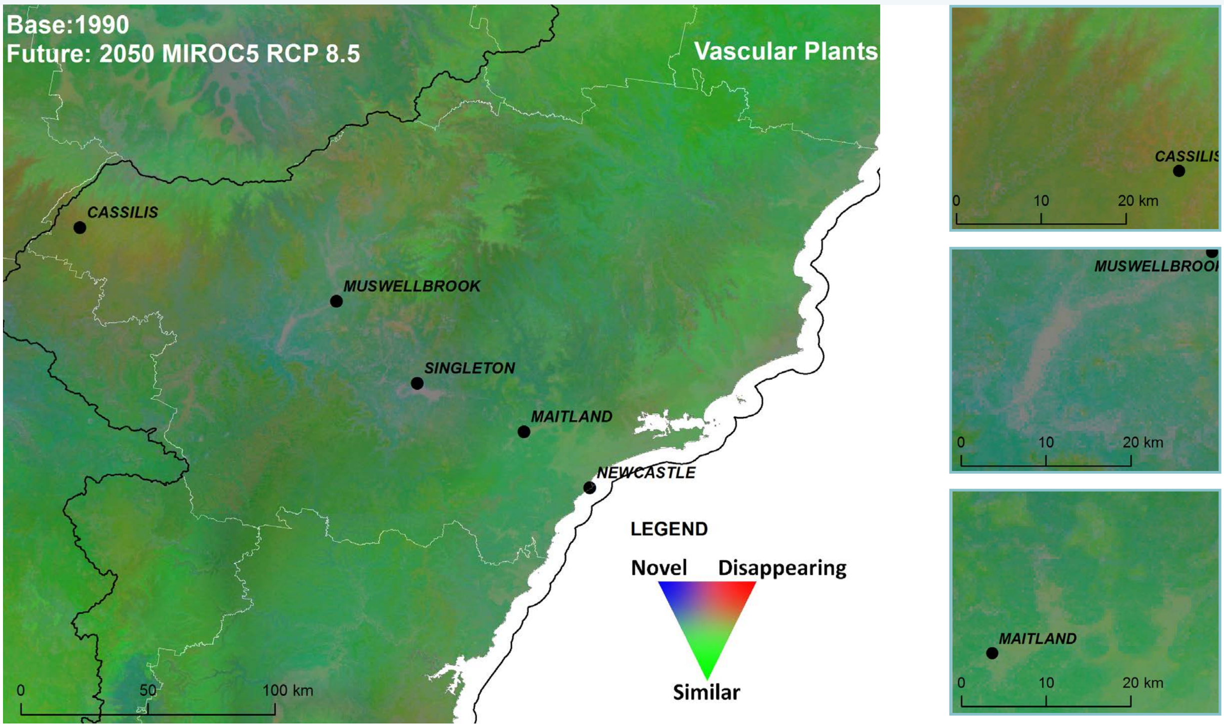
LESS CHANGE

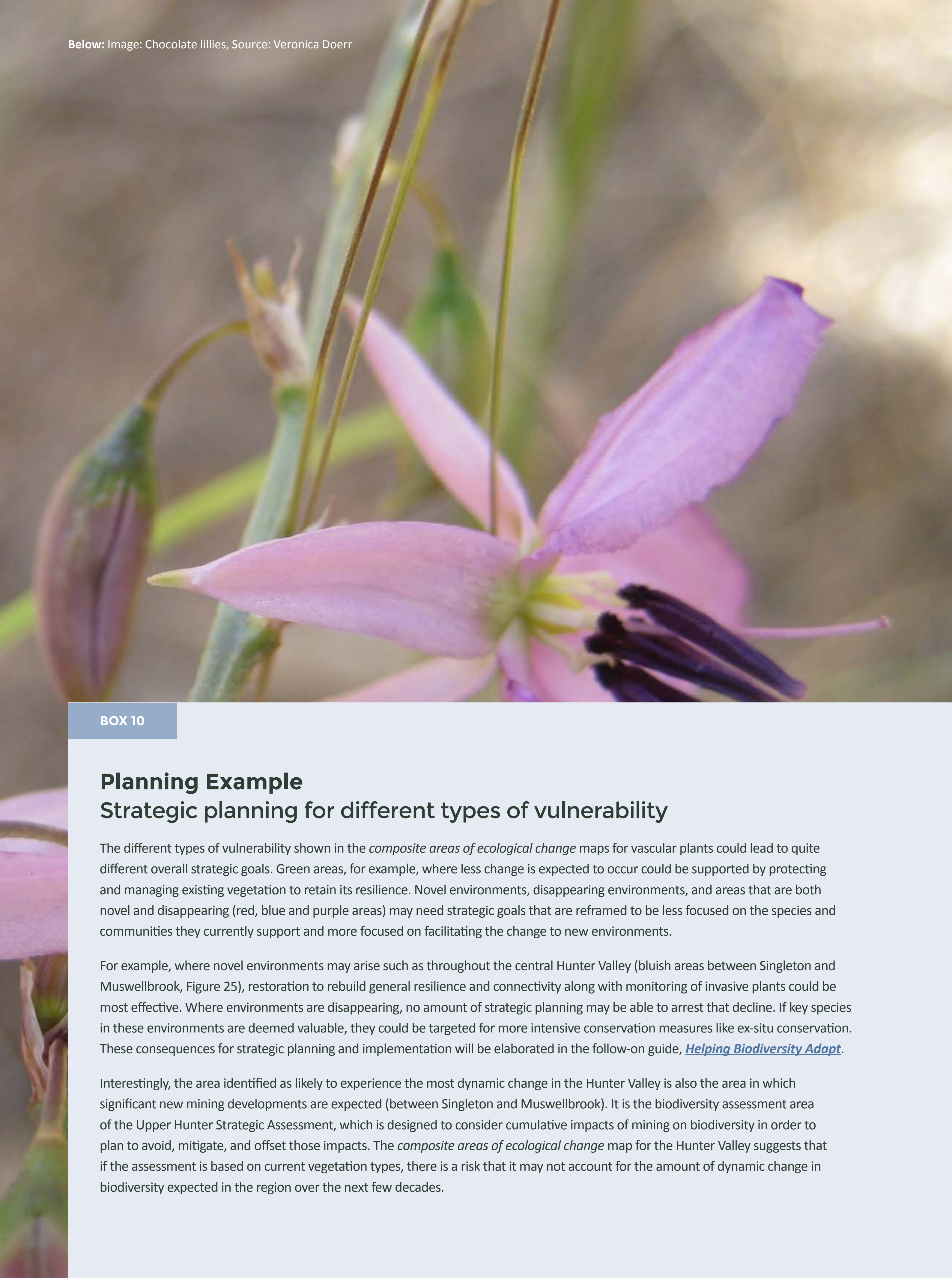
and therefore higher buffering capacity is suggested for vascular plants across the Great Dividing Range.

FIGURE 25

Composite ecological change

Composite ecological change identified for vascular plants under the high emissions' *mild MIROC5* climate scenario for the greater Hunter Valley region in New South Wales.





Below: Image: Chocolate lillies, Source: Veronica Doerr

BOX 10

Planning Example
Strategic planning for different types of vulnerability

The different types of vulnerability shown in the *composite areas of ecological change* maps for vascular plants could lead to quite different overall strategic goals. Green areas, for example, where less change is expected to occur could be supported by protecting and managing existing vegetation to retain its resilience. Novel environments, disappearing environments, and areas that are both novel and disappearing (red, blue and purple areas) may need strategic goals that are reframed to be less focused on the species and communities they currently support and more focused on facilitating the change to new environments.

For example, where novel environments may arise such as throughout the central Hunter Valley (bluish areas between Singleton and Muswellbrook, Figure 25), restoration to rebuild general resilience and connectivity along with monitoring of invasive plants could be most effective. Where environments are disappearing, no amount of strategic planning may be able to arrest that decline. If key species in these environments are deemed valuable, they could be targeted for more intensive conservation measures like ex-situ conservation. These consequences for strategic planning and implementation will be elaborated in the follow-on guide, ***Helping Biodiversity Adapt***.

Interestingly, the area identified as likely to experience the most dynamic change in the Hunter Valley is also the area in which significant new mining developments are expected (between Singleton and Muswellbrook). It is the biodiversity assessment area of the Upper Hunter Strategic Assessment, which is designed to consider cumulative impacts of mining on biodiversity in order to plan to avoid, mitigate, and offset those impacts. The *composite areas of ecological change* map for the Hunter Valley suggests that if the assessment is based on current vegetation types, there is a risk that it may not account for the amount of dynamic change in biodiversity expected in the region over the next few decades.

From assessment to strategic planning

SECTION 7

The purpose of this Guide has been to introduce a new concept (ecological similarity) and a new approach to mapping change in biodiversity under climate change (the various measures of ecological change).

Below: Image: Yellow footed rock wallabay,
Source: Steven Mallett

7.1

Summary

A new suite of measures for biodiversity assessment

The purpose of this Guide has been to introduce a new concept (ecological similarity) and a new approach to mapping change in biodiversity under climate change (the various measures of ecological change). Our aim has been to demonstrate how the data can be used by Natural Resource Management groups to assess the general implications of climate change for their regions, and to make this data available for public use through CSIRO's ***Data Access Portal***. This Guide should serve as a continuing resource as we hope to build on the available data over time.

Four main types of climate change analyses have been introduced in this Guide.

Potential degree of ecological change (Section 3) indicates the potential for future persistence of biodiversity at a location.

Extremes of ecological change such as potentially novel or disappearing environments (Section 4) allow us to ask whether the projected futures in any location will be unlike any present-day environment on the continent, and whether some environments and their typical assemblages of species are at risk of disappearing from the continent.

Change in effective area of similar ecological environments (Section 5) indicates changes in Australia's capacity to support its original biodiversity, and shows how this depends on the interplay between climate change and clearing patterns.

An integrated view of change based on three of the primary measures further shows how the *potential degree of ecological change* interacts with the *degree to which ecological environments are becoming novel or tending to disappear* (Section 6). While some types of change coincide, this is not always the case.

Each measure derives from projected ecological similarity, but is calculated in a slightly different way to emphasise the different types of change and implications of climate change for biodiversity. Community-level biodiversity models provide the basis for projected ecological similarity and, in so doing, demonstrate how different biological groups have different responses to present-day climate and therefore different outcomes can be expected from climate change.

The examples used to explain the measures in this Guide were drawn from four biological groups (see Section 2.4) and two indicative climate scenarios based on change from 1990 to 2050. One future portrays a relatively mild degree of change using the *MIROC5* climate simulation model, and the other is more extreme (hotter) using the *CanESM2* climate simulation model. Both assume a continuation of recent trends in global greenhouse gas emissions.

Below: Image: Pilbara landscape, Source: Veronica Doerr

7.2
Helping biodiversity adapt to climate change

Our new analyses of the implications of climate change for biodiversity have reinforced the evidence that ecological change in response to climate change is likely to be widespread and substantial. But most critically, these new whole-of-biodiversity measures provide a different perspective on how particular biological groups may respond to climate change and implications for how managers may plan to intervene.

This new perspective highlights that the implications of climate change for biodiversity are not within the control of planners and land managers. Changes are inevitable and ongoing. Thus, climate change is not a traditional threat to manage but a reminder that the world is dynamic and biodiversity plans need to embrace that dynamism.

We previously outlined broad approaches to planning that could accommodate such change, in ***The NRM Adaptation Checklist***, and the maps and measures introduced here can be used directly to accomplish some of those goals, including planning for multiple futures and engaging the community in envisioning the future.

The models introduced in this Guide also suggest that there may be several different types of change in biodiversity. Different strategic goals and objectives as well as implementation plans may be needed where different types of change are expected. This may be particularly true for disappearing ecological environments, where planners may only be able to maintain current species compositions through more intensive interventions, like ex-situ conservation.

Thus, while the measures introduced here and the maps and datasets provided are most useful during the assessment phase of planning, they help create continuity in the planning process. By providing a broad understanding of the nature of change, not just its magnitude, they help in identifying the most effective strategic goals and options for implementation.

The second Guide in this series, ***Helping Biodiversity Adapt***, will address those strategic and implementation considerations in more detail. It will broadly summarize potential adaptation options and deliver tools and datasets for evaluating specific options such as the potential benefits of revegetation, areas of refugia under climate change, and the potential to manage areas that complement the representation of biodiversity in the National Reserve System.

We believe this set of resources can help transform the way we plan for the future of biodiversity – helping us redefine our role as shepherds in managing ecological change.

Below: Image: Pilbara landscape, Source: Veronica Doerr

Glossary of technical terms and definitions used in this Guide

Term Used In This Guide	Definition
Alpha diversity	Alpha diversity is a measure of the composition of species at a site, for example the number of species observed. The term was introduced by Whittaker (1960, 1970) together with the terms beta diversity (β-diversity) and gamma diversity (γ-diversity).
Atlas of Living Australia	The ***Atlas of Living Australia*** contains information on all the known species in Australia aggregated from a wide range of data providers: museums, herbaria, community groups, government departments, individuals and universities. Data from the Atlas has been used in developing the biodiversity models for this Guide.
Beta diversity	Beta diversity is a measure of the differentiation among habitats, such as the difference between locations in their species compositions. Beta diversity is a term used in community ecology and has become an umbrella for measures of compositional dissimilarity, species turnover and indices of biotic heterogeneity. See also Alpha diversity.
Biotically-scaled environment	Biotically-scaled environments in a Generalised Dissimilarity Modelling context is a term used to describe the ecological distance scaling applied to each environmental predictor relating it to compositional dissimilarity. This term was used in Dunlop et al. (2012) to collectively describe the climate change scaling of environments. Here we use the term ‘projected ecological similarity’ for the same concept, because it more directly describes the measure.
Bray–Curtis dissimilarity	Bray–Curtis dissimilarity is a statistic used to quantify the compositional dissimilarity between two different sites, based on counts at each site. The index varies from 0 (identical) to 1 (completely different).
CanESM2 climate model	Developed by the Canadian Centre for Climate Modelling and Analysis, and is the second generation of Earth System Models developed by that centre. The new model couples together an atmosphere-ocean general circulation model, a land-vegetation model and terrestrial and oceanic interactive carbon cycle. For more information see Chylek et al. (2011).
Change in effective area of similar environments	The extent within a specified area to which a particular habitat may have changed in its suitability and therefore reduced or increased capacity to support its original biodiversity, for example due to climate change and/or land clearing patterns. If there is a loss of similar ecological environments, we expect a corresponding loss of original biodiversity, and vice versa.

Term Used In This Guide	Definition
Climate Futures Framework	A new approach to exploring climate projections that reduces the level of complexity for the end-user. It allows the user to generate climate change projections tailored to their application, whether it is a general overview of climate change for a region, an investigation of likely threats and opportunities, or a detailed risk assessment using impact models. For more information see *Climate Change in Australia* and Hennessy et al. (2012).
CMIP5	The Coupled Model Intercomparison Project (CMIP) is a framework and the analog of the Atmospheric Model Intercomparison Project (AMIP) for global coupled ocean-atmosphere general circulation models. CMIP5 is the current (2010-2014) phase of the project, and will include more metadata describing model simulations than previous phases.
Community-level modelling	Combines data from multiple species and produces information on spatial pattern in the distribution of biodiversity at a collective community level. This approach contrasts with species-level modelling which models the pattern of distribution one species at a time. Community-level modelling uses measures derived from multiple species occurrences, ideally from comprehensive survey data, such as the number of species at a site or a measure of compositional differences in species between pairs of sites (i.e., macro-ecological properties of the ecosystem). Ferrier and Guisan (2006) published a review of community-level modelling. Also see macro-ecological modelling.
Compositional dissimilarity	A measure of the differences in biological composition between two sites, termed beta diversity. The Bray-Curtis dissimilarity index is a statistic used to quantify the compositional dissimilarity between two different sites, based on counts at each site.
Compositional turnover	Sometimes used loosely as a synonym with compositional dissimilarity, but is not necessarily the same calculation. It is a measure of the replacement of species along a gradient, for example, how many times the species composition changes completely with distance between two locations.
Data access portal (CSIRO)	The *CSIRO Data Access Portal* provides access to data published by CSIRO across a range of disciplines. The portal is maintained by CSIRO to facilitate sharing and reuse of data held by CSIRO.
Disappearing ecological environments	Occurs where a present-day environment has a low similarity to its most similar environment in the future. It is estimated by comparing locations within a specified neighbourhood, such as the entire continent of Australia. The concept of novel and disappearing climates derives from Williams et al. (2007), and is applied here to projected ecological similarity. Disappearing ecological environments are scored on a scale of ecological similarity from 0 (completely different and disappeared) to 1 (identical and not at all disappearing).

Term Used In This Guide	Definition
Dissimilarity	Is the inverse of similarity, where dissimilarity = 1-similarity
Ecological change	Refers to how different two places are in their biota, or how the biota at one place varies over time. Change refers to a comparison of some sort. Ecological refers to a measure of ecosystem properties of some sort. In this Technical Guide, the change comparison context is typically between a baseline climate (e.g. 1990) and a future climate scenario (e.g. 2050), and the ecological measure is ecological similarity. See ecological similarity.
Ecological environments	The biotic-scaling of environments derived from using the community-level modelling approach (see Technical Note 2)
Ecological similarity	Ecological similarity is a term used to describe how similar two locations are in their predicted compositions, inversely related to the Bray-Curtis or Sørensen dissimilarity index. Similarity can vary from 0 (nothing in common) to 1 (effectively identical). Ecological similarity can be predicted within the same spatial and temporal domain for which the model was developed, or projected if applied to a future climate scenario. See also, projected ecological similarity.
Ecologically-relevant climatic indicators	Climatic indices such as the average monthly minimum temperature, that are considered relevant drivers of plant and animal distribution patterns, and are easily derived from the monthly datasets.
Effective habitat area	The proportional contribution that an area makes to overall biodiversity through habitat suitability. It is a measure of the relative capacity of any location to support all elements of its original (intact) biodiversity. If the effective habitat area is less than the original area, this indicates some loss in capacity to support all of the original biodiversity. For example, a 100ha plot of original suitable habitat may only contain 50 ha because of clearing or other driver of change. The effective area of suitable habitat within 100ha is therefore 0.5 x 100ha = 50ha. The change in effective habitat area is therefore 0.5.
Emissions scenario	Emissions scenarios describe future releases into the atmosphere of greenhouse gases, aerosols, and other pollutants and, along with information on land use and land cover, provide inputs to climate models. They are based on assumptions about driving forces such as patterns of economic and population growth, technology development, and other factors. Levels of future emissions are highly uncertain, and so scenarios provide alternative images of how the future might unfold. See representative concentration pathway.
Focal cell	The place, location or grid cell on the map layer (raster dataset) that is being scored for the calculation of interest.
Gamma diversity	Whittaker (1960) reasoned that alpha diversity and beta diversity constitute independent components of gamma diversity. The total biological diversity in a landscape (gamma diversity) is determined by the mean species diversity in sites or habitats at a more local scale (alpha diversity) and the differentiation among those habitats (beta diversity).

Term Used In This Guide	Definition
Generalised Dissimilarity Modelling, GDM	A community-level modelling technique for relating compositional dissimilarity (based on species, for example) between pairs of locations to environmental distances. The compositional dissimilarity measure can be defined for any biotic phenomena including species, taxonomic or phylogenetic branch lengths, genetic entities, and so forth. Generalised Dissimilarity Modelling (GDM) was invented by S Ferrier and G Manion (Ferrier et al., 2007). It is a novel non-linear statistical method for assessing variation in the magnitude and rate of change in observations of biota along different environmental gradients.
Geographic Information System, GIS	A geographic information system (GIS) is a computer system designed to capture, store, integrate, manipulate, analyse, manage, share, and present all types of geographical data.
Grid cell	A grid cell is a location on a map layer or raster dataset that has a value representing some characteristic of that location.
Local similarity	When the projected ecological similarity is defined between the same location or focal cell at different times (i.e. the comparison is ‘point on point’) then the ecological similarity measure relates to the local effects of similarity. A contrasting case is when similarity of a location or focal cell is compared with other locations in a surrounding region (as is the case in defining novel and disappearing ecological environments).
Location	A non-specific term to indicate a place, site or grid cell, for which a geographic reference may be associated (e.g., longitude and latitude).
Macro-ecological modelling	Macro-ecological modelling refers to quantitative (usually statistical) methods applied in the study of relationships between organisms and their environment at large spatial scales aimed at characterising and predicting patterns of abundance, distribution and diversity. Macro-ecology is the study of the properties of the system as a whole, and such approaches are often termed ‘top down’. Macro-ecological modelling is particularly valuable for highly diverse, poorly studied taxa, as it provides information relevant to all species: even those we know little about.
Macro-ecological properties	Ecosystem properties that may be observed and used in community-level or macro-ecological modelling usually related to measures of alpha, beta and gamma diversity. The most commonly modelled property is species richness (i.e., a measure of alpha diversity), either of a whole group (e.g. all vascular plants) or of a functional subgroup (e.g. annuals and trees). Many other macro-ecological properties (e.g. mean range size and endemism) can potentially be modelled. Compositional dissimilarity, as a measure of beta diversity, is also a macro-ecological property. See the review by Ferrier and Guisan (2006). See macro-ecological modelling.

Term Used In This Guide	Definition
MIROC5 climate model	The MIROC5 climate model is the atmosphere-ocean general circulation model cooperatively developed in the Japanese research community. That research community is known as the Model for Interdisciplinary Research on Climate (MIROC). For more information see the article by Watanabe et al. (2010).
Novel ecological environment	Occurs where a future environment has a low similarity to its most similar environment in the present. It is estimated by comparing locations within a specified neighbourhood, such as the entire continent of Australia. The concept of novel and disappearing climates derives from Williams et al. (2007), and is applied here to projected ecological similarity. Novel ecological environments are scored on a scale of ecological similarity from 0 (completely different and novel) to 1 (identical to contemporary analogues).
Potential degree of ecological change	Potential degree of ecological change is a term used in this Guide. In the context of climate change, it is an estimate of the projected ecological similarity between the same locations at different points in time, for example between a baseline period (e.g. 1990) and a future time (e.g. 2050). See also projected ecological similarity and local similarity.
Prediction	We use the term ‘predicted’ or ‘prediction’ when referring to ecological similarity calculated using baseline climate data, for which we can validate the outcome. See also ‘projection’.
Present-day	A term used in this Guide in referring to a baseline period against which change is referenced. Base or baseline is usually specifically defined in text and maps.
Pressure to change	The inverse of similarity (i.e., dissimilarity or 1-similarity) can be viewed as the potential for climate change to drive ecological change, i.e., a measure of ecological ‘pressure to change’. See also projected ecological similarity and projected ecological change. These are all the same measures, simple viewed from different perspectives.
Projected ecological change	An estimate of the ecological similarity between the baseline (in this study defined as 1990) and future ecological environments for any particular location (or grid cell). High similarity, i.e. the complement of species is likely to remain much the same, indicates a low pressure to change; low similarity (i.e. the complement of species is likely to be very different) indicates high pressure to change. See also, pressure to change and projected ecological similarity.
Projected ecological similarity	Projected ecological similarity measures how similar a single location is over two time periods in its predicted composition. Typically applied to a baseline (current) and future climate scenario. Similarity can vary from 0 (nothing in common) to 1 (effectively identical). The measure is inversely related to the Bray-Curtis or Sørensen dissimilarity index. See also ‘projection’ and ‘prediction’.
Projection	We use the term ‘projected’ or ‘projection’ when referring to ecological similarity calculated using derived estimates of future climate. See also ‘prediction’.

Term Used In This Guide	Definition
Raster dataset	Spatial data is stored as a grid of cells (pixels) in a geographic information system, each with a defined location reference, where it is termed a ‘raster’ dataset, in contrast with other spatial data types defined by points, lines and polygons. Raster datasets represent geographic features by dividing the world into discrete square or rectangular cells laid out in a grid. Each cell has a value that is used to represent some characteristic of that location.
Representative concentration pathway (RCP)	Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5). The pathways are used for climate modelling and research. They describe four possible future climates, all of which are considered plausible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively). See also emissions scenario. For more information see Jubb et al. (undated).
Similarity	Used in this Guide to make macro-ecological comparisons between two locations at the same point in time or for the same location at two points in time. Note that similarity is the inverse of dissimilarity, where similarity = 1- dissimilarity. See also dissimilarity.
Sørensen dissimilarity	A statistic used for comparing the similarity of two samples, originally applied to presence/absence data. When index is used as a distance measure, 1–Similarity, it is identical to Bray-Curtis dissimilarity. See Bray-Curtis dissimilarity.
Spatial	Used in this Guide to refer to the geographic features of a dataset or a concept related to geographic locations or variability among many locations at once.
Species composition	Species composition refers to the number, type and if applicable, abundances and potentially other attributes of each species (e.g. phylogenetic relationships) described for a particular location or areas.
Temporal	Used in this Guide to refer to the variation over time, such as between baseline climates in 1990 and future scenarios by 2050 (i.e., different time periods).
Vascular plants	Vascular plant is a collective term for a group of highly evolved plants characterised by the ability to conduct water and minerals throughout the plant using lignified tissues (the xylem). In this Technical Guide, the models of vascular plants include species of fern, gymnosperm and angiosperms.
Whole-of-biodiversity modelling approach	Whole of biodiversity modelling approaches have been developed as a means of identifying robust conservation and management strategies under climate change. The idea is that predictions of climate change impacts need to be relevant to biodiversity as a whole – that is, to many species from many different taxonomic groups. See macro-ecological modelling

Biodiversity projection datasets and maps

Supporting materials and information about the community-level biodiversity models applied to climate change are available from the CSIRO Data Access Portal, ***https://data.csiro.au/dap/***. Biodiversity projection datasets and map posters are organised by biological group, climate change scenario and measures of change in biodiversity.

We suggest that you initially access the smaller (~10Mb file size) map posters relevant to your region for exploration while reading this Guide as these will be quicker and easier to download. You can then decide which map posters you wish to download and use for planning and/or printing (~50Mb file size, greater resolution) and which datasets (~1Gb in size) you wish to download and work with in GIS.

How to access datasets and map posters on the Data Access Portal

1. Access the DAP at the following URL: ***https://data.csiro.au/dap/*** or search for 'CSIRO Data Access Portal' using your search engine. The link to DAP is also available on the AdaptNRM webpage, ***www.adaptnrm.org***

2. Use the search engine to locate datasets and maps you are after (see map series table for what is available). Below is a list of search terms we recommend you use.

    a. 'adaptnrm': results in all AdaptNRM products, including Weeds and Climate Change (module 2), Biodiversity Implications (module 3) and Biodiversity Adaptation (module 4) data sets and maps.

    b. 'adaptnrm biodiversity': results in all AdaptNRM biodiversity products, including Biodiversity Implications (this module) and Biodiversity Adaptation (module 4)

    c. 'adaptnrm biodiversity' plus any of the measures of change will limit your search to more specific datasets and maps. For example, entering 'adaptnrm biodiversity disappearing' will result in datasets and maps for "disappearing ecological environments"

3. Once you have selected and clicked the map or dataset you would like to access, you will come across two tabs – the first containing a description of that data set, and the second ('data') containing links to download data. Follow the instructions provided to download the datasets you have selected. For more information, visit the Biodiversity Data Access Portal pages at the AdaptNRM website.

4. Map posters are provided at a medium resolution A0 size (picture files .png) for printing as posters (~50Mb file size per poster) to use in planning if you do not use GIS datasets. The maps posters are also provided at a lower resolution (pdf files .pdf) for initial exploration (~10Mb file size each). Further information on how to use the datasets is available under the 'description' tab.

5. More information on how to use the Data Access Portal is available on ***www.adaptnrm.org***

Map posters available on the ***Data Access Portal***

The map-posters cover broad groupings of NRM regions based on the cluster boundaries for the NRM fund (***http://www.climatechange.gov.au/reducing-carbon/land-sector-measures/nrm-fund/stream-2***). Map-posters are provided in PNG image format at moderate resolution (300dpi) to suit A0 printing as well as in PDF format to suit initial printing and exploration at A3 size.

Each map-poster contains four dataset images coloured using standard legends encompassing the full range in ecological similarity (from 0 to 1). Each series is provided in two parts: part 1 shows the two climate scenarios for vascular plants and mammals and part 2 shows reptiles and amphibians. Annotation briefly outlines the topics presented in the Guide so that each poster stands alone as a quick reference guide.

Example citation: Williams KJ, Raisbeck-Brown N, Harwood T, Prober S (2014) Novel ecological environments for vascular plants and mammals (1990-2050), A0 map-poster 3.1 - East Coast NRM regions. CSIRO Land and Water Flagship, Canberra. Available online at ***www.AdaptNRM.org*** and ***https://data.csiro.au/dap/***.

Guide Section	Map Series	Monsoonal North	Wet Tropics	Ranglelands	Central Slopes	Murray Basin	East Coast	Southern Slopes	Southern & Flatlands
3.2	1.1 Potential degree of ecological change for vascular plants and mammals (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
3.2	1.2 Potential degree of ecological change for reptiles and amphibians (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
3.2	2.1 Disappearing ecological environments for vascular plants and mammals (1990-2050	✓	✓	✓	✓	✓	✓	✓	✓
4.2	2.2 Disappearing ecological environments for reptiles and amphibians (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
4.5	3.1 Novel ecological environments for vascular plants and mammals (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
4.5	3.2 Novel ecological environments for reptiles and amphibians (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
5.3	4.1 Change in effective area of similar ecological environments (intact) for vascular plants and mammals (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
5.3	4.2 Change in effective area of similar ecological environments (intact) for reptiles and amphibians (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
5.4	5.1 Change in effective area of similar ecological environments (cleared) for vascular plants and mammals (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
5.4	5.2 Change in effective area of similar ecological environments (cleared) for reptiles and amphibians (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓
6.2	6.1 Composite ecological change for vascular plants and mammals (1990-2050	✓	✓	✓	✓	✓	✓	✓	✓
6.2	6.2 Composite ecological change for reptiles and amphibians (1990-2050)	✓	✓	✓	✓	✓	✓	✓	✓

Datasets available on the Data Access Portal

		Biological Group				
Guide Section	**Measure of change in biodiversity**	**Amphibians**	**Mammals**	**Reptiles**	**Vascular Plants**	**Climate Change Scenario**
3.2	Potential degree of ecological change, 1990:2050	✓	✓	✓	✓	Can ESM2
		✓	✓	✓	✓	MIROC5
4.2	Disappearing ecological environments, 1990:2050	✓	✓	✓	✓	Can ESM2
		✓	✓	✓	✓	MIROC5
4.5	Novel ecological environments, 1990:2050	✓	✓	✓	✓	Can ESM2
		✓	✓	✓	✓	MIROC5
5.3	Change in effective area of similar ecological environments (intact), 1990:2050	✓	✓	✓	✓	Can ESM2
		✓	✓	✓	✓	MIROC5
5.4	Change in effective area of similar ecological environments (cleared natural areas), 1990:2050	✓	✓	✓	✓	Can ESM2
		✓	✓	✓	✓	MIROC5
5.4	Change in effective area of similar ecological environments (cleared natural areas), 1990:1990	✓	✓	✓	✓	Baseline
		✓	✓	✓	✓	MIROC5
6.2	Composite ecological change, 1990:2050	✓	✓	✓	✓	Can ESM2
		✓	✓	✓	✓	MIROC5

The data layers have been developed at approximately 250m resolution across the Australian continent to incorporate the interaction between climate and topography, and are best viewed using a geographic information system (GIS). Each GIS dataset is provided as an ESRI binary export grid (float file format: *.flt; *.hdr) in GDA94[1] , Australian geographic coordinate system, and is a 1 gigabyte raster file.

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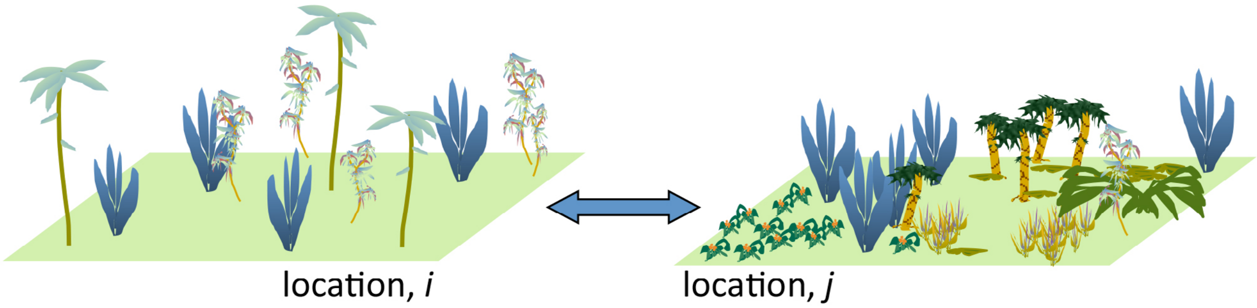
[1] http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/geodetic-datums/gda

TECHNICAL NOTE 2

Community-level modelling using Generalised Dissimilarity Modelling

Generalised Dissimilarity Modelling (GDM, Ferrier et al., 2007) is a novel non-linear statistical method for assessing variation in the magnitude and rate of change in observations of species occurrences along different environmental gradients.

The community-level measure used in this Guide is the Sørensen dissimilarity index, calculated from the counts of similarities and differences in the presence of distinct assemblages of species found at two locations (see Figure 1). The index is bound between 0 and 1, where 0 means the two locations have the same composition (they share all the species), and 1 means they do not share any species (no species in common). This measure is directly related to the similarity index between the same two locations where, similarity=1-dissimilarity. While the biodiversity model is developed using dissimilarity, the predictions are presented as ecological similarity for ease of interpretation.



Compositional Dissimilarity,

$$d_{ij} = 1 - \frac{2A}{2A+B+C} = 1 - \frac{2*2}{2*2+1+5} = 0.6$$

Where,

A is the number of species common to both locations *i* and *j* = 2

B is the number of species present only at location *i* = 1

C is the number of species present only at location *j* = 5

Figure 1.
Compositional dissimilarity is a measure of the differences in biological composition between two sites. The index quantifies the compositional dissimilarity between two different sites, based on the counts of species in common or unique at each site. Compositional dissimilarity is the response variable in a statistical analysis of the relationships between biodiversity and environment using *Generalised Dissimilarity Modelling*.

Modelling ecological similarity

The number of pair-wise calculations available to the biodiversity model can be large when using survey data compiled from across the entire continent of Australia. For n locations, n(n-1)/2 pair-wise dissimilarities are needed to account for comparisons between each pair of locations. A dataset with 100 locations would have 4950 pairs, and a dataset with 100,000 locations has 5.00495 x 10^9, pairs. A sample of location pairs is therefore generated from large datasets by randomly sampling from the pool of available pairs. Stratified random sampling may be used to even up sampling bias, for example between biogeographic regions as a proxy for differences in environment heterogeneity.

TECHNICAL NOTE 2 (CONTINUED)

GDM uses linear statistical models of compositional differences between pairs of locations to predict the magnitude and rate at which similarity between assemblages of species declines with ecological distance. The statistical model is formulated with a link function addressing the asymptotic relationship between the ecological distance separating a given pair of locations, and the compositional dissimilarity between locations. That is, upon increasing ecological distance until no species are in common, then even more distance will make no further difference. Ecological distance in this case can be defined by geography such as the distance in kilometres between two locations, or by environment, such as the difference defined by 300mm of rainfall and 1000mm between two locations (i.e., a 'distance' of 700mm).

This relationship between change in species compositions and change in environment is characteristically non-linear and monotonically increases with distance. For example, we might initially see small differences in species composition along a rainfall gradient, but when a threshold is reached (e.g. where rainfall is less than the adaptive capacity of a given assemblage of species) a more sudden change in composition may occur. When viewed as a continuum, the shift in species composition from dry to moist is initially rapid and then tails off as rainfall reaches surplus (see Figure 2, left). A similar pattern of nonlinearity in rates of turnover in species compositions occurs along temperature (e.g., Figure 2, right) and other environmental gradients such as soil fertility.

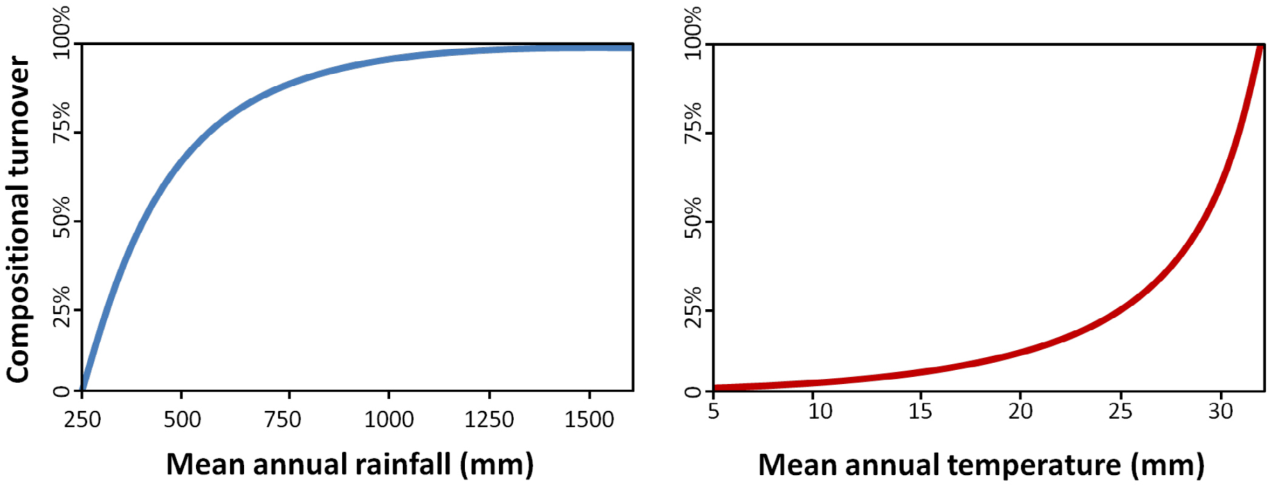
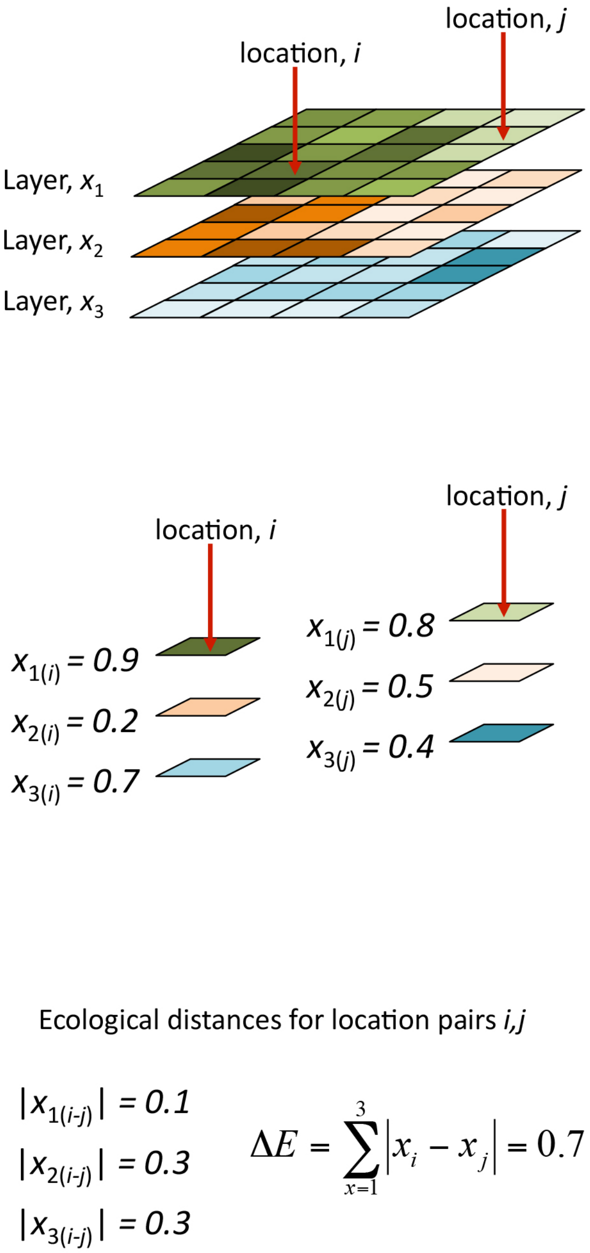


Figure 2.
A schematic plot showing the non-linear relationship between rate of change or turnover in species compositions along single environmental gradients: left) rainfall, right) temperature.

Spatially predicting ecological similarity

When the predictor variables used in a GDM are drawn from remote mapping of environment, such as soil and geology maps, climate grids and landform types, then the results can be predicted spatially. A set of 'scaled' environmental surfaces are generated by the model from which the ecological similarity prediction can be derived from pairs of grid cells representing different locations (see Figure 3).



$$\Delta E = \sum_{x=1}^{3} \left| x_i - x_j \right| = 0.7$$

FOR A GIVEN SET OF GDM-SCALED ENVIRONMENTAL LAYERS, X_1, X_2 AND X_3 (E.G., RAINFALL, TEMPERATURE AND SOIL FERTILITY), TWO LOCATIONS, *i* AND *j*, ARE COMPARED AT THE SAME POINT IN TIME (E.G. 1990 CLIMATES).

EACH OF THE TWO LOCATIONS, *i* AND *j*, HAVE DIFFERENT VALUES FOR THE SAME SCALED ENVIRONMENTAL LAYER AND EACH LAYER DERIVES FROM DIFFERENT TYPES OF ENVIRONMENT (E.G., RAINFALL, TEMPERATURE AND SOIL FERTILITY).

THE ECOLOGICAL DISTANCE IS CALCULATED FOR EACH LAYER BETWEEN THE TWO LOCATIONS, *i* AND *j*, AND THEN SUMMED. SIMILARITY, $s_i j$, IS THE NEGATIVE EXPONENTIAL OF ECOLOGICAL DISTANCE:

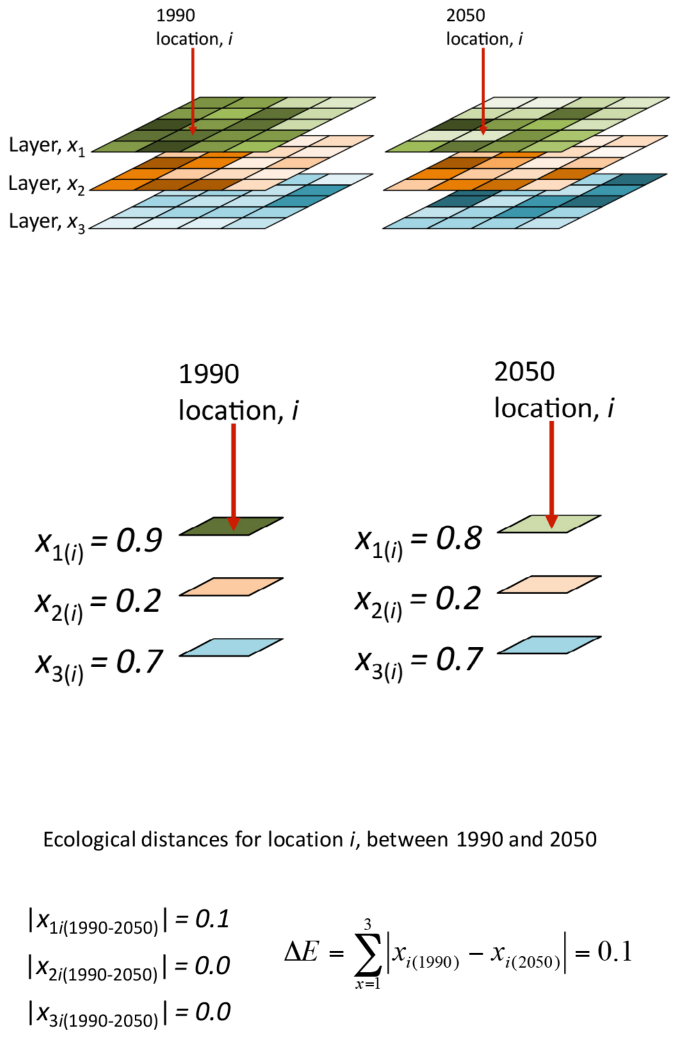
$$s_{ij} = e^{-\Delta E} = 0.497$$

Figure 3.
How similarity is calculated from a set of GDM-scaled environmental predictor layers. This example shows two locations, *i* and *j*, at the same point in time (e.g. 1990 climates).

Spatially projecting ecological similarity

Ecological similarity can be projected into the future by replacing the climate variables used to fit the model with those derived from climate scenarios. The similarity prediction is now derived from pairs of grid cells from the same location but at different times (e.g. baseline climate and future climate) (see Figure 4).

The biodiversity models used a wide range of ecologically-relevant climatic indicators derived from monthly averages such as the hottest, wettest, coolest or driest, and various measures of seasonality to represent inherent variation in annual conditions. Other measures related to soil and landform types are also used in the models and are considered stable over the time period of change presented here.



$|x_{1i(1990\text{-}2050)}| = 0.1$

$|x_{2i(1990\text{-}2050)}| = 0.0$

$|x_{3i(1990\text{-}2050)}| = 0.0$

$$\Delta E = \sum_{x=1}^{3} \left| x_{i(1990)} - x_{i(2050)} \right| = 0.1$$

A SINGLE LOCATION, *i*, IS COMPARED WITH ITSELF AT DIFFERENT POINTS IN TIME (E.G. 1990 AND 2050).

THE SAME LOCATION, *i*, MAY HAVE DIFFERENT VALUES FOR THE SAME GDM-SCALED ENVIRONMENTAL LAYER AT DIFFERENT TIME PERIODS, DEPENDING ON WHETHER THE LAYER IS DERIVED FROM CLIMATE OR IS 'STATIC' (E.G. CHANGE IN SOIL AND TOPOGRAPHY IS ASSUMED NEGLIGIBLE OVER THE SCENARIO TIME FRAMES).

THE ECOLOGICAL DISTANCE IS CALCULATED FOR EACH GDM-SCALED ENVIRONMENTAL LAYER, FOR THE SAME LOCATION, *i*. SIMILARITY, *s*, IS THE NEGATIVE EXPONENTIAL OF ECOLOGICAL DISTANCE:

$$s_{i_{(1990)} i_{(2050)}} = e^{-\Delta E} = 0.905$$

Figure 4.
The community-level model of biodiversity (predicted pattern) is projected into the future using climate scenarios. Ecological similarity is then estimated between the same locations but at different points in time, for example between 1990 and 2050. This calculation represents the degree of change derived from the non-linear scaling of environments as defined by the model for a particular biological group.

In the context of climate change, the capacity of GDM to account for non-linear relationships between species compositions and environment, as well the relative importance of a range of climate and substrate variables, results in a more realistic view of the potential for ecological change than only using unscaled climatic variables. This basic calculation of ecological similarity between two different locations or two time periods represents how we use GDM in a climate change context.Further information and example applications of GDM in biodiversity assessment can be found in the references and suggested reading appended with this Guide.

Climate data used to model and project ecological similarity in this Guide

The use of climate projection data in assessments to inform adaptation planning requires that choices be made about which future scenarios to explore, including which of the 50 or so CMIP5[1] global climate models to use, which emissions scenario[2] to apply and over what time period. Making these choices is a major challenge.

To guide emissions scenario and climate model selection, CSIRO developed an approach called Climate Futures. This approach uses any two climate variables, such as rainfall and temperature, to identify the range of scenarios encompassing, for example, the 'Maximum Consensus', 'Best Case' or 'Worst Case' plausible futures. Information about this approach and a tool to assist selection or review of climate scenarios is available online[3].

For demonstrating the use of projected ecological similarity in natural resource planning, we needed to limit the number of climate scenarios presented in this Module to just two. Combined with the four biological groups, this leads to eight biodiversity assessment scenarios. In making this decision, we considered natural resource management planning decisions that would have implications over the next 30-50 years, for example, current actions influencing the retention of overall biodiversity in the landscape.

We therefore chose a scenario for the year 2050 that assumes a continuation of recent trends in emissions using the representative concentration pathway (RCP) of 8.5. This is one of several pathways for how global human behaviour with regard to emissions can influence the radiative forcing on climate (Figure 1). Each RCP represents an emissions scenario, and for each emissions scenario there is some uncertainty around the strength of the climate response. This, combined with differences within the models means that each climate model projects a somewhat different future climate. Thus, by 2050, the emissions scenarios are diverging. RCP 8.5 in this context presents a greater amount of change for biodiversity, and provides a useful framework for planning potential management responses.

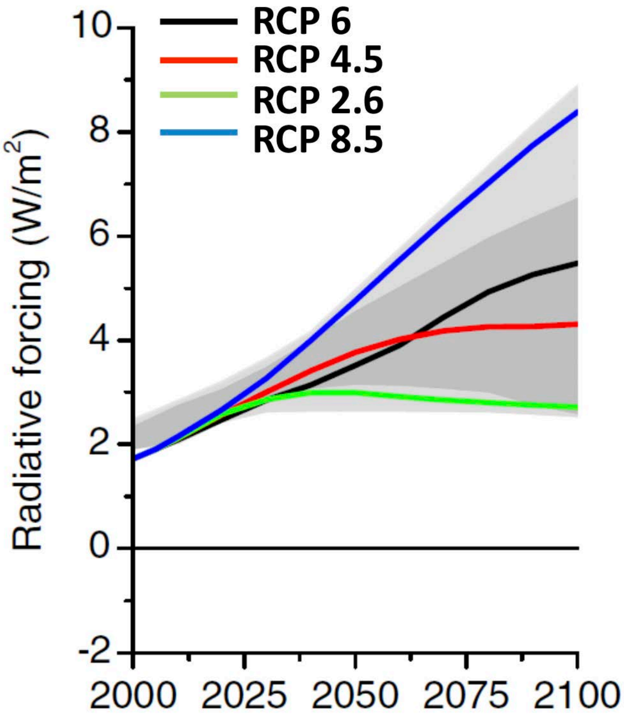


Figure 1.
Radiative Forcing of the Representative Concentration Pathways. From van Vuuren *et al.* (2011) The light grey area captures 98% of the range in previous IPCC integrated assessment modelling scenarios, and dark grey represents 90% of the range.

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[1] CMIP5 - Coupled Model Intercomparison Project Phase 5: ***http://cmip-pcmdi.llnl.gov/cmip5/***

[2] Scenario process for Assessment Report 5, ***http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html***

[3] Climate change in Australia: ***http://www.climatechangeinaustralia.gov.au/***

The two climate models—the Model for Interdisciplinary Research on Climate produced by the Japanese research community (*MIROC5, Watanabe et al. 2010*) and the Canadian Earth System Model (*CanESM2, Chylek et al. 2011*)—were selected because they represent the spectrum of 'Maximum Consensus' futures for Australia, where the most models agree.

These choices of climate model and scenarios are appropriate for planning decisions given current global trends in greenhouse gas emissions and in-built momentum in the climate system. They represent a relatively mild and a hot climate future, respectively. For simplicity, we call them the high emissions' *mild MIROC5* and *hot CanESM2* climate scenarios. Additional analyses are possible but will depend on demand and resources.

The climate scenario data were downscaled to match the ~250m grid resolution of the climate data used to model ecological similarity. Broad patterns were rescaled using 1990-centred (30 year average) monthly gridded historic climate data. The climate scenario data represented similar 30-year averages centred on 2050. The resulting future climate scenario data therefore captured some of the fine-scale topographic patterns that are important drivers of biodiversity response. Our approach to downscaling is described in Reside et al. (2013) and Harwood et al. (2012).

Figure 2 shows the downscaled variation in continental patterns of change in two indicative variables – mean annual temperature and total annual rainfall, for each scenario between 1990 (baseline) and 2050 for the high emissions' *mild MIROC5* and *hot CanESM2* scenarios. Rainfall patterns vary regionally, for example across northern and central Australia, and show similar drying in southwest Western Australia: already a feature of the changed climatic regime in that region. The two models differ substantially in their projected temperature increases. This variation is expected, since we chose the two models to encompass the 'Maximum Consensus' spectrum. Under a high emissions scenario, the *hot CanESM2* climate model suggests temperatures could be up to 3.5°C warmer by 2050 in some regions than they were in 1990, while the *MIROC5* model projections are up to 2°C warmer.

More details about these scenarios and how they compare or contrast with other climate models and scenarios can be found on the Climate Change in Australia website: ***www.climatechangeinaustralia.gov.au***

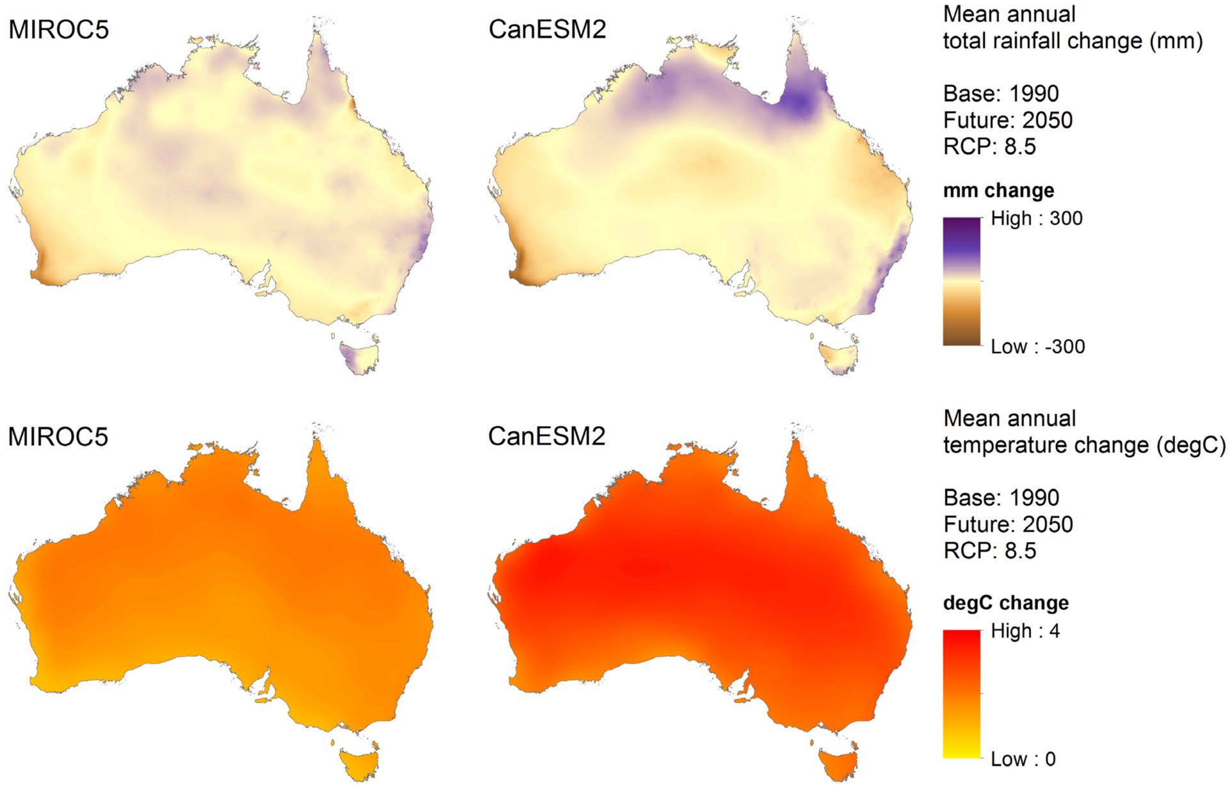

Figure 2.
Variation in continental patterns of change in mean annual temperature and total annual rainfall between 1990 (baseline) and 2050 for the two global climate models and RCP 8.5 used to project ecological change in this Guide (see Technical Note 2 for details).

Spatially estimating biodiversity model limitations

Information about the limitations of any model of biodiversity or the environment assists planners to decide how much emphasis to place on the outputs and their usefulness in the different phases of planning. Here we provide two measures that characterise different types of spatial limitations in the biodiversity modelling and their application to climate change. These are additional to the uncertainty associated with climate change, which is expressed through the use of different climate models and emissions scenarios (for those details see Technical Note 3).

The continental coverage of biological survey data used in the model

The first measure describes how well the biological survey data represent the different places where species are found across Australia, as a basis for modelling ecological similarity. This is calculated as a function of the proportion of the density of survey effort within GDM-scaled environmental space. A threshold is defined, specific to the biological group, beyond which the environmental space is considered adequately sampled (Figure 1).

Overall, survey coverage is high for all biological groups, although some areas for improvement are suggested. In the case of amphibians, gaps in survey coverage are apparent throughout the western parts of arid Australia (where fewer habitats support amphibians). For reptiles, survey coverage appears sparse in western Tasmania where fewer species are adapted to the generally cooler environmental conditions.

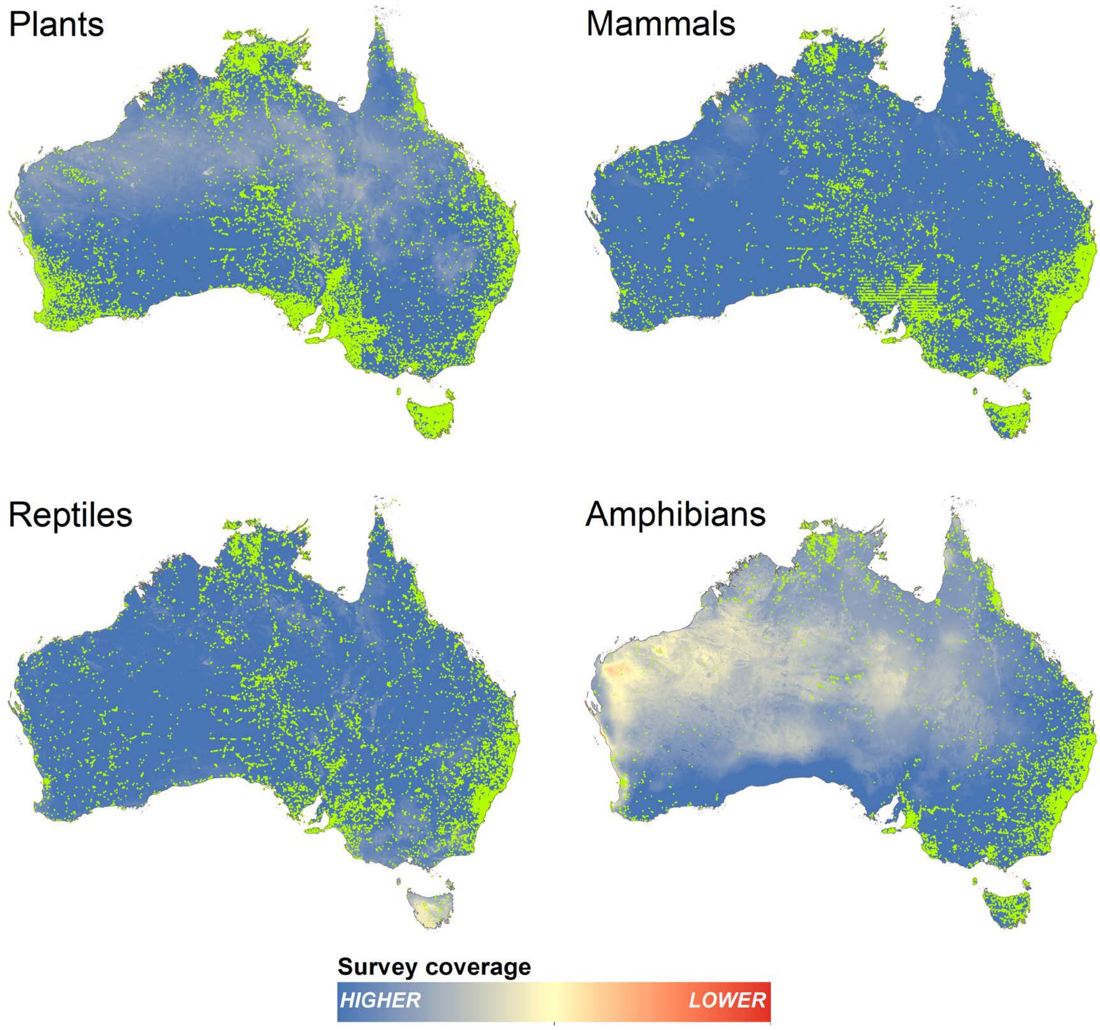

Figure 1.
Continental coverage of biological survey data used in each model (vascular plants, mammals, reptiles and amphibians). Green dots are specific locations where species recorded

The degree of model extrapolation under climate change

Extrapolation of statistical models to new environments outside the range of the data used to fit them is sometimes necessary. This is not ideal because potential novel relationships between species composition and the more extreme environments expected under climate change cannot be fully accounted for. Where extrapolation is high in some parts of the landscape, greater caution is needed in using the data to make critical decisions about those places.

The second measure therefore shows where future GDM-scaled environments may be outside the range of the data used to fit the biodiversity model given its non-linear relationship to compositional turnover. (See Technical Note 2 for a discussion of the inherent non-linearity in the relationship between compositional turnover and environmental gradients such as rainfall and temperature.)

Extrapolation is calculated as the sum of the absolute ecological distances for each of the GDM-scaled environmental variables, beyond the data range used to fit the model (Figure 2). The contribution to extrapolation by individual variables (not shown) indicates how sensitive the model is to each.

Extrapolation is nil or low across most of Australia for all biological groups and the two climate scenarios investigated here (Figure 2). As might be expected, the projection of ecological similarity using the more extreme high emissions' *hot CanESM2* climate scenario results in more areas of extrapolation. There is also high consistency in the areas of extrapolation between the four biological groups, across north-western and central Australia. This suggests a common pattern of sensitivity to the degree of change in underlying climate drivers in these regions.

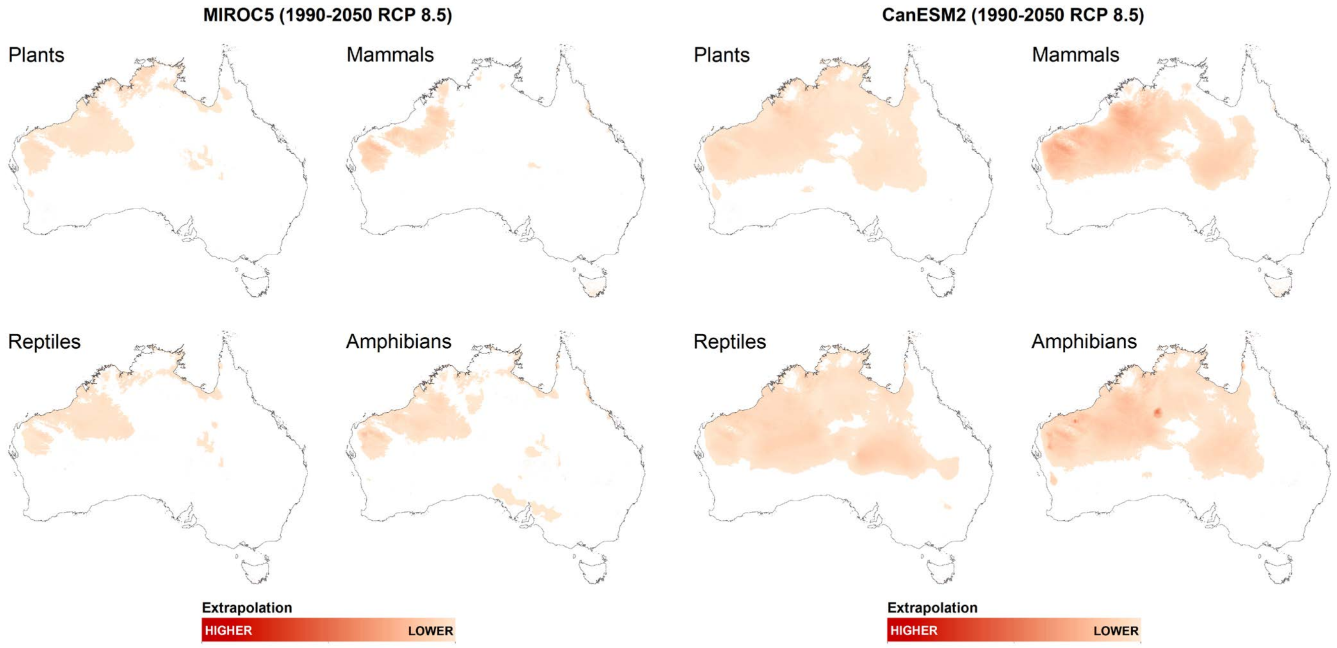

Figure 2.
Schematic maps showing the degree to which the model has been extrapolated to new environments for each biological group (vascular plants, mammals, reptiles and amphibians) and climate scenario (MIROC5 and CanESM2).

References and further reading

The following list of references draws upon material referred within or relevant to this Guide.

Ackerly DD, Loarie SR, Cornwell WK, Weiss SB, Hamilton H, Branciforte R, Kraft NJB (2010) The geography of climate change: implications for conservation biogeography. Diversity and Distributions 16(3), 476-487.

Allnutt TF, Ferrier S, Manion G, Powell GVN, Ricketts TH, Fisher BL, Harper GJ, Irwin ME, Kremen C, Labat J-N, Lees DC, Pearce TA, Rakotondrainibe F (2008) A method for quantifying biodiversity loss and its application to a 50-year record of deforestation across Madagascar. Conservation Letters 1(4), 173-181.

Blois JL, Williams JW, Fitzpatrick MC, Ferrier S, Veloz SD, He F, Liu Z, Manion G, Otto-Bliesner B (2013a) Modeling the climatic drivers of spatial patterns in vegetation composition since the Last Glacial Maximum. Ecography 36(4), 460-473.

Blois JL, Williams JW, Fitzpatrick MC, Jackson ST, Ferrier S (2013b) Space can substitute for time in predicting climate-change effects on biodiversity. Proceedings of the National Academy of Sciences 10(23), 9374–9379.

Burrows MT, Schoeman DS, Richardson AJ, Molinos JG, Hoffmann A, Buckley LB, Moore PJ, Brown CJ, Bruno JF, Duarte CM, Halpern BS, Hoegh-Guldberg O, Kappel CV, Kiessling W, O/'Connor MI, Pandolfi JM, Parmesan C, Sydeman WJ, Ferrier S, Williams KJ, Poloczanska ES (2014) Geographical limits to species-range shifts are suggested by climate velocity. Nature 507(27 March 2014), 492-495.

Chylek P, Li J, Dubey MK, Wang M, Lesins G (2011) Observed and model simulated 20th century Arctic temperature variability: Canadian Earth System Model CanESM2. Atmospheric Chemistry and Physics Discussion. 11(8), 22893-22907.

Drielsma M, Ferrier S (2009) Rapid evaluation of metapopulation persistence in highly variegated landscapes. Biological Conservation 142(3), 529-540.

Drielsma M, Ferrier S, Howling G, Manion G, Taylor S, Love J (2014a) The Biodiversity Forecasting Toolkit: Answering the 'how much', 'what', and 'where' of planning for biodiversity persistence. Ecological Modelling 274(0), 80-91.

Drielsma M, Manion G, Love J, Williams KJ, Harwood T (2014b) '3C Modelling for Biodiversity Management Under Future Climate.' (NSW Office of Environment and Heritage: Armidale).

Dunlop M, Hilbert DW, Ferrier S, House A, Liedloff A, Prober SM, Smyth A, Martin TG, Harwood T, Williams KJ, Fletcher C, Murphy H (2012a) 'Implications for policy makers: climate change, biodiversity conservation and the National Reserve System.' (CSIRO Climate Adaptation Flagship: Canberra) 11, available online: ***http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/adapt-national-reserve-system.aspx***

Dunlop M, Hilbert DW, Ferrier S, House A, Liedloff A, Prober SM, Smyth A, Martin TG, Harwood T, Williams KJ, Fletcher C, Murphy H (2012b) 'The implications of climate change for biodiversity, conservation and the National Reserve System: Final Synthesis.' (A report prepared for the Department of Sustainability, Environment, Water, Population and Communities, Canberra. CSIRO Climate Adaptation Flagship: Canberra) 79, available online: ***http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/adapt-national-reserve-system.aspx***

Dunlop M, Parris H, Ryan P, Kroon F (2013) 'Climate-ready conservation objectives: a scoping study.' (National Climate Change Adaptation Research Facility: Gold Coast) 102; available online: ***http://www.nccarf.edu.au/publications/climate-ready-conservation-objectives-scoping-study***

Ferrier S, Drielsma M (2010) Synthesis of pattern and process in biodiversity conservation assessment: a flexible whole-landscape modelling framework. Diversity and Distributions 16(3), 386-402.

Ferrier S, Guisan A (2006) Spatial modelling of biodiversity at the community level. Journal of Applied Ecology 43(3), 393-404.

Ferrier S, Harwood T, Williams KJ (2012a) 'Queensland's biodiversity under climate change: ecological scaling of terrestrial environmental change.' (CSIRO Climate Adaptation Flagship Working Paper No. 12B: Canberra) 49, available online: ***http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/CAF-working-papers/CAF-working-paper-12.aspx***

Ferrier S, Harwood T, Williams KJ (2012b) 'Using Generalised Dissimilarity Modelling to assess potential impacts of climate change on biodiversity composition in Australia, and on the representativeness of the National Reserve System.' (CSIRO Climate Adaptation Flagship Working Paper No. 13E: Canberra) 62, available online: ***http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/CAF-working-papers/CAF-working-paper-13.aspx***

Ferrier S, Powell GVN, Richardson KS, Manion G, Overton JM, Allnutt TF, Cameron SE, Mantle K, Burgess ND, Faith DP, Lamoreux JF, Kier G, Hijmans RJ, Funk VA, Cassis GA, Fisher BL, Flemons P, Lees D, Lovett JC, Rompaey V, R. RSA (2004) Mapping More of Terrestrial Biodiversity for Global Conservation Assessment. Bioscience 54(12), 1101-1109.

Harwood T, Williams KJ, Ferrier S (2012) 'Generation of spatially downscaled climate change predictions for Australia.' (Generation of spatially downscaled climate change predictions for Australia. CSIRO Climate Adaptation Flagship Working Paper No. 13F: Canberra) 12, available online: ***http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/CAF-working-papers/CAF-working-paper-13.aspx***

References and further reading (continued)

Hennessy K, Clarke J, Whetton P, Kent D (2012) 'An introduction to internally consistent climate projections.' (CSIRO Marine and Atmospheric Research: Aspendale, Australia) 10, available online: ***http://www.climatechangeinaustralia.gov.au/documents/resources/An%20introduction%20to%20internally%20consistent%20climate%20projections.pdf***

Jubb I, Canadell P, Dix M (undated) 'Representative Concentration Pathways (RCPs).' (CSIRO and the Bureau of Meteorology: Melbourne) 3, available online: ***http://www.cawcr.gov.au/publications/otherreports/ACCSP_RCP.pdf***

Murphy H, Liedloff A, Williams RJ, Williams KJ, Dunlop M (2012) 'Queensland's biodiversity under climate change: terrestrial ecosystems.' (CSIRO Climate Adaptation Flagship Working Paper No. 12C: Canberra) 110, available online: ***http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/CAF-working-papers/CAF-working-paper-12.aspx***

Reside AE, VanDerWal J, Phillips B, Shoo L, Rosauer D, Anderson BA, Welbergen J, Moritz C, Ferrier S, Harwood TD, Williams KJ, Mackey B, Hugh S, Williams SE (2013) 'Climate Change refugia for terrestrial biodiversity: the role of refugia ecosystem resilience and maintenance of terrestrial biodiversity in the face of global climate change.' (National Climate Change Adaptation Research Facility: Griffith University, Gold Coast, Qld) 216, available online: ***http://www.nccarf.edu.au/publications/climate-change-refugia-terrestrial-biodiversity***

Rissik D, Boulter S, Doerr V, Marshall N, Hobday A and Lim-Camacho L (2014) The NRM Adaptation Checklist: Supporting climate adaptation planning and decision-making for regional NRM. (CSIRO and NCCARF, Australia.) ISBN 78-1-4863-0319-9. Available online: ***www.AdaptNRM.org***

Rosauer DF, Ferrier S, Williams KJ, Manion G, Keogh JS, Laffan SW (2014) Phylogenetic generalised dissimilarity modelling: a new approach to analysing and predicting spatial turnover in the phylogenetic composition of communities. Ecography 37(1), 21-32.

Scott, J.K., Webber, B.L., Murphy, H., Ota, N., Kriticos, D.J. and Loechel, B. (2014) AdaptNRM Weeds and climate change: supporting weed management adaptation. (CSIRO, Australia.) ISBN 978-1-4863-0401-1. Available at: www.AdaptNRM.org

Sinha P, Kumar L, Drielsma M, Barrett T (2014) Time-series effective habitat area (EHA) modelling using cost-benefit raster based technique. Ecological Informatics 19(0), 16-25.

Steffen W, Burbidge AA, Hughes L, Kitching R, Lindenmayer D, Musgrave W, Smith MS, Werner PA (2009) 'Australia's Biodiversity and Climate Change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change.' (CSIRO Publishing: Melbourne, VIC) 290, available online: ***http://www.climatechange.gov.au/sites/climatechange/files/documents/04_2013/biodiversity-vulnerability-assessment.pdf***

Taylor KE, Stouffer RJ, Meehl GA (2012) An overview of CMIP5 and the experiment design Bulletin of the American Meteorological Society 93(4), 485-498, doi:10.1175/BAMS-D-11-00094.1

van Vuuren D, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt G, Kram T, Krey V, Lamarque J-F, Masui T, Meinshausen M, Nakicenovic N, Smith S, Rose S (2011) The representative concentration pathways: an overview. Climatic Change 109(1-2), 5-31.

Watanabe M, Suzuki T, O'ishi R, Komuro Y, Watanabe S, Emori S, Takemura T, Chikira M, Ogura T, Sekiguchi M, Takata K, Yamazaki D, Yokohata T, Nozawa T, Hasumi H, Tatebe H, Kimoto M (2010) Improved Climate Simulation by MIROC5: Mean States, Variability, and Climate Sensitivity. Journal of Climate 23(23), 6312-6335.

Whitford KR (2012) Jilakin jarrah. Western Wildlife: Newsletter of the Land for Wildlife Scheme 16(3), 12–13.

Whitford KR, White PS, McCaw L, Durell G, Whitford E (2008) 'Deaths of jarrah in 2008 at Jilakin Rock: an outlying population of jarrah: a report of initial observations.' (Western Australian Department of Environment and Conservation: Kensington, WA, Australia) 22

Whittaker RH (1960) Vegetation of the Siskiyou Mountains, Oregon and California. Ecological Monographs 30(3), 279-338.

Whittaker RH (1972) Evolution and Measurement of Species Diversity. Taxon 21(2/3), 213-251.

Williams JW, Jackson ST (2007) Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment 5, 475-482.

Williams JW, Jackson ST, Kutzbacht JE (2007) Projected distributions of novel and disappearing climates by 2100 AD. Proceedings of the National Academy of Sciences of the United States of America 104(14), 5738-5742.

Williams KJ, Belbin L, Austin MP, Stein J, Ferrier S (2012a) Which environmental variables should I use in my biodiversity model? International Journal of Geographic Information Sciences 26(11), 2009-2047.

Williams KJ, Dunlop M, Bustamante RH, Murphy HT, Ferrier S, Wise RM, Liedloff A, Skewes T, Hardwood TD, Kroon F, Williams RJ, Joehnk K, Crimp S, Stafford Smith M, James C, Booth T (2012b) 'Queensland's biodiversity under climate change: impacts and adaptation - synthesis report.' (A Report Prepared for the Queensland Government, Brisbane. CSIRO Climate Adaptation Flagship: Canberra) 105, available online: ***http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/Queensland-biodiversity-under-climate-change.aspx***

Woinarski JCZ, Armstrong M, Brennan K, Fisher A, Griffiths AD, Hill B, Milne DJ, Palmer C, Ward S, Watson M, Winderlich S, Young S (2010) Monitoring indicates rapid and severe decline of native small mammals in Kakadu National Park, northern Australia. Wildlife Research 37(2), 116-126.

ABOUT ADAPTNRM

The National AdaptNRM Impacts and Adaptation Project is a multidisciplinary endeavour that brings together a diverse group of scientists working with NRM practitioners.

While the project itself consists of researchers from CSIRO and NCCARF, our output and initiatives have been shaped and informed through the generous input of NRM practitioners across Australia as well as a multitude of researchers, state and federal government stakeholders.

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Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

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Implications of Climate Change for Biodiversity

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