Contextual analysis of ecological change for Tasmania

Chris Ware, Kristen J. Williams, Tom Harwood and Simon Ferrier
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The authors thank Talia Jeanneret for comments on an early version of this report.

This report is a technical supplement to the AdaptNRM explanatory guide ‘implications for biodiversity’ (http://adaptnrm.csiro.au/biodiversity-impacts/).
CSIRO has developed a suite of national-scale biodiversity change datasets using community-level modelling to support climate adaptation planning by Natural Resource Management groups. These datasets have been published in two ‘AdaptNRM’ modules with explanatory guides and maps (www.adaptnrm.org). The datasets were developed to show change in a national context. Given the ecological distinctiveness of Tasmania and surrounding islands, the State Government of Tasmania and Tasmanian NRMs requested CSIRO to minimally contextualise the measures of biodiversity change. The contextual measures used the same models and climate scenarios, and where calculations between locations were needed, made these over just the extent of Tasmania.

This report summarises how these contextualise measures were developed with limited guidance on how to use the data. Further details are provided in the AdaptNRM explanatory guides, ‘implications for biodiversity’ (http://adaptnrm.csiro.au/biodiversity-impacts/) and ‘helping biodiversity adapt’ (http://adaptnrm.csiro.au/biodiversity-options/). This technical report should be read in conjunction with those guides and refers to just a subset of the range of measures originally provided and, specifically, those that can be updated with minimal effort to contextualise change for Tasmania.

The contextual measures apply to two key dimensions of climate change: the degree to which available ecological environments will disappear, or novel ecological environments will form. Disappearing ecological environments are defined as “present-day ecological environments scaled by ecological similarity that may become absent from an entire region in the future”, whereas novel ecological environments are “possible new ecological environments scaled by ecological similarity that may arise in the future but which do not exist regionally at present”. The two dimensions are indicative of different types of pressure on species and ecosystems under climate change.

Measures of disappearing and novel ecological environments were previously calculated at the national scale based on a series of comparisons made over the entire continent. An implicit assumption is that biological dispersal can occur across the geographical extent of the analysis over the period of the scenario (e.g., over 60 years from 1990 to 2050). To provide more contextual measures of ecological change for the geographically isolated State of Tasmania, we developed an additional series of analyses calculated for the Tasmanian extent only.

The new datasets provide projections of ecological change for four taxonomic groups: amphibians, mammals, reptiles, and vascular plants. The underpinning community-level models are the same as those used in the national level assessments, derived using Australia-wide data. Ecological change was calculated based on projections using two separate climate models for the year 2050, both of which were forced by a ‘business as usual’ high emissions scenario (RCP 8.5), and are the same change scenarios used in the two ‘AdaptNRM’ modules. Little change (i.e. ecologically similar environments) between 1990 and 2050 in Tasmania is a dominant feature of the datasets. This result is similar to that found for Tasmania in the continental analyses, and reflects the high degree of ecological similarity projected between a location in 1990 and under a future climate scenario for 2050. Contextualising the disappearing and novel analyses for Tasmania provides
additional insight into the spatial distribution and direction of where most regional ecological change is projected to occur between 1990 and 2050.

Overall, the magnitude of change is generally projected to be less under the contextualised analyses for Tasmania compared to the continental projections. The Tasmania data series suggest ecological environments for all four biological groups (vascular plants, mammals, reptiles and amphibians) will change most in north-east Tasmania and across the Bass Strait Islands. The mammal model suggests substantially greater change than projected under the continental equivalent. Other patterns vary across the biological groups, with higher levels of change suggested around the Central Plateau, northern midlands, and central West Coast regions, amidst other more localised changes. Marked differences are apparent between ecological projections forced by the two different climate models. Fully explaining these differences, related both to differences in the climate scenarios and the nature of biotic-environment correlations in the taxon group models, is beyond the scope of this report.

The composite ecological change measures for each of the four biological groups depict different vulnerabilities to change. Two alternative measures are provided, one that is directly comparable with the original Australia context and another adjusted for comparison within this contextual Tasmania data series only. We also provide an ensemble version which averages across the four groups for each climate scenario. The ensemble composite ecological change for both climate scenarios reveals the overall pattern of change, wherein the different biological groups have varying emphasis. The results are strongly influenced by the reptile and vascular plant groups which show greater propensity to change and especially with the hot CanESM2 climate model.

The datasets and maps, consistent with the AdaptNRM series, can be downloaded from CSIROs data access portal from this landing page: https://data.csiro.au/dap/landingpage?pid=csiro:19936.
CSIRO has developed a suite of national-scale biodiversity change datasets using community-level modelling of four biological groups (vascular plants, mammals, reptiles and amphibians) to support climate adaptation planning by Natural Resource Management groups. These datasets have been published in two ‘AdaptNRM’ modules with explanatory guides (www.adaptnrm.org) (Prober et al., 2015; Williams et al., 2014g). The datasets were developed to show change in a national context (Williams et al., 2014f). Given the ecological distinctiveness of Tasmania and surrounding islands, the State Government of Tasmania and Tasmanian NRMs requested CSIRO to contextualise the measures of biodiversity change for Tasmania.

The contextual measures apply to two key dimensions of climate change: the degree to which available ecological environments will disappear, or novel ecological environments will form. Disappearing ecological environments are defined as “present-day ecological environments scaled by ecological similarity that may become absent from an entire region in the future”, whereas novel ecological environments are “possible new ecological environments scaled by ecological similarity that may arise in the future but which do not exist regionally at present”. The two dimensions are indicative of different types of pressure on biological communities under climate change.

This report summarises the results of those supplementary analyses, compared with the National context, and provides details on how to access the data and maps.

1.1 Rationale

A number of primary ecological measures of climate change were developed and presented in Williams et al. (2014g). Of particular interest to Tasmania was the composite of three measures that provided an integrated view of change to facilitate adaptation planning, known as the ‘composite ecological change’ (see section 6 in Williams et al., 2014g). Measures of the potential degree of ecological change and of disappearing and novel ecological environments combine to show not only where change might be greatest, but also something about the nature of the change to recognise different types of vulnerability. Two of these key dimensions of ecological change - the degree to which present-day ecological environments will disappear, or novel ecological environments will form (Section 4 in Williams et al., 2014g) – are calculated relative to the entire continent of Australia.

An implicit assumption of these measures is that biological dispersal can occur across the geographical extent of the analysis over the time frame under consideration (here, over 60 years from 1990 to 2050). For this work, we contextualised the analyses for the geographically isolated case of Tasmania by calculating these dimensions of ecological change for the Tasmanian geographical extent only. The third dimension - the ‘Potential degree of ecological change’ (Section 3 in Williams et al., 2014g) – is calculated by comparing each location with itself between baseline and 2050, and is already locally contextual.
To provide more contextual measures, we calculated novel and disappearing ecological environments relative to Tasmania, and then combined these with the potential degree of ecological change to also generate a Tasmania version of the *composite ecological change* measure. The measures are presented in a series of poster-maps for the Tasmania context, as a supplement to the AdaptNRM poster series (Williams et al., 2014e), and the data are accessible to the public via the CSIRO data access portal ([www.data.csiro.au](http://www.data.csiro.au)).
2 Methods summary

2.1 Community-level models

The contextual measures for Tasmania used the community level models for the four biological groups considered in AdaptNRM – vascular plants, mammals, reptiles and amphibians. These models were developed at a continental scale and used in the national-level ecological change measures (Prober et al., 2015; Williams et al., 2014g). The data used, and fitted model outputs can be found at www.data.csiro.au (Williams et al., 2014b; 2014c; 2014d; Williams et al., 2013). A summary of the community-level modelling methods and rationale for choice of biological groups and climate change scenarios is given in Section 2 and Technical Note 2 of Williams et al. (2014g).

2.2 Climate projections

To demonstrate the potential for different outcomes for biodiversity, two CMIPS\(^1\) 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 used to project ecological change by 2050 under the high emissions scenario defined by the Representative Concentration Pathway (RCP) 8.5 (radiative forcing of climate in energy units of Wm\(^{-2}\)) that assumes a continuation of recent trends in greenhouse gas emissions (van Vuuren et al., 2011).

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\(^2\) guided the process of choosing just two climate models (Whetton et al., 2015). The selected models fall within the spectrum of ‘Maximum Consensus’ futures for Australia, for the RCP8.5 scenario. This is a measure of agreement among model projections (Whetton et al., 2012). Separately, they represent a relatively mild warming and a hot climate future.

We chose to use the high emissions trajectory to demonstrate the possible outcome for biodiversity by 2050, indicative of the ecological potential to respond 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 based on different emission trajectories, such as RCP 4.5, and different global climate models (ACCESS1.0: Bi et al., 2013; MPI-ESM-LR: Block and Mauritsen, 2013; GFDL: Dunne et al., 2012) are possible, as these data have been generated by CSIRO using 9-second baseline climates to provide additional views on ecological change using community level models, if desired.

\(^1\) http://cmip-pcmdi.llnl.gov/cmip5/

\(^2\) www.climatechangeinaustralia.gov.au
2.3 Disappearing and novel ecological environments

The methods used to derive the degree to which available ecological environments will disappear, or novel ecological environments will form is outlined in Section 4 of Williams et al. (2014g), and equations are given in Appendix A of this report.

Disappearing ecological environments are calculated for each grid cell as the estimated ecological similarity between a focal cell in the present (1990 baseline) and its most similar cell anywhere in Tasmania in the future (2050). The resulting index shows the degree to which ecological environments are tending to disappear (see glossary for precise definitions). We use this terminology to convey the continuous nature of the measure. When calculated this way, locations with projected ecological similarity scores approaching zero presently support ecological environments that may not exist in the future anywhere in Tasmania – they will have disappeared, but may still be present somewhere in Australia. Higher scores signify some level of similarity in the future with present-day ecological environments.

Novel ecological environments are defined by looking back in time from each focal cell in the future (2050) to find the most similar cell anywhere in Tasmania in the baseline period (1990). The resulting index shows the degree to which ecological environments are becoming novel. Focal cells with future environments showing a low similarity even to the most similar cell in the present are indicative of novel ecological environments. This reverses the direction of the calculation for disappearing ecological environments.

2.4 Composite ecological change

As outlined in section 6 of Williams et al. (2014g), we created composite views by assigning each of the three component measures - the potential degree of ecological change (local similarity) for each location and the degree to which ecological environments are becoming novel or tending to disappear - to a different RGB colour band: local similarity as shades of green; novel as shades of blue; and disappearing as shades of red (Figure 1). The three ecological change measures are then mapped simultaneously, showing the varying degrees of similar, novel and disappearing ecological environments and their combinations. This provides a way of expressing the degree and nature of the ecological change that can be expected. Appendix B provides a detailed account of this visualisation method, and how to reproduce the colouring of associated images using the data.

To contextualise this composite measure for Tasmania, the results for each component measure (disappearing, novel, or potential degree of ecological change—here denoted ‘similar’—ecological environments) were converted to integer values and stretched across the range of possible RGB values (0-255) in one of two ways. The first method (hereafter ‘range stretch’) scaled values between the value representing no change, and the value representing complete change. Because the disappearing and novel ecological environment measures are measures of dissimilarity (higher values mean greater dissimilarity in ecological environments), whereas the measure of potential ecological change is a measure of similarity (higher numbers mean greater similarity in ecological environments), the scaling of component values needs to be performed differently according to whether they represent dissimilarity or similarity. For the disappearing ecological environment components, this meant stretching values between 0 and 1, where a value of 0 in the component measure was assigned the integer value of 0, and the value of 1 in the component measure
assigned the value 255. Values in between were linearly stretched between these bounds. For similar ecological environments, the value of 1 represents no change, and 0 represents complete change; in this case, the scaling was performed in the reverse order.

Figure 1. 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.
The shape of the ternary diagram, with more emphasis on similarity reflects the actual combinations.

When plotted as an RGB image, the resulting colour for each pixel is determined by the combination of integer values for the corresponding pixels in each of the three rasters (i.e. the scaled integer value for disappearing, novel, and similar). In the RGB colour system, the colour code for green (that is, lime green) is: (0,255,0). In other words, if the pixel value is 0 in the first raster, 255 in the second, and 0 in the third, the pixel will be green in the RGB image. We assigned the red channel to disappearing ecological environments, green to local similarity (potential degree of ecological change), and blue to novel ecological environments. Because the range stretch assigns RGB values to the full range of possible combinations in the three component measures (each scaled 0-1, stretched 0-255), it is directly comparable with the continent-wide measures (e.g. Williams et al., 2014a). While the range stretch provides the best objective visualisation of the magnitude and direction of change, it does not emphasise where change is occurring. This is because the dominant trend for Tasmania is a high degree of ecological similarity between the baseline period (1990) and 2050, and the full spectrum of colours are not used because many combinations do not exist. As a result, the ‘greenness’ of the green channel in an RGB image dominates.

To provide an alternative view to better highlight where change is occurring in Tasmania, we developed a second objective method to stretch composite change values. This method (hereafter the ‘range-adjusted stretch’) scales values between no change (0 for disappearing and novel ecological environments, and 1 for local similarity), and the maximum value (minimum for local similarity). To ensure comparability between biological groups and across the two climate scenarios, we used the maximum and minimum values found in the full range of data series for Tasmania. In the case of novel and disappearing ecological environments, the maximum value was 0.62 and in the case of local similarity the minimum value was 0.38 (i.e., 1-0.62). Values were then consistently stretched (0-255) across all combinations of biological groups and climate scenarios.
Using the range-adjusted stretch, a clearer picture emerges of the locations where change is occurring and also the type and magnitude of that change.

Using either view, wherever the potential degree of ecological change is scored low, ecological 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 ecological 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 (for further discussion of adaption options, see Prober et al., 2015).

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 somewhere 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 may describe these cases using the contrasting classes ‘high’ or ‘low’, the actual measure is continuous.

2.5 Extent of change in ecological environments and comparisons

We undertook two additional analyses of the resulting measures for the Tasmania context to determine how much difference has arisen and a comparison with the National AdaptNRM datasets:

1. Histograms showing the area (km²) of change between the 1990 baseline and 2050 future due to either disappearing or novel ecological environments, and also showing the overall area of decreasing similarity in ecological environments (potential degree of ecological change). This analysis provides an alternative means of viewing the gross area of change, and a convenient way of viewing the area of a given magnitude of change.
2. Maps of differences in novel and disappearing ecological environments calculated by subtracting the National dataset from the Tasmania dataset. Given that the measure for potential degree of ecological change is not influenced by its setting within a region (i.e. it
is a location specific measure in contrast to the disappearing and novel ecological environment measures which consider the surrounding region – all of Tasmania), the calculated difference demonstrates the added information provided by the contextual analyses for Tasmania.

2.6 Ensemble measure for composite ecological change

We also created an ensemble of the composite ecological change measures by calculating the arithmetic average of the results across the four biological groups for each of the component measures and climate scenarios. In the ensemble, each pixel represents the average of the corresponding pixels in the component measures (similar, novel and disappearing) for the four biological groups. The standard deviations of the ensemble means for the component measures were also calculated. RGB images were created for the ensemble means to create the ensemble composite ecological change results, using both the range stretch and the range-adjusted stretch methods. The ensemble of composite ecological change for both climate scenarios helps reveals the overall pattern of change, wherein the different biological groups will have varying emphasis.
3 Results

3.1 Measures of change in ecological environments

Here we show the data outputs for each biological group for each component measure (Figure 2 to Figure 5), coloured according to the RGB colour band it is assigned for the composite ecological change measure (see next section). To create the colour ramps, colours were linearly interpolated between white and red, green or blue, and stretched (0-255) over the range of possible values (i.e. between 0 and 1). The values of 0 and 1 do not exist in the data set, and so all values are represented as shades of red, green, or blue. White in the maps show regions of Tasmania not considered in the analyses (i.e., no data, such as lakes and oceans).

The data and map posters for each of these component measures, presented in an AdaptNRM template contextualised for Tasmania, are also available for download with the data collection (Harwood et al., 2016) from CSIROs data access portal from this landing page: https://data.csiro.au/dap/landingpage?pid=csiro:19936.
Figure 2. The three component measures of Composite ecological change for the mammal group. Each measure is coloured according to the colour channel assigned to it in an RGB image: disappearing as shades of red (top); novel as shades of blue (middle); local similarity as shades of green (bottom). Colour shades are stretched between 0 and 1 (i.e. the range of valid values for each measure). Low values for disappearing and novel ecological environments indicate little change, where high values for projected ecologically similar environments also indicate no change. The lower maps show results using the CanESM2 climate model scenario, while the upper maps show results using the MIROC5 climate model scenario. Appendix B provides details of how these figures were created.
Figure 3. As for Figure 2, but results are for the reptile group.
Figure 4. As for Figure 2, but results are for the amphibian group.
Figure 5. As for Figure 2, but results are for the vascular plant group.
3.2 Composite measures of change in ecological environments

The two alternative ways of presenting the composite ecological change measure are shown in Figure 6 to Figure 9. The range stretch (upper map series in each case below) scales each measure equally across the complete range of possible ecological similarity values (0 to 1). The maps are comparable with each other and with the national map and data series (Williams et al., 2014e; 2014f).

The second method (range-adjusted stretch, lower map series) scales values between no change (0 in for disappearing and novel ecological environments, and 1 for potential degree of ecological change) and the maximum value (minimum for potential degree of ecological change). Maximum and minimum values were identified across the range of data series for Tasmania (across the four biological groups and two climate models) so a consistent stretch (0-255) could be applied. In this case, the maximum data value for novel and disappearing ecological environments is 0.62, and the minimum value for potential degree of ecological change is 0.38. The range-adjusted stretch method helps clarify where changes are occurring in Tasmania and is consistent across this data series, but is not directly comparable with the AdaptNRM national maps and data series.
Figure 6. Composite ecological change for the mammal group showing results using the mild MIROC5 (left) and hot CanESM2 (right) climate model. The first method (range stretch; upper maps) scaled values between 0 and 1. The second method scaled values differently to accentuate where changes were occurring (range-adjusted stretch; lower maps). Legends show the ecological similarity values over which the RGB integer values were stretched. Appendix B provides details of how these figures were created.
Figure 7. As for Figure 6, but showing results for the reptile group.
Figure 8. As for Figure 6, but showing results for the amphibian group.
Figure 9. As for Figure 6, but showing results for the vascular plant group.
3.3 Extent of change in ecological environments

For each biological group and scenario, the histograms in Figure 10 to Figure 13 depict the area in km² of ecological change projected to occur between the 1990 baseline and 2050 future. These figures provide an alternative means of viewing the results. The dominant trend of little change is evident in the projected degree of ecological change series, where the area of projected similarity is generally high. While these figures do not show the spatial location of where change is projected to occur, they more readily depict the area of a given magnitude of change. They highlight also that the area of disappearing and novel ecological environments projected to occur by 2050 broadly follows the same trend within each biological group, with the hot CanESM2 scenario consistently suggesting greater change.
Figure 10. Histograms showing the number of raster cells with values denoting either increasing change (the measure of disappearing and novel ecological environments) or decreasing similarity (the measure of potential degree of ecological change) along the x axis for the mammal group.
Figure 11. As for Figure 10, but showing results for the reptile group.
Figure 12. As for Figure 10, but showing results for the amphibian group.
Figure 13. As for Figure 10, but showing results for the plant group.
3.4 Comparison with national AdaptNRM data series

Figure 14 to Figure 17 demonstrate the added information provided by the contextual analyses for Tasmania. Where change was projected to be greater by the National analysis, the differences are negative (shown in shades of red), and where change in Tasmania is greater, the differences are positive (shown in shades of yellow). These maps show a trend of reduced change compared to the National analysis across the biological groups and scenarios, with the exception of the mammal model which predicts mostly greater change. Differences are generally concentrated around the coast and Bass Strait Islands, and vary in strength between the two climate scenarios.

Figure 14. Maps showing differences in raw values between the Tasmanian focussed measures of disappearing and novel ecological environments, and those for the continental scale analysis for the mammal group. Differences were calculated by subtracting the Australian-based values from the Tasmanian-based values. Accordingly, where greater change was projected under the continental analysis, differences are negative (red), whereas greater change projected under the Tasmanian analysis are positive (yellow).
Figure 15. As for Figure 14, but showing results for the reptile group.
Figure 16. As for Figure 14, but showing results for the amphibian group.
Figure 17. As for Figure 14, but showing results for the plant group.
3.5 Ensemble measure for composite ecological change

Ensemble measures of *composite ecological change* show projected change averaged across all four biological groups, and separately for the two climate scenarios applying the two RGB stretches (Figure 18). Consistent with the individual models, the overall trend is of little change (see the range stretch results, upper panels). The range-adjusted stretch (lower panels) highlights where change is projected to occur, and is strongly influenced by the signal of the reptile and vascular plant models (see component measures: Figure 7 and Figure 9, respectively). The ensemble range-adjusted stretch was calculated using the same values as for the composite ecological change measures for individual groups, and so are all comparable.

![Figure 18. Ensemble composite ecological change for the range stretch (upper) and range-adjusted stretch (lower) methods applied to the mild MIROC5 (left) and hot CanESM2 (right) climate scenario. Appendix B provides details of how these figures were created.](image)
3.6 List of datasets and maps and how to access these

The contextual analysis presented here has resulted in 73 datasets provided in the data collection for public access on CSIRO’s data access portal; detailed in Appendix D and summarised in Table 1. These data extend the analyses provided in the AdaptNRM series (Williams et al., 2014g) by including ensemble versions of each component measure used to generate the ensemble composite ecological change measures. The range-adjusted stretch method of deriving the composite ecological change measure is also new to enhance visualisation of contrasts among biological groups and climate scenarios for the Tasmania context analyses.

Table 1. Summary list of datasets, maps and related files (see Appendix D for details).

<table>
<thead>
<tr>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component measure raster files (24 datasets)</td>
<td>Raster file for each component measure (disappearing, novel, or projected ecological change) for each biological group and climate scenario combination.</td>
</tr>
<tr>
<td>Ensemble component measure raster files (6 datasets)</td>
<td>Raster files for each ensemble mean of the biological groups for each component measure (disappearing, novel, or projected ecological change) and climate scenario.</td>
</tr>
<tr>
<td>Composite ecological change raster files, range stretch (8 datasets)</td>
<td>Composite ecological change raster file (multiband raster) for each biological group and climate scenario using the range stretch.</td>
</tr>
<tr>
<td>Composite ecological change raster files, range-adjusted stretch (8 datasets)</td>
<td>Composite ecological change raster file (multiband raster) for each biological group and climate scenario using the range-adjusted stretch.</td>
</tr>
<tr>
<td>Difference maps (16 datasets)</td>
<td>Raster files showing the differences between projections for disappearing and novel ecological environments for the National analyses and the current Tasmanian analyses for each climate scenario.</td>
</tr>
<tr>
<td>Ensemble composite ecological change, range stretch (2 datasets)</td>
<td>Ensemble composite ecological change raster file (multiband raster) for each climate scenario using the range stretch.</td>
</tr>
<tr>
<td>Ensemble composite ecological change, range-adjusted stretch (2 datasets)</td>
<td>Ensemble composite ecological change raster file (multiband raster) for each climate scenario using the range-adjusted stretch.</td>
</tr>
<tr>
<td>Areas of projected ecological change (1 dataset)</td>
<td>Spreadsheet of the areas of projected ecological change in km² for each biological group and climate scenario combination.</td>
</tr>
<tr>
<td>Report images</td>
<td>High resolution (600 dpi) *.png files for each of the results images published in this report.</td>
</tr>
<tr>
<td>Map posters using Tasmania AdaptNRM template (8 maps)</td>
<td>A series of posters displaying the datasets in the context of Tasmania for comparison with the AdaptNRM cluster map series.</td>
</tr>
</tbody>
</table>
Conclusions

The analyses reported here provide additional context for the State of Tasmania over and above that provided in the Australia-wide AdaptNRM series of national measures (Williams et al., 2014g). Two of the key measures of change, novel and disappearing ecological environments, are contingent on the scale of analysis. As these measures are calculated relative to all land pixels in the AdaptNRM analyses, an implicit assumption is that biological dispersal can occur across the geographical extent of the analysis over the period of the scenario (e.g. over 60 years from 1990 to 2050). To contextualise the results for the isolated region of Tasmania, these measures were calculated for that extent only.

The contextualised analyses suggest reduced change relative to the National models for all biological groups and across both scenarios, with the exception of the mammal model which projects greater change to occur under a future climate scenario for 2050. The dominant trend of little change was apparent in the Tasmanian analyses as for the National context. The similarity in result reflects the high degree of ecological similarity projected between a location in 1990 and under a future climate scenario by 2050 for the potential degree of ecological change, which is a local measure that is not spatial-context dependent. Marked differences are apparent between ecological projections forced by the two different climate models. These are most likely due to the substantially different climate scenarios underpinning the analyses, and the nature of biotic correlations with these. However, teasing out the proximate environmental and climate drivers of the observed patterns is beyond the scope of this work.

A challenge in communicating the results of the analyses reported here is to create objective visualisations which portray the dominant trends – in this case little projected ecological change – but which also depict where change is projected to occur. While the magnitude and extent of land projected to undergo change is less than that projected to remain similar (see histograms Figures 10-13) it is indicative of a trend which is likely to continue and magnify as climate changes intensity beyond the future climate scenario for 2050 used here. For this reason, we presented two methods of viewing the composite measures of ecological change; the first shows the dominant trends and best represents the magnitude of change projected to occur (the RGB range stretch), while the second better highlights within Tasmania where changes will occur and in what direction (range-adjusted stretch). We ensured that the second method (range-adjusted stretch) enabled comparisons to be made across the biological groups for this data series, so that the results could be interpreted consistently, but emphasize that these results are not comparable with the National analyses of composite ecological change. The shades of red, green, and blue in the range-adjusted stretch images (Figures 6-9) are scaled to pronounce where changes are projected to occur, and should be interpreted alongside those created using the range stretch.

An important caveat of the analyses reported here is that while the calculation of disappearing and novel ecological environments has been contextualised for Tasmania, they are based on National context generalised dissimilarity models (GDMs) of compositional turnover in the four biological groups. Contextualising the underpinning GDMs would be an important step in further increasing the value of the analyses for the State of Tasmania. Further, a set of finer resolution
analyses is possible (e.g., 3 arc second / ~ 90m gridded) with the use of newly produced spatial layers for Tasmania. By better representing the responses of biological groups to finer-grained variables used in the underlying models of compositional turnover, additional insight should be gained.

We have not provided interpretations of the ecological meaning of these measures beyond simple summaries of the magnitude and extent of change that is portrayed. Nor have we attempted to suggest how the results might be interpreted for adaptation planning. For guidance on how to use the models in planning we refer readers to the AdaptNRM series of reports and supporting materials available at www.adaptnrm.org. Five modules are designed to support climate adaptation planning and decision-making for regional NRM. The first by Rissik et al. (2014) outlines four main challenges that NRM planners face in climate adapting management practices to prepare for projected scenarios of change. The second by Scott et al. (2014) shows how weeds and invasive plants are likely to respond to climate change and how to plan for weed management. The third, by Williams et al. (2014g), upon which this contextual analysis for Tasmania is based, presents a new way to view the magnitude, extent and type of changes in biodiversity using community-level modelling with examples on how the measures might be used to support planning. It also acts as a reference for the more integrated measures supporting decisions about priority adaptation actions, which is presented in the fourth report in the series by Prober et al. (2015). The material provided by Prober et al. (2015) supports more strategic and implementation phases of planning, including discussion of climate-ready goals for biodiversity conservation and potential options to achieve them. Examples are included to show how this information can be used for specific tasks in planning. Finally, the shared learnings by Doerr et al. (in prep.)³, documents principles to enable collective development of planning products and deeper collaborations inspiring innovative solutions to the challenges posed by rapid climate change.

Further insights supporting the use of the contextual analyses for Tasmania presented here, may be drawn from the collective wisdom of local ecologists and NRM planners working together. The 'Biodiversity Adaptation Toolbox' developed by Prober et al. (2015) is designed as a conversation starter to assist such exploration of planning and implementation options alongside models and projections of ecological change.

The data presented in this report and supporting materials (Harwood et al., 2016) can be accessed online at https://data.csiro.au/ (see Appendix D for details).

³ http://adaptnrm.csiro.au/shared-learning/
Glossary of acronyms and technical terms


**Biodiversity surrogate**: proxy information for assessing biodiversity complementarity of places. A common hypothesis is that the pattern of species "turnover" over different geographic areas for one taxonomic group will indicate the pattern for all biodiversity.\(^4\)


**Community-level model**: 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.

**Composite ecological change**: 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.

**Compositional turnover**: 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.

**DAP – Data Access Portal**: CSIRO’s data repository, [https://data.csiro.au](https://data.csiro.au)

**Disappearing ecological environments**: present-day ecological environments scaled by ecological similarity that may become absent from the entire continent in the future. 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.

**Ecological environments**: the biologically-scaled environments derived from using the GDM method of community-level modelling.

**Ecological similarity**: 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).

**Ensemble**: a related group of measures are averaged or statistically combined in some way to create an overall measure. For example, a climate ensemble may be derived by running many slightly different models and then generating an average to allow an understanding of the variability and level of concordance.

**Ensemble composite ecological change**: a measure of the average of composite ecological change across biological groups. To derive this measure, the arithmetic mean of each of the three component measures of composite ecological change is calculated across all biological groups for each climate scenario.

**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

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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.

**MIROC5**: The MIROC5 climate model is Version 5 of the atmosphere-ocean general circulation model cooperatively produced by 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 environments**: possible new ecological environments scaled by ecological similarity that may arise in the future but which doesn’t exist anywhere within a specified region at present. Novel ecological environments could be used to encourage collaboration, for example to ensure that assembling ecosystems are managed to avoid dominance by invasive species introduced by human activity.

**Potential degree of ecological change**: measures ecological similarity between a baseline and future climate for every location within a specified area: the lower the score of ecological similarity, the greater the potential for compositional change in biodiversity. Maps depicting the Potential degree of ecological change could be used in climate change risk/vulnerability assessments to better incorporate the interactions between climate exposure and sensitivity.

**Range stretch**: a method used to convert and scale values across the range of RGB integer values in order to create an RGB image. The range stretch linearly stretches values of a component of composite ecological change between the minimum and maximum possible values (i.e., between 0 and 1). In this way, the range stretch best reflects the magnitude and overall direction of projected change, and is comparable to RGB images in the AdaptNRM series.

**Range-adjusted stretch**: a method developed to convert and scale values across the range of RGB integer values in order to create an RGB image. The range-adjusted stretch linearly stretches values of a component of composite ecological change between the value representing no change (0 in the case of disappearing and novel ecological environments, and 1 for projected ecological change), and the value representing the maximum recorded change. The latter value is the highest value recorded for disappearing and novel ecological environments, and the lowest value recorded for projected ecological change (where 1 represents no change). To ensure comparability across biological groups and between climate scenarios, standard values were used to stretch values between. These were selected as the maximum or minimum value of change recorded in any of the data series. The benefit of the range-adjusted stretch is to highlight where and in what direction change is projected occur. It is not comparable to RGB images in the AdaptNRM series which were developed using the range stretch method across all possible values (0-1).

**RCP – Representative Concentration Pathway**: four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its Fifth Assessment Report (AR5) for climate modelling and research. They describe possible future climates, all of which are considered plausible depending on emission levels 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).

**Vascular plants**: 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). The model of vascular plants used in this report included species of fern, gymnosperm and angiosperms.

**Other terms**: see also the glossary of terms in the AdaptNRM report “Implications of climate change for biodiversity: a community-level modelling approach” (Williams et al., 2014g).
Appendix A Biodiversity Analyses

Biological data were compiled from the Atlas of Living Australia and ANHAT, by extracting and filtered the data to correct for invasive species, incorrect records and synonym names for the same species. Best-available environmental data at 9 second resolution across Australia were compiled, including climate, substrate and landform variables. Climate surfaces were calculated for both present (1990:1976-2005) and future (2050:2036-2065) climates using a consistent methodology. Generalised Dissimilarity Modelling was used to statistically fit the observed Sorenson dissimilarity in species composition between pairs of sites to environmental gradients, providing coefficients for the biotic-scaling (transformation) of each environmental layer used in the model (henceforth ‘transformed grids’).

GDM-transformed environmental grids are in units of ecological distance ($\Delta E$), such that the difference in value between any two grid cells ($i,j$) for a given layer ($x$) represents the contribution to ecological distance between the two cells for that layer. By summing the absolute differences within all the transformed layers ($\sum_{x} |x_i - x_j|$), we obtain the modelled $\Delta E$ between the two cells. By applying a negative exponential back-transformation, we can then calculate the modelled Sorenson compositional similarity ($s_{ij}$) between the two cells (Equation 1). The intercept term, or offset $o$, cancels out and so can be ignored for analyses working across time periods.

$$s_{ij} = e^{-\Delta E} = e^{-\sum_{x} |x_i - x_j| + o} \quad \text{[Equation 1]}$$

Taking two ‘stacks’ of transformed grids, one for the present and one for the future, we can compare each cell in either of the time points with all the cells in both its own and alternative time point. For the 9” grid of Tasmania used in these analyses, this requires around 2.4 million comparisons.

The modelled compositional similarity can be used to scale environmental change. However, under climate change, in situ persistence of species, ecological lag effects, local adaptation of species and limited dispersal will act to limit the loss of species from a site. This is offset by the potential inability of suitable new species to colonise the site including due to negative biotic interactions that may preclude population establishment. In practice, therefore, we do not necessarily expect this ecological change to be realised, but to provide an indication of the potential ecological drivers of change acting on locations.

S: Potential degree of ecological change: By calculating the similarity between the same locations (grid cells) at two points in time using equation 1, we obtain the projected similarity as a function of changing climate.

$$DS_i = \max_{j=1}^{n_{\text{present}}} \left( s_{ij}, s_{ji} \right) \quad \text{[Equation 2]}$$

DS: Disappearing ecological environments: The state of each cell in the present is compared with the future state of all cells. The similarity of the most similar cell is recorded, wherever it is found (Equation 2).

NS: Novel ecological environments: The state of each cell in the future is compared with the present state of all cells. The similarity of the most similar cell is recorded, wherever it is found (Equation 3).
\[ NS_i = \max_{j=1}^{n} \left( \frac{s_{future, present}}{s_j} \right) \]  

[Equation 3]

In combination these three metrics can be used to describe the character of change at a site, from low change in a novel direction, to high change towards a more familiar environment. However, it is not possible to directly ascertain what a future environment would look like from these metrics, which would require a map for each grid cell.
Appendix B Visualisation of composite results

To enhance the visualisation of output raster files, raster values may be stretched across the range of red, green, and blue (RGB), colour values (range: integer values between 0 and 255). In doing so, the differences among values are pronounced by using the full range of colour intensity. Often, raster values are stretched linearly between their minimum and maximum values. It is possible to assign one RGB channel (red, green, or blue) to each of three bands of a multi-band or composite raster file. Because each cell has multiple values in a composite raster, a resulting RGB image is an additive mixing of the three values to obtain a final colour per cell. The values for each band can be stretched between their minimum and maximum to enhance visualisation, and the colours of the final RGB image will correspond to the influence of each band. Here, we combined each S, D, and N raster for each biological group and climate scenario combination into a composite raster. Using Equation 4, we linearly stretched the values across the range of RGB values selecting minimum and maximum values according to the method applied (range stretch or range adjusted stretch – see main text).

$$\text{stretch} = \frac{255 \cdot (x - \text{minimum})}{\text{maximum} - \text{minimum}}$$  \hspace{1cm} \text{[Equation 4]}

where x denotes a raster cell. We assigned the red channel to the D band (disappearing); the blue channel to the N band (novel); and the green channel to the S band (potential similarity). Resulting RGB images of the composite rasters depict whether a location’s biologically scaled environment is expected to disappear, be novel, or be similar under the corresponding future climate scenario.

Spatial processing was performed in R using the ‘raster’ package. The following function was used to stretch composite raster values:

```r
stretchRGB <- function(img, minmax = NULL) {
  # Summary:
  # stretches values over the range of RGB values
  # Args:
  #   img: raster object in memory
  #   minmax: vector of min/max stretch values (default 0/1)
  # Returns:
  #   RasterLayer

  if(is.null(minmax)) {
    minmax <- c(min(getValues(img), na.rm=T),
               max(getValues(img), na.rm=T))
  }

  temp <- calc(img, fun=function(x) as.integer((255*(x-minmax[1]))/(minmax[2]-minmax[1])))
  # set all values above or below minmax to 0 or 255
  temp_minmax <- c(cellStats(temp, 'min'), cellStats(temp, 'max'))
  if(temp_minmax[2] > 255) {
    temp[temp < 0] <- 0
    temp[temp>255] <- 255
  }

  return(temp)
}
```

Finally, histograms showing the frequency of values in the raw raster outputs were also created. These don’t convey the spatial pattern of change, but the magnitude of projected change is made more apparent.
The following provides instructions detailing how to display a projected composite change raster in ArcGIS as per the images in this report.

1. With the relevant raster loaded, open up the layer properties by right clicking on the layer.
2. In the Layer Properties dialogue box that opens, select the symbology tab (Figure 19).

3. In the left hand column, make sure ‘RGB Composite’ is selected (Figure 19).
4. Change the order of the raster bands so that Band_1 is the red channel, Band_2 is the blue channel, and Band_3 is the green channel (Figure 19).
5. Change the Stretch Type to ‘Minimum-Maximum’ (Figure 19).
6. Change the Statistics option to ‘From Custom Settings (below)’ (Figure 19). This will expose the button ‘Load XML’ (see Figure 20). Hit this button, and navigate to the corresponding .xml file (ArcGIS_band_settings.xml, available from https://data.csiro.au/dap/). See Appendix D for further details).
7. Once you have selected the .xml file, a dialogue box will appear with a selection of band order. Leave the defaults, and hit OK.
8. Hit OK in the original dialogue box.

The following provides a minimal example of how to display a projected composite change raster in R, as per the images in this report.

```r
# get raster library if need be and load
if (!require(raster)) install.packages('raster')

# open a file - assumes here that the file is saved in the C drive
P_CAN_SND_RA <- stack('C:/TP_CAN85_SND_RA.tif')

# plot as RGB image using raster::plotRGB function
plotRGB(P_CAN_SND_RA, r = 1, g = 3, b = 2, maxpixels = ncell(P_CAN_SND_RA))
```
Appendix C Calculation of 9s gridded climate and projected climate changes surfaces

Climate surfaces for the present were based on the ANUCLIM 6.1 (Xu and Hutchinson, 2011; Xu and Hutchinson, 2013) 30 year average climate surfaces for Australia, with elevational lapse rate correction applied over the 9s GEODATA digital elevation model (Hutchinson et al., 2008). Radiative correction derived from the same DEM was applied to radiation and maximum temperature before calculation of evaporation, using the CSIRO TerraFormer software (Harwood et al. in Reside et al., 2013). Projected future climates were generated by applying within-model changes (e.g. MIROC5 2036-2065 – MIROC5 1976-2005) calculated at the native general circulation model grid resolution to these current surfaces, using ANUCLIM 6.1 prior to radiative adjustment. Summary statistics for each variable were then calculated (Figure 21).

Figure 21. Calculation of present and future climate surfaces using a consistent approach for all time points.

An approach was taken which minimises the data requirements for projection of climate, whilst maintaining consistency of calculation across time points. We followed Allen et al. (1998) FAO 56 p 76 “Calculation procedures with missing data” and Example 20 p77-78, which outlines standard procedures for the estimation of Ep (ET0) as a function of monthly average daily maximum and minimum temperatures. Due to concerns as to the validity of derived or projected wind and humidity variables, we substitute the Priestley-Taylor formulation for the Penman-Monteith equation. Whilst FAO 56 Eq 50 (Hargreaves) is used for the estimation of Rs, we used the Samani
(2000) derivation of KT ($kRs$) to deal with geographical variation in KT. Once $Rs$ has been estimated from diurnal temperature range, we adjust both radiation and maximum temperature using the ratio $S$ (shaded inclined radiation/unshaded flat surface radiation, calculated in GRASS using the r.sun routine) following Wilson and Gallant (2000).

All variables $T_{max}$, $T_{min}$, $Ppt$, $Rs$, $Ep$, $Ea$ and $WD$ ($Ppt-Ep$) are calculated monthly. These are then summarised as: Annual total or mean, Maximum monthly value, Minimum Monthly value, Maximum rate of month to month change and Minimum rate of month to month change. Interactions between variables such as temperature of the wettest month are avoided for climate change sensitivity reasons.

**Potential Evaporation ($Ep$)**

Humidity data is difficult to come by, since it is partly a function of local surface moisture. Estimates of humidity as a function of temperature are very unreliable for much of the tropics. Consequently we would be forced to make extreme assumptions about humidity in order to properly incorporate it into the Penman-Monteith formula.

Wind data is similarly sparse, but is also subject to topographic funnelling leading to strong local heterogeneity. Whilst this can be modelled for the present, the data has high commercial value and is not readily available. Projections of future wind by GCMs are non-standard and subject to local topographic interactions which would require further modelling. The use of a uniform 2m-s wind speed effectively removes the contribution of wind to the Penman-Monteith formula.

We therefore apply the purely energy-driven Priestley-Taylor formula (Fig. 20) (e.g., Wilson and Gallant, 2000), which requires as inputs $T_{max}$, $T_{min}$, $T_{dew}$ and $Rs$. We estimate $T_{dew}$ as $T_{min}$ which has minimal implications in the Priestley-Taylor approach. In the current algorithm, $Rs$ is derived from diurnal temperature range to ensure consistency between variables at any site/time point.

**Actual Evaporation ($Ea$)**

Two actual evaporation products are produced, a raw modelled output and a remotely sensed adjusted output.

a) Modelled output ($Eamod$). $Ea$ is calculated monthly using the Budyko framework (Budyko, 1958; 1974; Choudhury, 1999) in a bucket model (Pike, 1964) as in Equation 5:

$$E_a = \frac{(V+P)ET_p}{[(V+P)^n + ET_p^n]^{1/n}}$$

[Equation 5]

where $V$ is stored water, $P$, precipitation and recorded as an annual sum. The bucket size $V_{max}$ is calculated as a TWI corrected PAWHC value, according to Claridge et al. (2000).

b) Remote sensing corrected $Eacorr$. Remote sensed $Ears$ in the present is taken as truth. The offset on the Phi axis of the Budyko framework between the modelled $Eamod$ and $Ears$ in the present is used to correct all projected $Eamod$ surfaces (Figure 22). By definition this results in $Eacorr=Ears$ in the present. The calculation is standard for all time points and scenarios.
Future climate scenarios

Future climate was calculated following the ANUCLIM 6.1 approach to generate monthly Maximum and Minimum Temperatures and Precipitation (Xu and Hutchinson, 2011; Xu and Hutchinson, 2013). Monthly change grids for these variables were calculated as within Generalised Circulation Model changes for long term averages centred on the relevant time points. Data were extracted from the CMIP5 database (Taylor et al., 2012) and calculations applied in the native grid resolution, using the following equations:

- \( \Delta T_{\text{max}} = T_{\text{max}} (\text{projected 2036-2065}) - T_{\text{max}} (1976-2005) \)
- \( \Delta T_{\text{min}} = T_{\text{min}} (\text{projected 2036-2065}) - T_{\text{min}} (1976-2005) \)
- \( \Delta P_{\text{month}} = 100 \times \left[ P_{\text{month}} (\text{projected 2036-2065}) - P_{\text{month}} (1976-2005) \right] / P_{\text{month}} (1976-2005) \)
Appendix D Accessing the data


9-second gridded ecological change measures for Tasmania: novel, disappearing and composite

The models underpinning the information presented here were assembled for Tasmania to provide consistent information for regional planning. Relatively fine-grained source data in the modelling (approximately 250m resolution) captures local, topographic and other influences on biodiversity distribution.

The resulting datasets depicting novel and disappearing ecological environments and composite ecological change for mammals, reptiles, amphibians and vascular plants are listed in Table 2 and are available for public download via the CSIRO Data Access Portal (Harwood et al., 2016).

Data are provided in two forms:

1. Zipped ESRI float grids: Binary float grids (*.flt) with associated ESRI header files (*.hdr) and projection files (*.prj). After extracting from the zip archive, these files can be imported into most geographic information system (GIS) software packages, and can be used as other binary file formats by substituting the appropriate header file.
2. GeoTIFF files (*.tif): composite rasters are provided in this file format.

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.
2. Use the search engine to locate the data collection Recommended DAP search term: ‘AdaptNRM Tasmania Biodiversity’.
3. Once you have selected the data collection 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 (see lists in Table 2 and Table 3). Select the files you would like to download, then click ‘download selected files as ZIP archive’. The files are not always immediately available. If files cannot be selected for download by ticking the ‘boxes’, then a request for the data will need to be submitted. To submit a request, enter your email address in the form provided and click ‘request files’. A notification and link to the data will be sent to this email address when the files have been made available. A similar process is required for accessing large collections, and additional instructions will appear in the data tab/window when applicable.
Table 2. List of datasets in the collection on the CSIRO Data Access Portal (Harwood et al., 2016).

<table>
<thead>
<tr>
<th>File name</th>
<th>Title of measure</th>
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<tr>
<td>TM_90_CAN85_D</td>
<td>9-second gridded Tasmania disappearing ecological environments for Mammals 1990:2050 CanESM2 RCP 8.5 (CMIP5) (GDM: MAM_V1_R2)</td>
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<tr>
<td>TM_90_MIR85_D</td>
<td>9-second gridded Tasmania disappearing ecological environments for Mammals 1990:2050 MIROC5 RCP 8.5 (CMIP5) (GDM: MAM_V1_R2)</td>
</tr>
<tr>
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<td>Area_of_change</td>
<td>The area (km2) of ecological change projected to occur between the 1990 baseline and 2050 future climate scenario. Values are provided for each data series in this file.</td>
</tr>
<tr>
<td>readme_filenames</td>
<td>A file with explanations of the different abbreviations used in the file names of the data sets, and of the spatial file formats used.</td>
</tr>
</tbody>
</table>
Table 3. List of map posters in the collection on the CSIRO Data Access Portal.

<table>
<thead>
<tr>
<th>File name</th>
<th>Poster title and citation</th>
<th>Datasets represented</th>
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</thead>
</table>
Table 4 lists two additional sets of files provided with the data collection. These include high resolution versions of the images used in this report. To reduce the publication size of this report, the image resolution was reduced. Higher resolution images are useful when preparing communication materials or presentation.

Additional guidance is provided for reproducing the composite ecological change colours in ArcMap (see Appendix B for details).

Table 4. List of image files published in the report and available for download, and files required to recreate these.

<table>
<thead>
<tr>
<th>File name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Report images</strong></td>
<td>High resolution (600 dpi) source files of the images published in this report. The naming of the files follows the naming of the images as published here. Note that some of the images were split into two parts in order to create them, and are denoted by ‘a’ and ‘b’ in their filenames.</td>
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<tr>
<td><strong>ArcGIS_band_settings</strong></td>
<td>An .xml file used to pass in parameters to ArcGIS in order to display RGB images (composite ecological change datasets) as published here. For further details, see Appendix B of this report.</td>
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</table>
References


