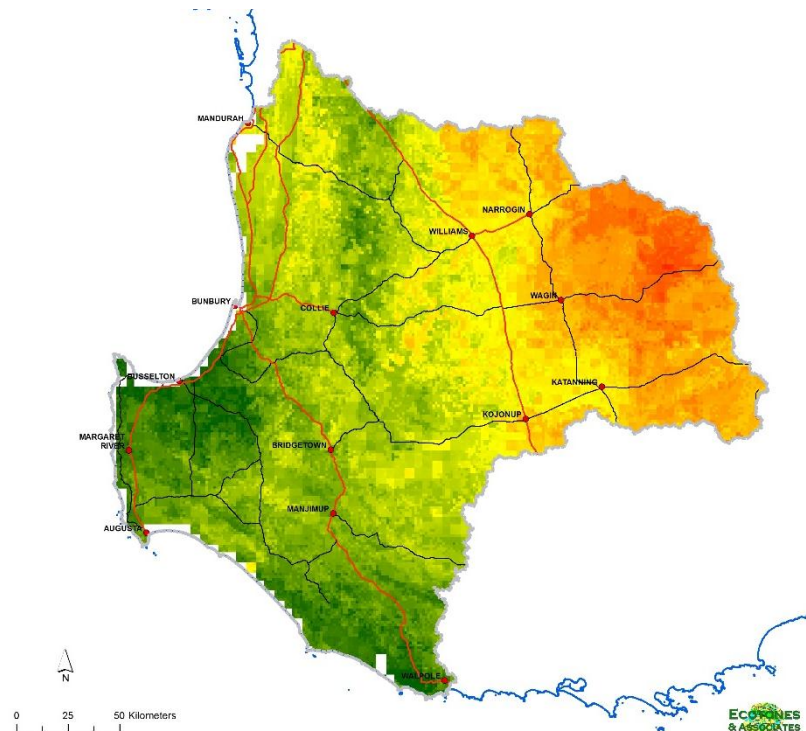


South West Catchments Council
Planning for Climate Change Project

Bio-Climatic Projections & Landscape Linkages Review



Ecotones & Associates

November 2014



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Cover image:

Component C1 - Climate Change Impacts on SWCC.

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Abbreviations

CENRM	Centre for Excellence in Natural Resource Management
CMIP	Coupled Model Inter-comparison Project
CSIRO	Commonwealth Scientific and Industrial Organisation
DEC	Department of Environment and Conservation
DoT	Department of Transport
DPaW	Department of Parks and Wildlife
GCM	Global Climate Model
GIS	Geographic Information System
MCAS-S	Multi-Criteria Analysis Shell
NCCARF	National Climate Change Adaptation Research Facility
NRM	Natural Resource Management
PRNRM	Perth Region Natural Resource Management
SCNRM	South Coast Natural Resource Management
SDM	Species Distribution Model
SWCC	South West Catchment Council

1. INTRODUCTION

Brief & Response

The simple brief for this project extensions is as follows:

- Revise SWCC's existing linkage framework, look at key linkages, and determine where there will be real problems - for example where are lifeboats under increased climate stress.
- Provide a clear explanation of the aggregated Centre for Excellence in NRM data sets and technical analysis that has been generated by Ben Ford at CENRM.
- Place the CENRM data into a framework and show how Climate Change is affecting it for example overlaps, changes, projected species reduction and loss etc.

Questions to be considered in the report include:

- Where would we consider Climate Change and where it impacts assets?
- Where Climate Change is impacting on plants and animals?
- What are the main climate drivers?
- Where is Climate Change going to have the most impact?

The report should include some discussion of the overlaps and refugia datasets, species and directionality, link to existing assets, and provide some re-analysis of connectivity and linkages.

This information is required to guide SWCC's management actions.

Product required by the first week of November 2014.

This Report

Our response to this is to provide the following:

- Presentation and explanation of the major CENRM aggregated datasets.
- Development of three new MCAS-S Components
 - B2 Protection afforded under Existing Tenure
 - B3 Landscape Linkages
 - C1 Climate Impacts on Biodiversity (CENRM/NCCARF Products)
- Development and presentation of combinations of existing and new work to provide climate Impacts on Biodiversity/Assets, including areas where isolated remnants may be particularly affected.

2. SPECIES DISTRIBUTION MODELING (CENRM & NCCARF)

Most of this modeling has been carried out by Ben Ford of CENRM, and the description of the modeling is adapted in part from information provided by him. The animal SDM data was provided by Dr April Reside from James Cook University.

Individual Species

Spatial extent

Environmental layers and species records for the whole of WA were utilised in the analyses, although reporting only covers the South West Mediterranean ecoregion, composed of the Avon Wheatbelt, Coolgardie, Esperance Plains, Geraldton Sandplains, Jarrah Forest, Mallee, Swan Coastal Plain, Warren, and Yalgoo IBRA bioregions, an area of 478,576km². The whole of WA was used in analyses as not all species are restricted to just the SW – therefore their current climatic envelope extends beyond that of SW WA.

Models, scenarios and timeframes

Future climates are based on the average of three GCMs deemed appropriate for WA – CSIRO Mk3, MIROC-M, and MIUB ECHO-G. GCM layers were obtained from the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) website at <http://www.ccafs-climate.org/>.

The climate projections are from the CMIP 3¹ GCMs, as data from CMIP 5 was not available at the time the modeling project started. Low, medium, and high impact scenarios are being modeled represented by B1, A1B, and A2 emission scenarios respectively. These scenarios reflect particular futures and were part of the CMIP 3 datasets. While they have been superseded by the CMIP 5 scenarios (e.g. RCP 8.5) and datasets, the differences in both the climate projects and the scenarios are relatively minimal (Dr Leanne Webb, CSIRO, pers. comm.).

Two timeframes - 2030's and 2080's are being modeled, thus, six models are created for each species (three scenarios at two timeframes). Historical (≈1950-2000) bioclimatic layers are used for the “current” scenario.

In the reporting on these results in this report we have limited our comments and maps to a single scenario – A2 at 2080. This is for two reasons:

- We are limited in time and do not want to provide an overwhelming variety of maps results and options;
- The scenario used represents a fairly severe future climate futures, but one that is increasingly being used as a standard future: at present the lack of emissions reductions put us track for such a future (or worse; some studies such as Reside et al 2013 use RCP 8.5 as the only reporting scenario; this is slightly worse again). The timeframe is the furthest out that we are getting climate projections for the GCMs.

Bioclimatic and environmental variables

Current (≈1950-2000) bioclimatic layers were downloaded from the WorldClim website (<http://www.worldclim.org/current>). Annual mean temperature (BioClim 1) was correlated with eight other bioclimatic layers (at the spatial scale of WA) and was not incorporated into the analyses. In addition to the remaining 18 bioclimatic layers, altitude (also from WorldClim website) and soil (from Geoscience Australia website - <http://mapconnect.ga.gov.au/MapConnect>) layers were included. A spatial resolution / cell size of 2.5 arc minutes (≈5 km) was used in the analyses.

¹ CMIP = Coupled Model Inter-comparison Project. Process used to make the results of the wide variety of GCM comparable.

Species

Species records were obtained from NatureMap (<http://naturemap.dec.wa.gov.au/>) and Atlas of Living Australia (<http://www.ala.org.au>) websites. Only species records with accuracy of 5 km or less were incorporated to create concordance with the spatial layer resolution. Furthermore, as rainfall in SW WA displayed a significant step decrease in 1975, only records from 1976 onwards were included.

Groups which have been modeled to date are – threatened species (mammals, birds, and flora), coastal vegetation, NRM requested / iconic vegetation.

Region Group	No.
WA_Coastal Veg	61
WA_Iconic Veg	35
WA_Reveg Species	27
WA_Threatened Flora	34
Total	157

Table 1: SDM Species Modeling Groups

For each species, the study produced 7 grids: a current modeled distribution, plus 6 future distributions for the three scenarios at two time periods 2030 and 2080. An example of these is given below.

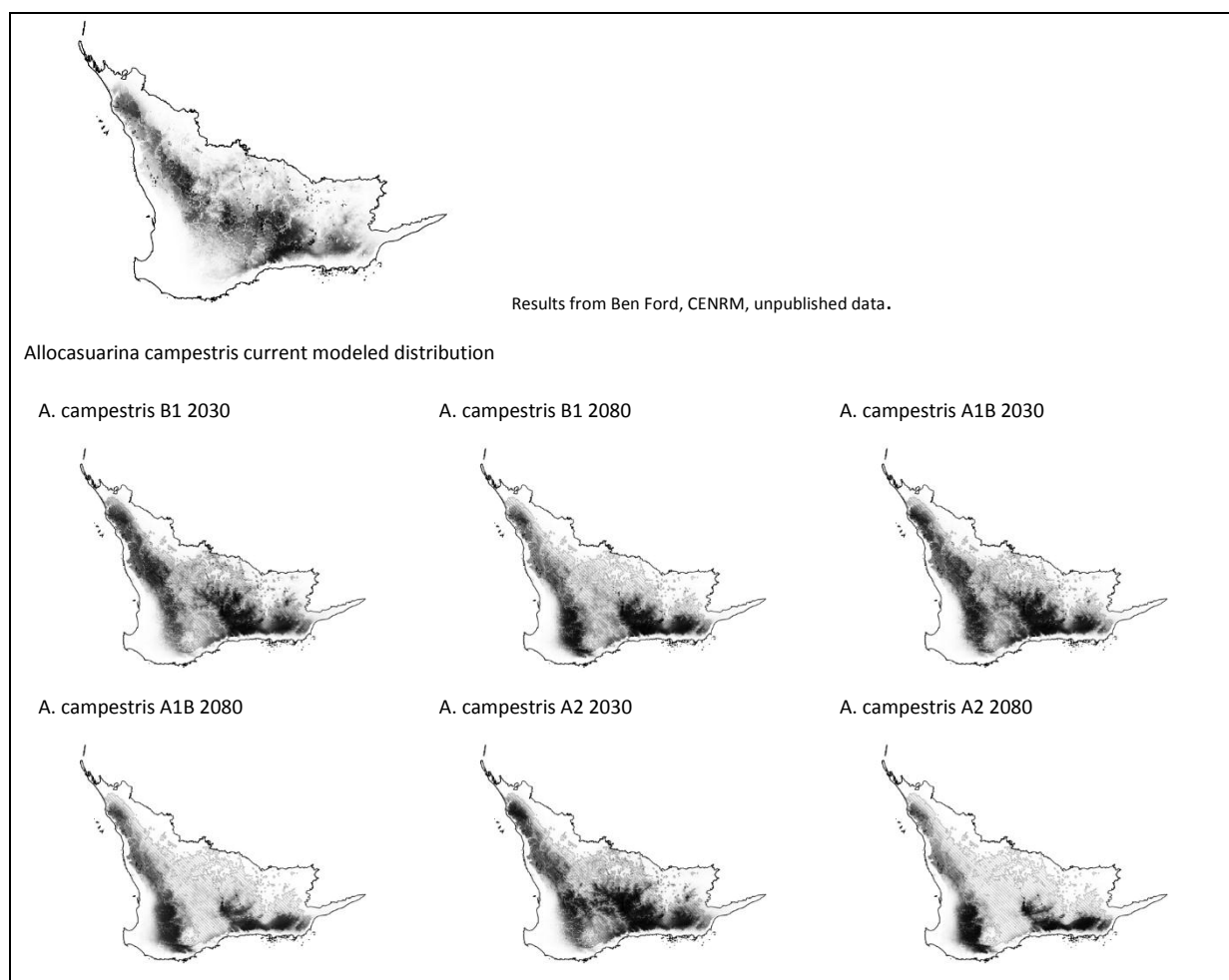


Figure 1: Example SDM Results for a single species (Ben Ford, CENRM)

We have not made use of these individual maps in this study. The range and complexity of this information is not informative in the context of regional biodiversity management decisions. However should SWCC require

projections for specific species, they can refer to the appendices to see which species are covered. All grids will be available when the final information package is provided to the WA NRM groups.

Species Summaries

A number of summary maps were produced based just on the modeled species (important!). These summary indicators included:

- Species Richness (total of all species modeled in each cell) for current and each of the six future scenario/timeframes.
- Number of Emigrants (the projected loss of modeled species for each cell) as a number and as a proportion of the modeled species in the cell; for each of the six future scenario/timeframes.
- Number of Immigrants (the projected gain of modeled species for each cell) as a number and as a proportion of the modeled species in the cell; for each of the six future scenario/timeframes.
- Net Migration (the projected gain/loss of species for each cell) as a number and as a proportion of the modeled species in the cell; for each of the six future scenario/timeframes. Note that a net gain does not preclude significant changes in species composition.

Current Species richness indicates the total number of species modeled which have an indicated current distribution in each cell. The highest cell count is 70 species.

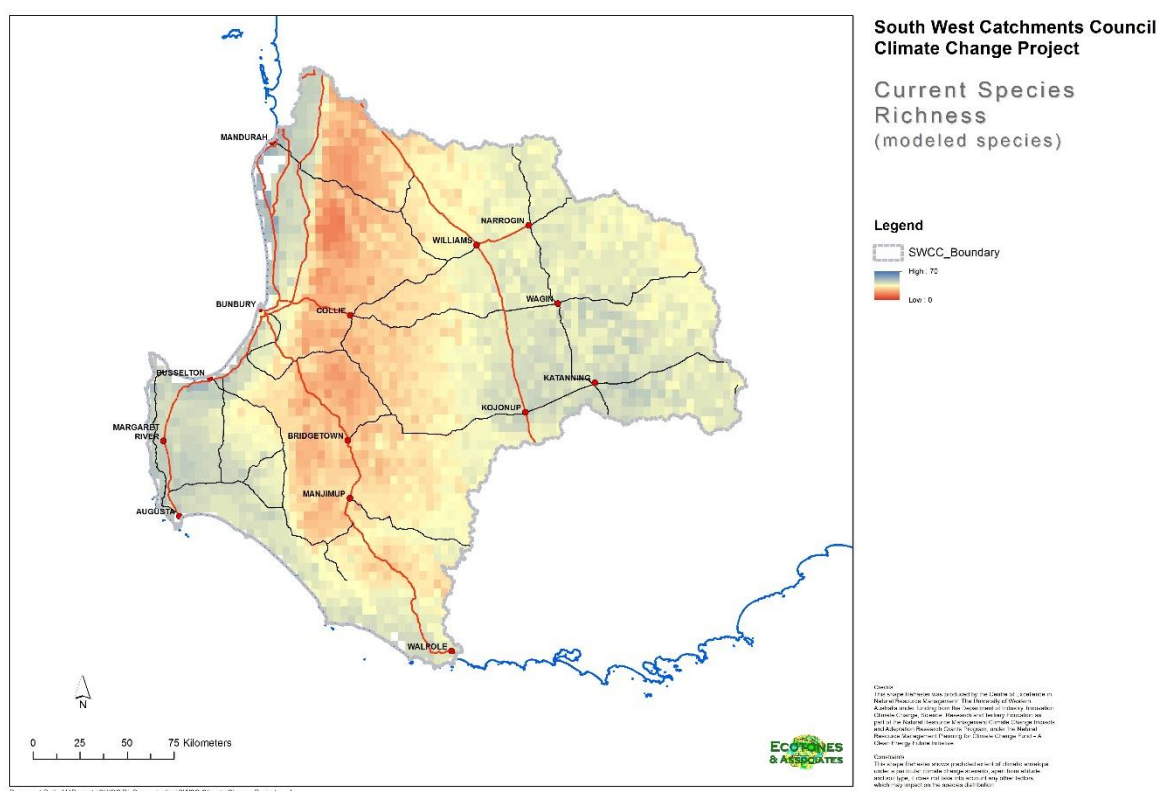


Figure 2: Current Species Richness (SDM)

Species Emigrations indicate the number of current species (as modeled) that are projected to go by the year 2080. The highest cell score for this is 46 – meaning that 46 species are indicated as being lost from a cell. The areas losing most species are concentrated in the east of the region, and for much of this part of the region the species loss as a % of all modeled species is high – in excess of 50% as seen in Figure 4. Note that this is indicative only – the cells do not necessarily have the modeled current species, nor in fact do they necessarily have vegetation cover at all.

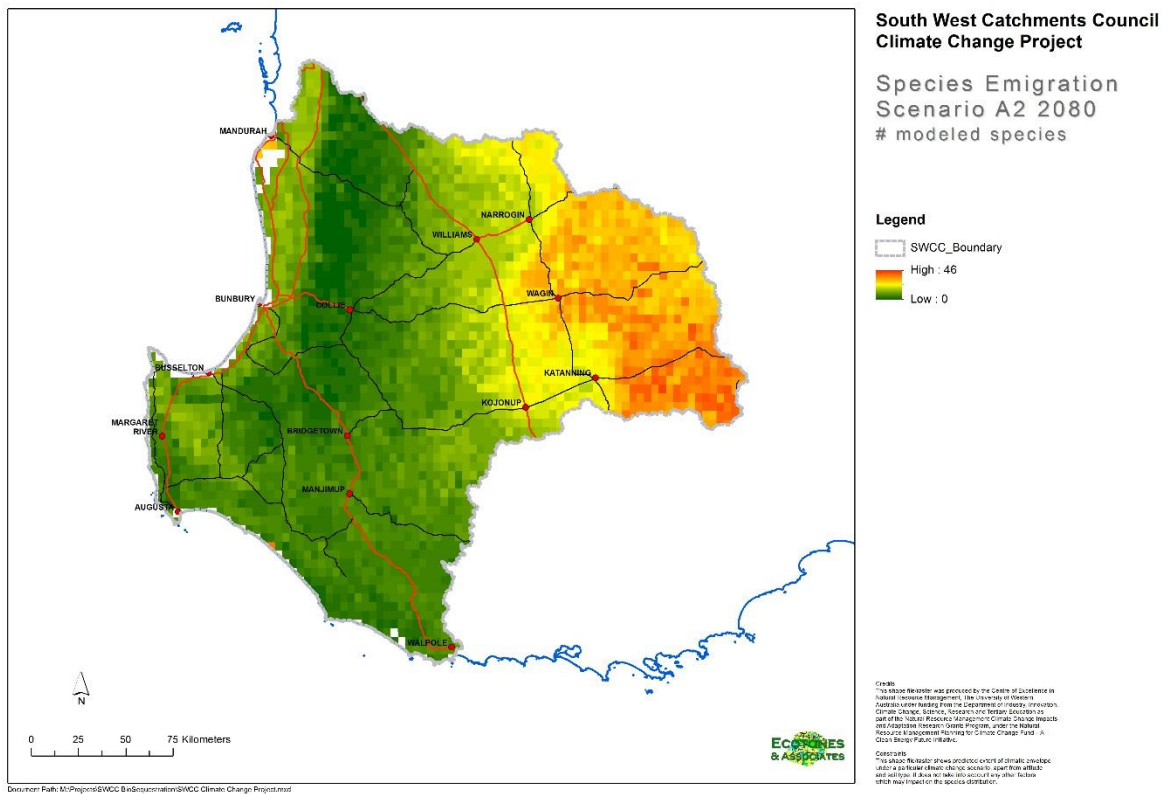


Figure 3: Species Emigration Scenario A2 2080

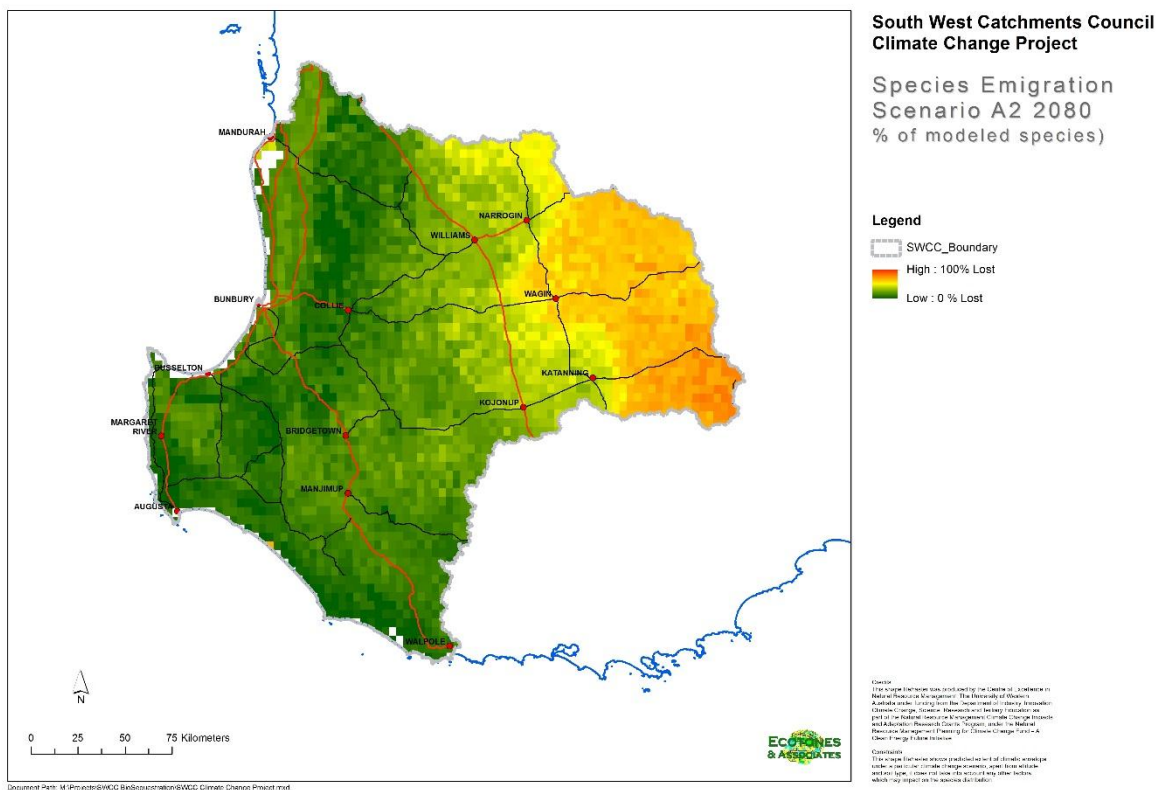


Figure 4: Species Emigration (%) Scenario A2 2080

Species immigration builds on this picture of species loss in the east of the region: immigration is indicated as very low there, but highest in the center and west of the region. The suggestion here is of species moving from

east to west with rainfall decline, illustrated also as net migration in Figure 7. The % immigration in these areas is very high (Figure 6), but this must be taken in the context of relatively low numbers of modeled species.

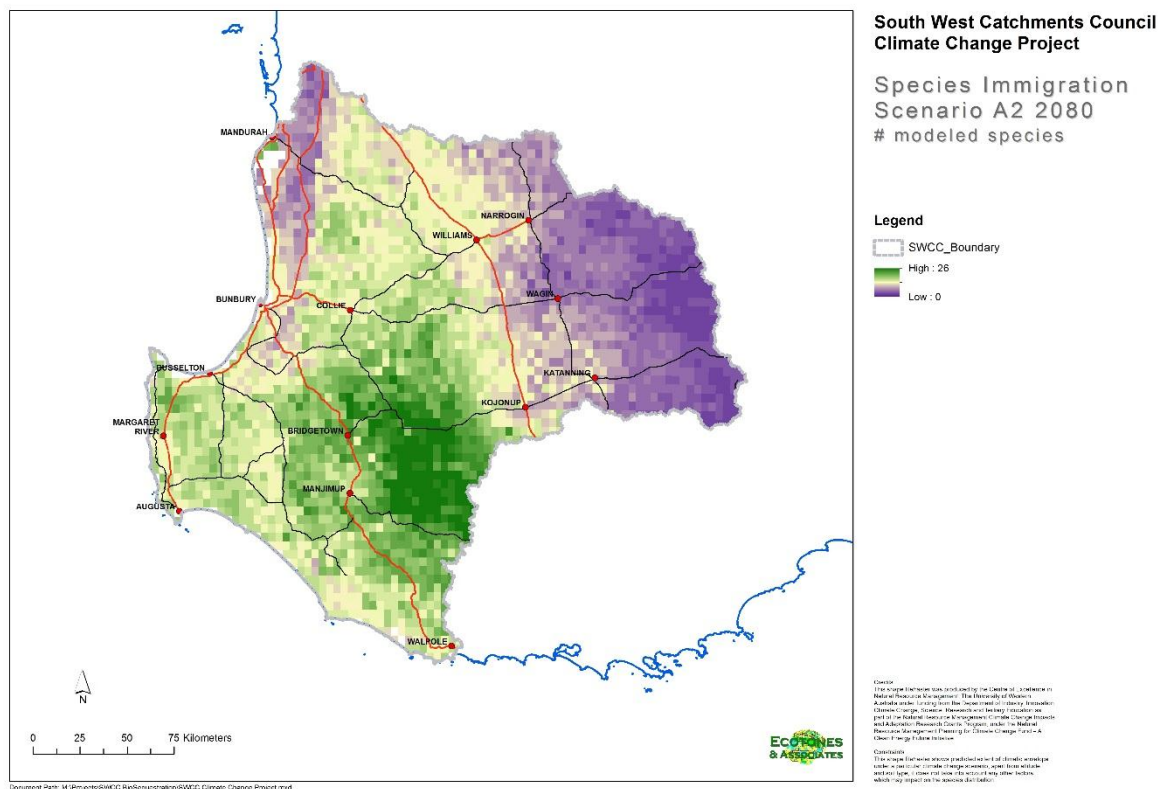


Figure 5: Species Immigration Scenario A2 2080

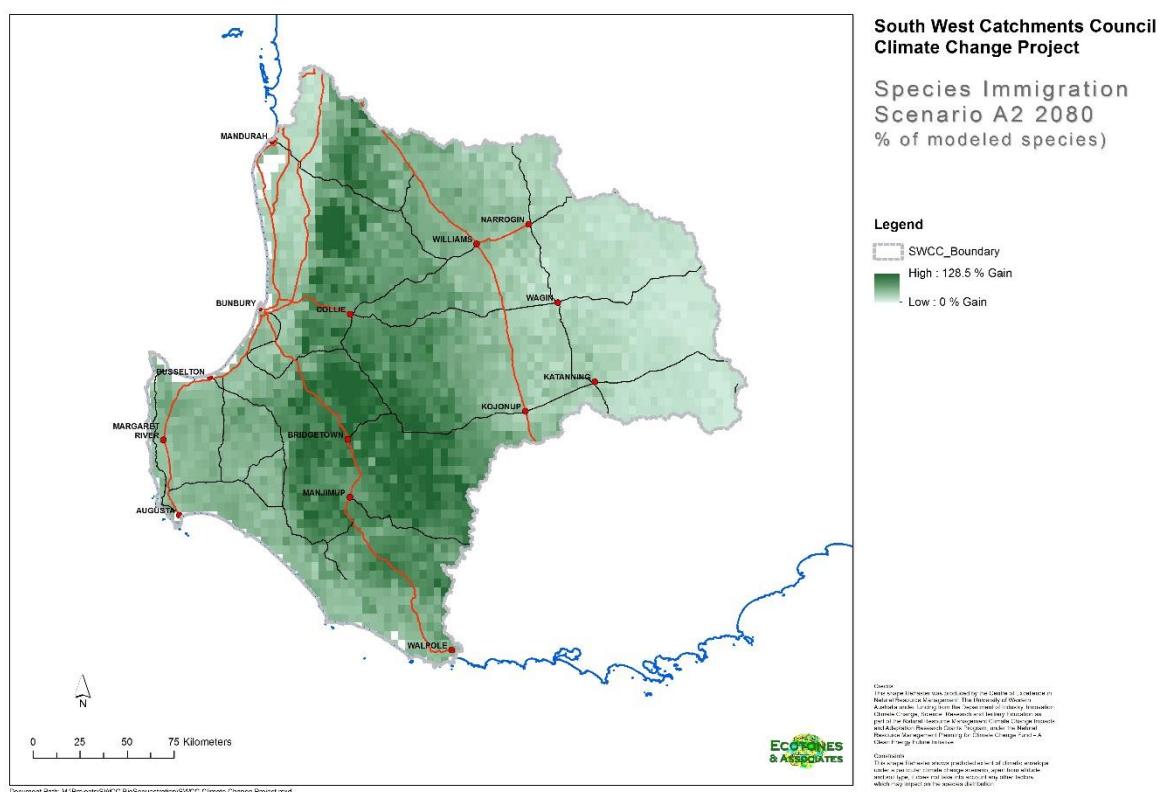


Figure 6: Species Immigration (%) Scenario A2 2080

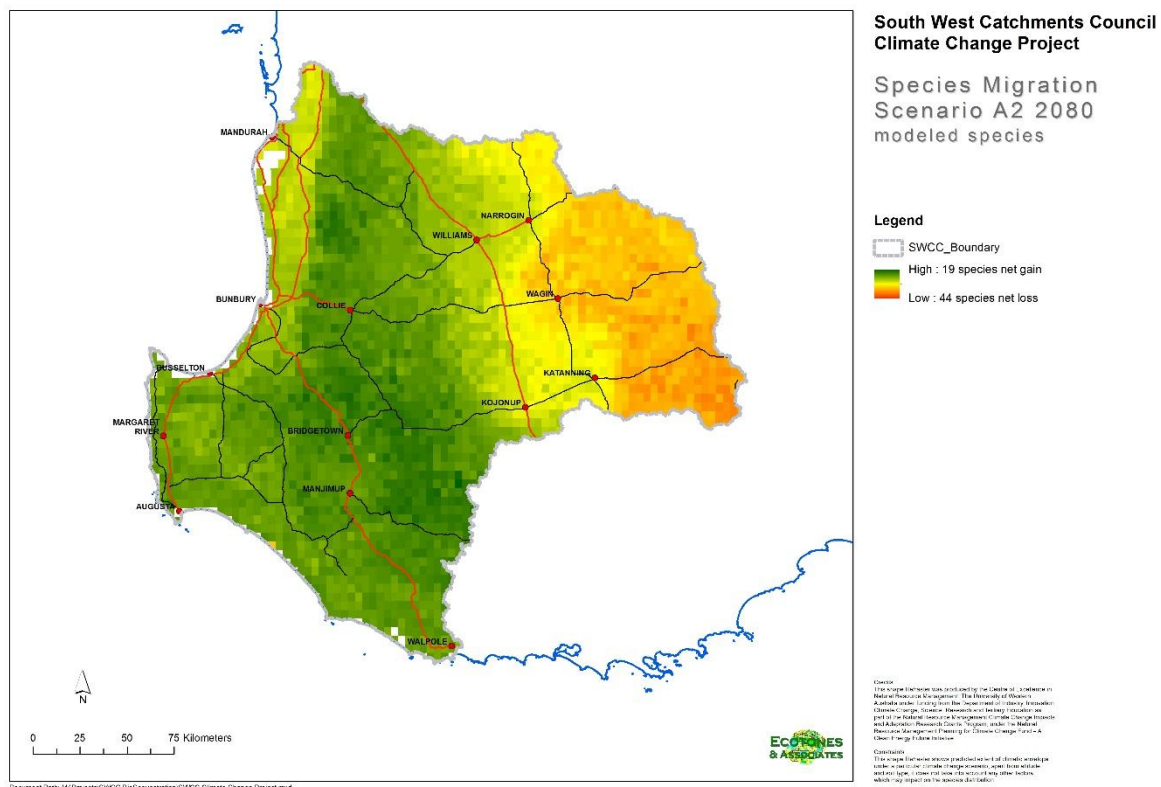


Figure 7: Species Migration Scenario A2 2080

In this study we have used the emigration map as the clearest indicator of change over time. The species richness map indicates the number of current species that were modeled, and can be used in conjunction with the immigrant and emigrant maps to register what they infer.

Refugia Modeling

Species Response Groups

Statistical analysis was carried out by Ben Ford to identify species response groups (species which respond to the same climatic variable). These groups represent species that responded most strongly to the listed climate drivers.

Groups are based on the following (climate) variables:

- Altitude (20 species)
- Maximum Summer Temperature (13 species)
- Mean Summer Temperature (18 species)
- Soil Properties (7 species)
- Summer Rainfall (25 species)
- Winter Rain (36 species)

List of species within each group are provided in the Appendices. Clearly the most significant variable is rainfall followed by temperature, and within these the most important single variable is winter rainfall.

Another set of summary grids were produced by CENRM, based just on the modeled species in each group. These summary indicators included:

- Species richness (total of all species modeled in each cell) for current for each of the six groups.
- Number of Emigrants (the projected loss of modeled species for each cell) as a number and as a proportion of the modeled species in the cell; for each of the six groups for the scenario/time A2/2080.

- Number of Immigrants (the projected gain of modeled species for each cell) as a number and as a proportion of the modeled species in the cell); for each of the six groups for the scenario/time A2/2080.

Winter Rain group

The winter rain group species are concentrated on the coastal plains and in the central parts of SWCC (Figure 8). Notably, there are reasonably few species in the forest areas. Species loss from this group is concentrated in the eastern part of the region, where it is high in species numbers (Figure 9) and % of modeled species.

Summer Rain group

The summer rain group species are concentrated in the east part of SWCC. Species loss from this group is also concentrated in the eastern part of the region.

The small numbers of species in these groups means that the results as % can be misleading. This is well illustrated in Figure 12 showing the group Summer Rain and the emigration (species loss) as a proportion of species modeled. Here the red color for much of the south-west corner indicates that 100% of summer rain effected species will emigrate (be lost) by 2080 - but these numbers relate to low numbers of modeled species, as shown in Figure 10.

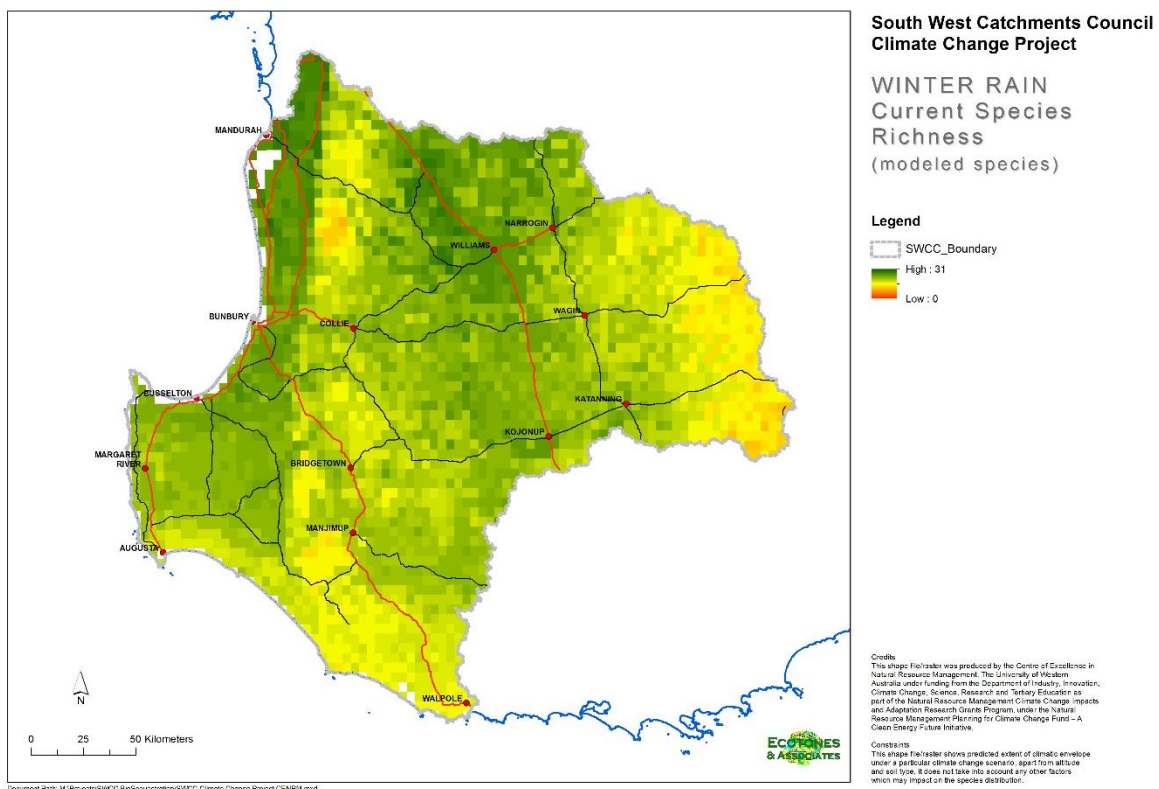


Figure 8: Winter Rain Group – Species richness

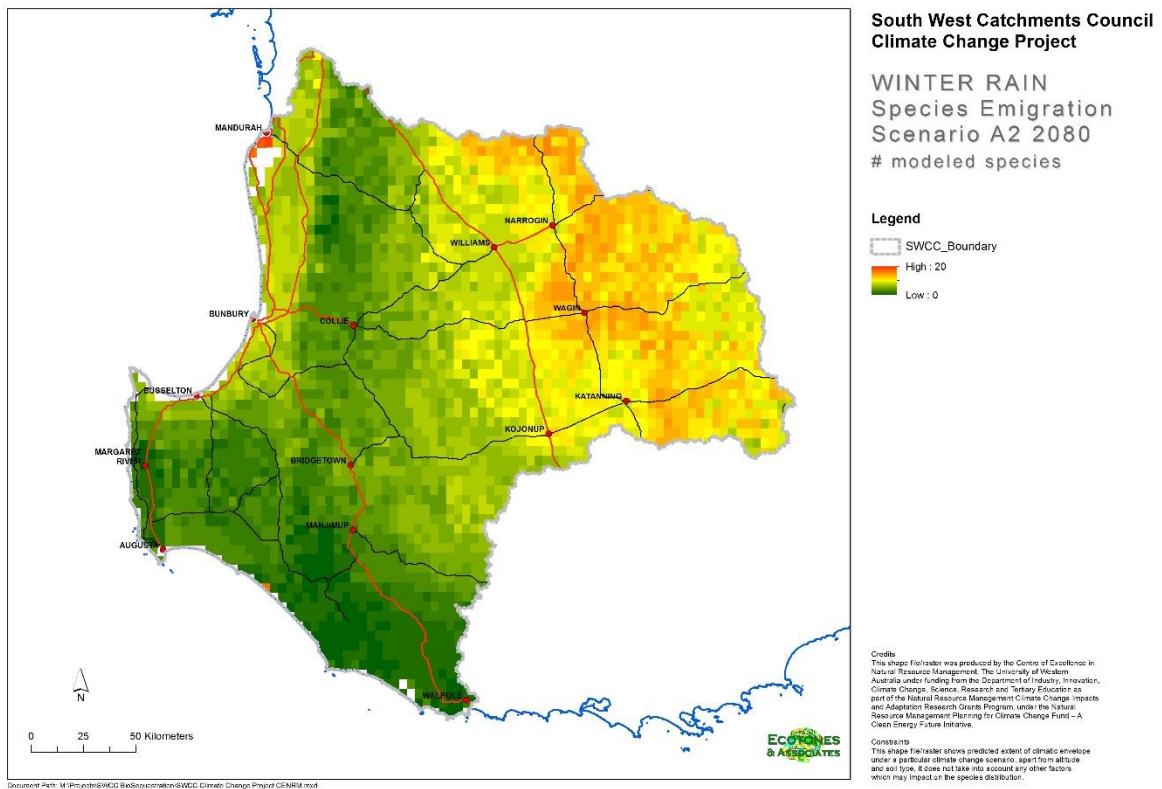


Figure 9: Winter Rain Group – Species Emigration A2 2080

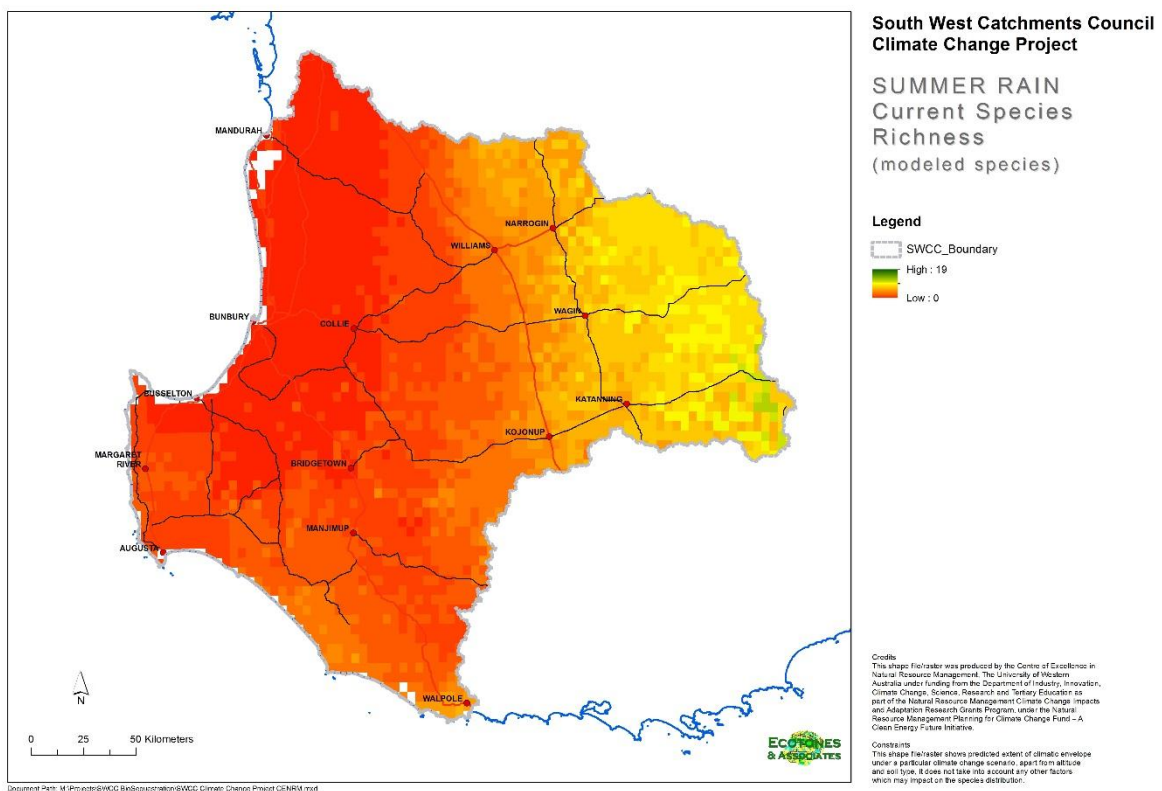


Figure 10: Summer Rain Group – Species richness

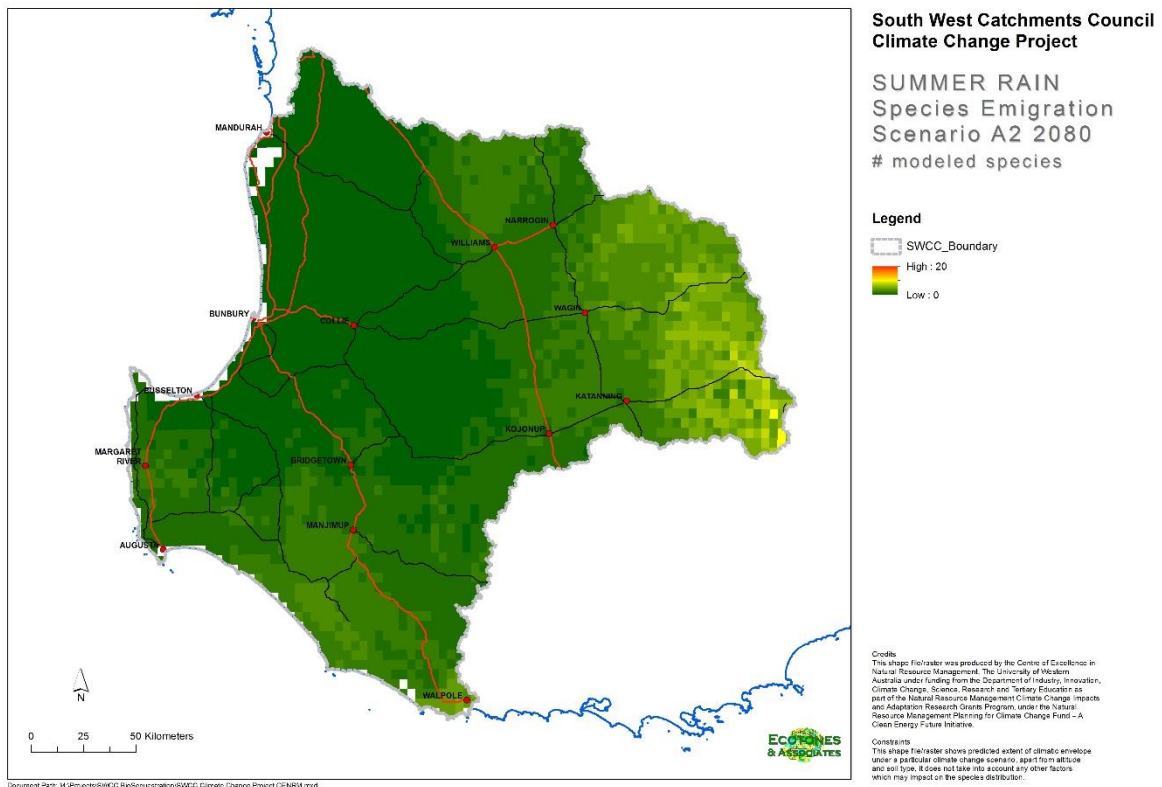


Figure 11: Summer Rain Group – Species Emigration A2 2080

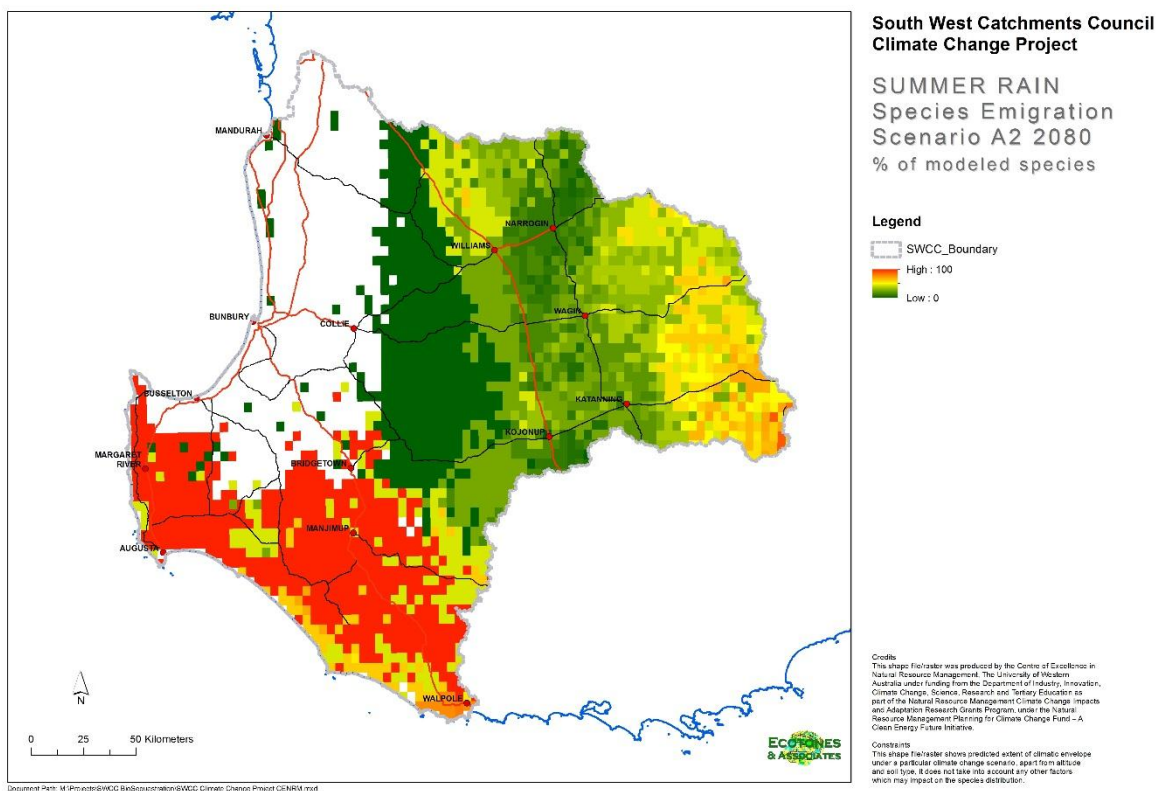


Figure 12: Summer Rain Group – Species Emigration A2 2080 – Proportion of modeled

Refugia

Plant Refugia (CENRM)

Using the data from the species response groups, Ben Ford at CENRM has calculated which cells are in both the lowest 10th percentile (<10th percentile) for emigrants and the highest 10th percentile (>90th percentile) for immigrants in each group. This identifies areas which are projected to both lose the least and gain the most species in each group. Each time a cell scores in one of these groups it receives a value of 1, meaning a cell can score up to 10 when emigrants and immigrants are summed for all groups. Such areas can be viewed as Refugia (Reside et al 2013).

This is a version of the NCCARF methodology to identify refugia (Reside et al 2013), which uses groups of mammals (birds, mammal, reptiles and amphibians) instead of species response groups. Note that the definition means that areas which potentially will see an influx of species over time are ranked highly, however such changes will not necessarily be advantageous to the existing communities. For this reason we have also used the Emigrants grids alone as a measure of climate impact.

The refugia mapping for plants (Figure 13) identifies higher refuge values in the forests and south-west corner, and lower values on the swan coastal plain west of the scarp and in the eastern margins of the region. In the context of the south west of the State however (shown in Figure 14) the entire region is a relative refuge, and contains much of the highest value plant refugia.

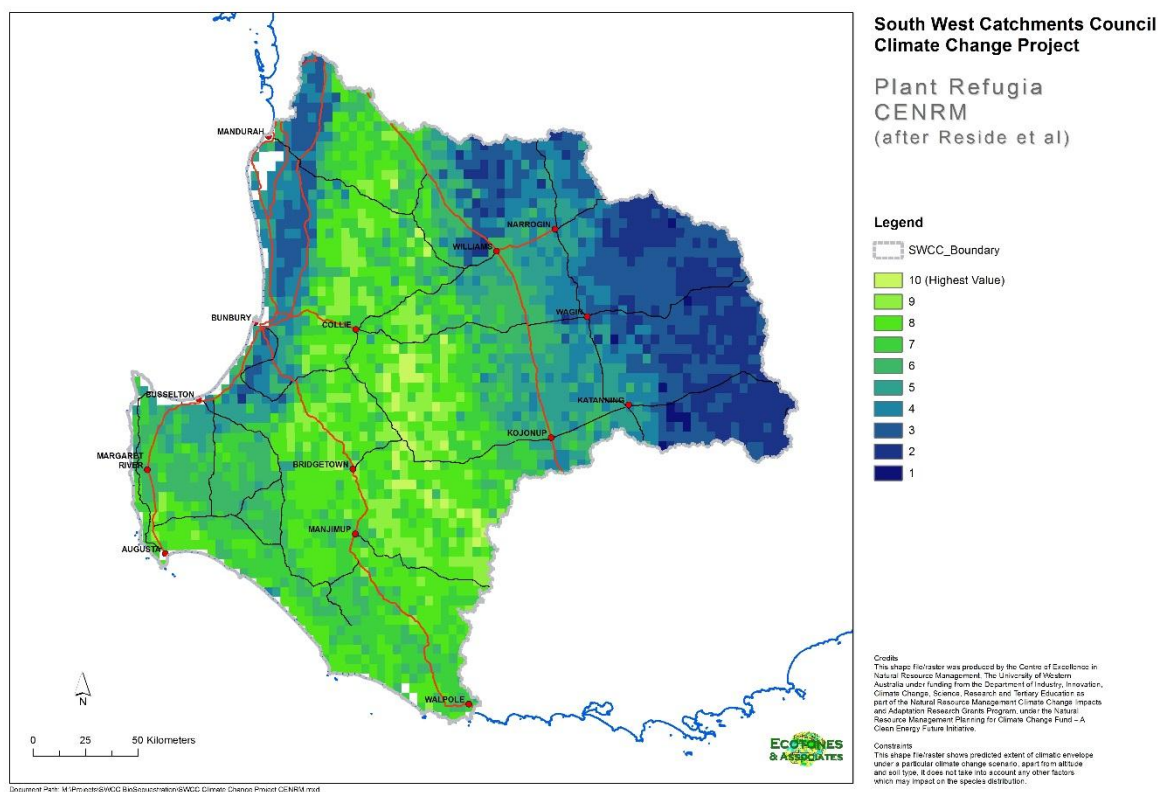


Figure 13: CENRM Plant Refugia map –SWCC

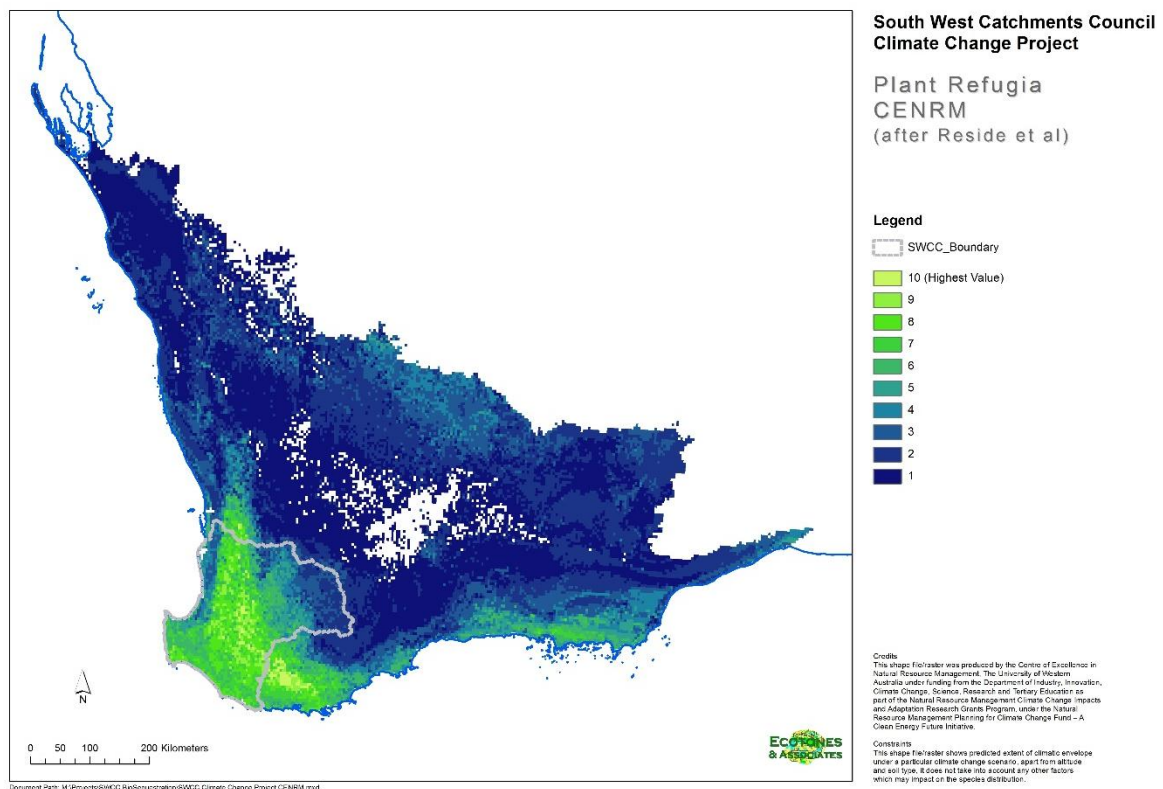


Figure 14: CENRM Plant Refugia map – SW WA

Animal Refugia (NCCARF)

A previous climate modeling project from NCCARF (Reside et al 2013) has produced a refugia map for Australia. This is part of a much larger bio-climatic modeling study of over 1400 species of birds, mammals, reptiles and amphibians. The maps produced are different but reflect a similar trend to the plant refugia analysis. One notable difference is the relative ranking of the south-west of WA – which must be seen in an Australia-wide context rather than just SW WA. For the SWCC region, the forest and coastal areas are projected to fare significantly better than the inland, but no areas score better than 5 out of a maximum of 7. Much of the state however ranks far lower, indicating that for none of the groups used (birds, mammals, reptiles and amphibians) does an area rank at the top of either retention (emigrants) or attraction (immigrants).

A better indicator of the projected impact of a severe future climate can be seen in the figures showing animal species emigration – i.e. the number or % of species modelled to occur in an area now that would not be retained in the future. Figure 17 indicates that projected species loss in the east and along the coastal plain may be significant – over 100 species – while the percentage of modelled occurrences could be as high as 60% in the east of the region (Figure 18). These projections have very serious implications.

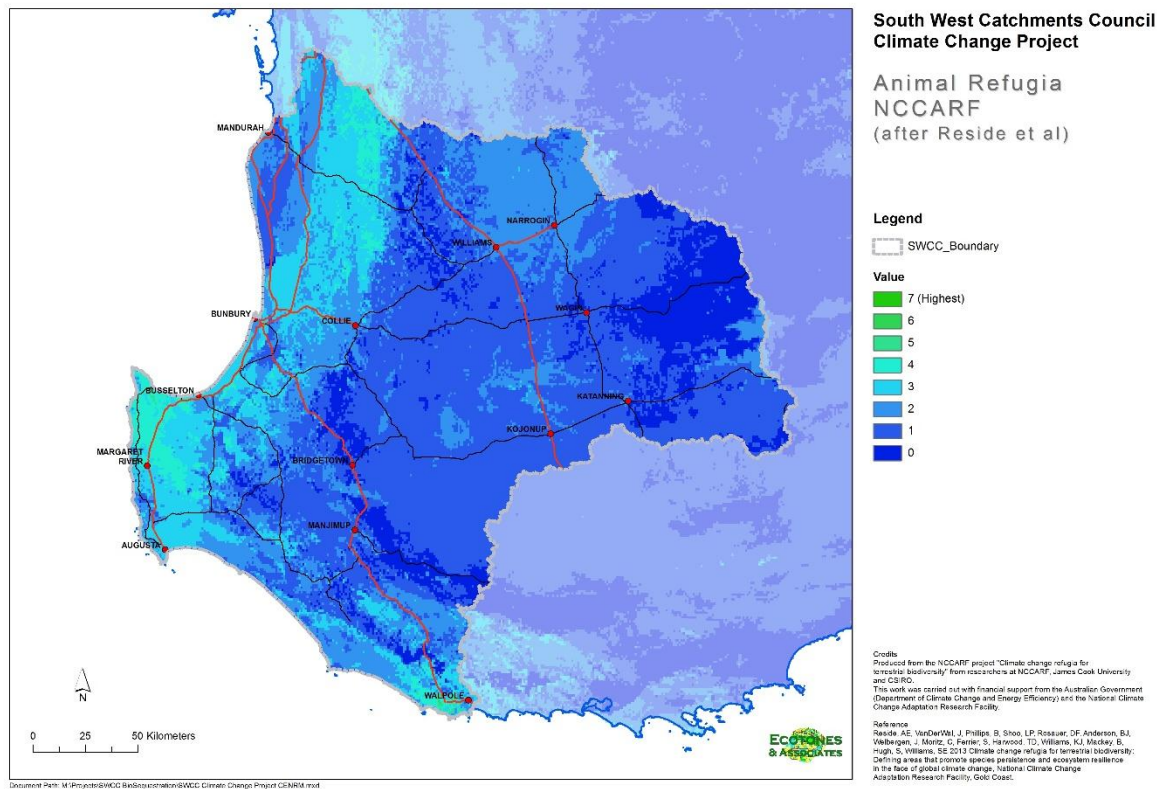


Figure 15: NCCARF Animal Refugia map – SWCC

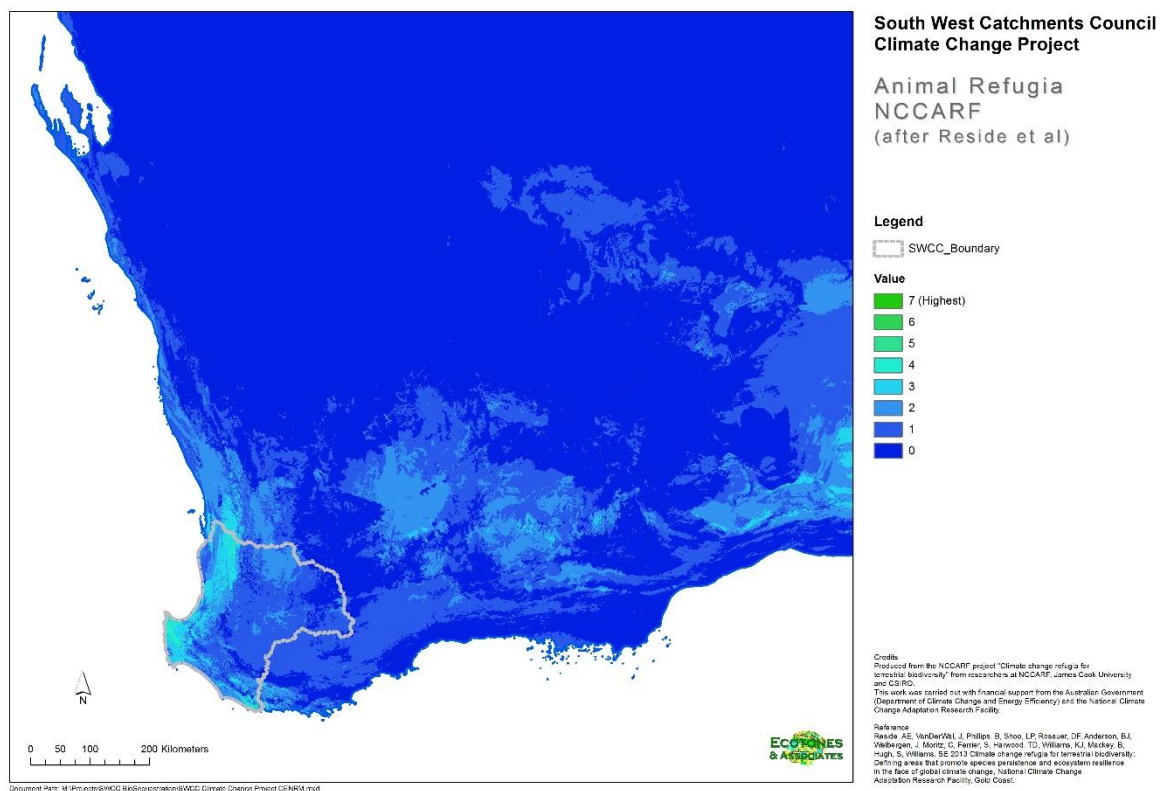


Figure 16: NCCARF Animal Refugia map – SW WA

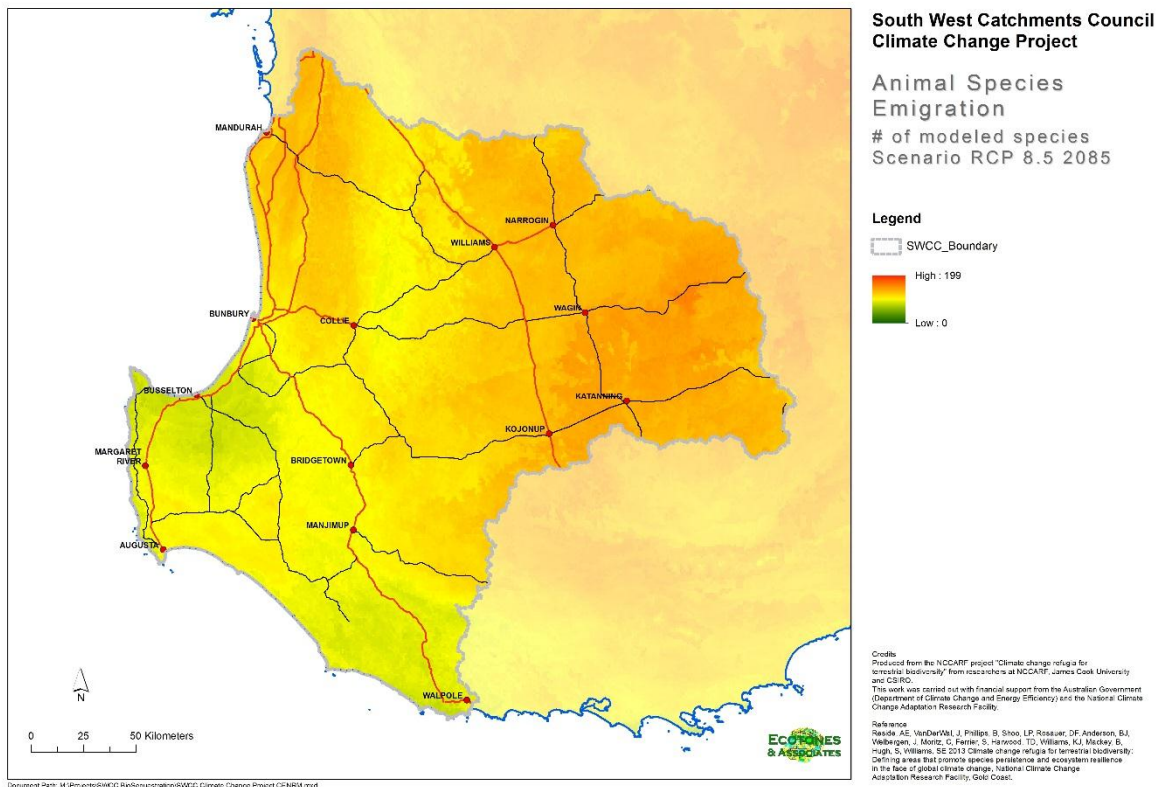


Figure 17: NCCARF Animal Emigrants RCP8.5 2085 (species numbers)

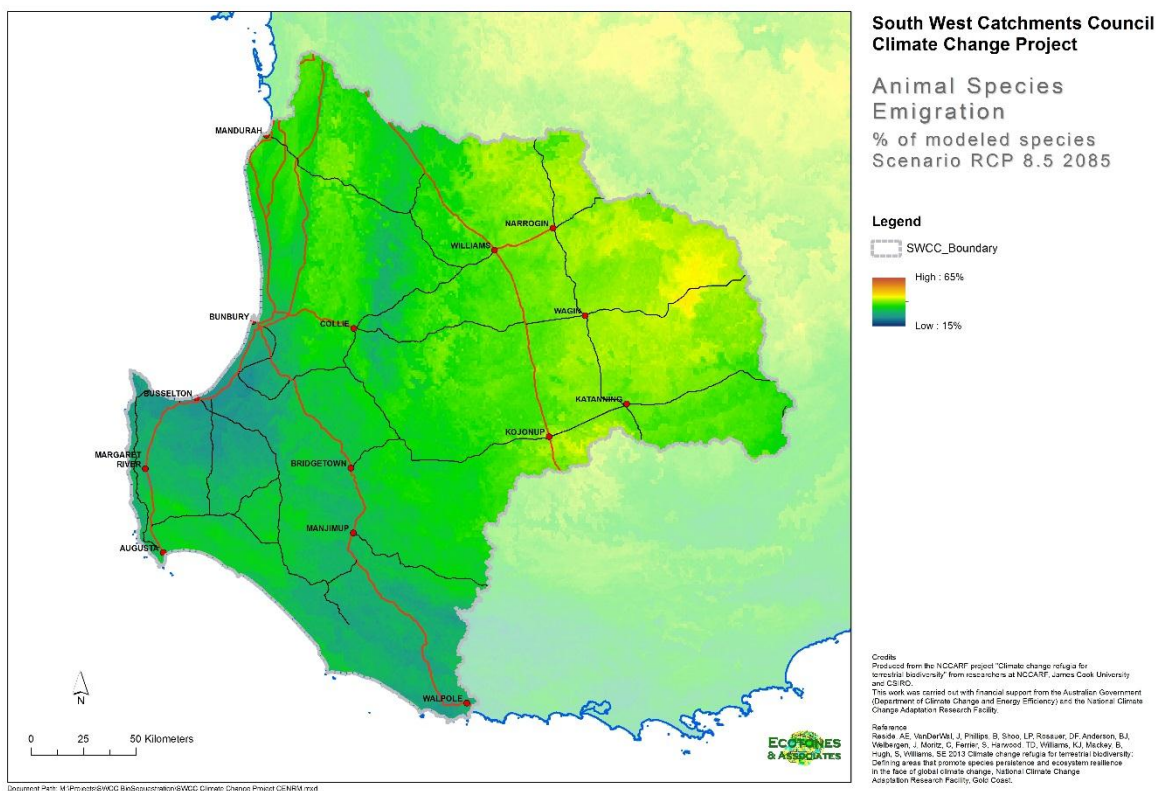


Figure 18: NCCARF Animal Emigrants RCP8.5 2085 (percentage)

Overlap Modeling

As part of an attempt to create indicators that are useful to NRM groups, and in conjunction with the author, Ben Ford has carried out 'overlap modeling'. This process identifies areas of overlap between current and future predicted climate envelopes for all species, and sums these for each cell. The higher the overlap proportion, the greater the number of species that persist, which may indicate the least change in community. Note that we have said 'may' indicate the least change: the interdependence of species and the significance of individual species within a community is not well known, and outcomes of species loss cannot be predicted with any certainty (Angela Sanders, Bush Heritage Australia, pers. com.).

A measure of overlap has been created from this work to show overlap as a proportion of current richness. Note however that whilst this appeals as an indicator, it is actually the same data as emigrants.

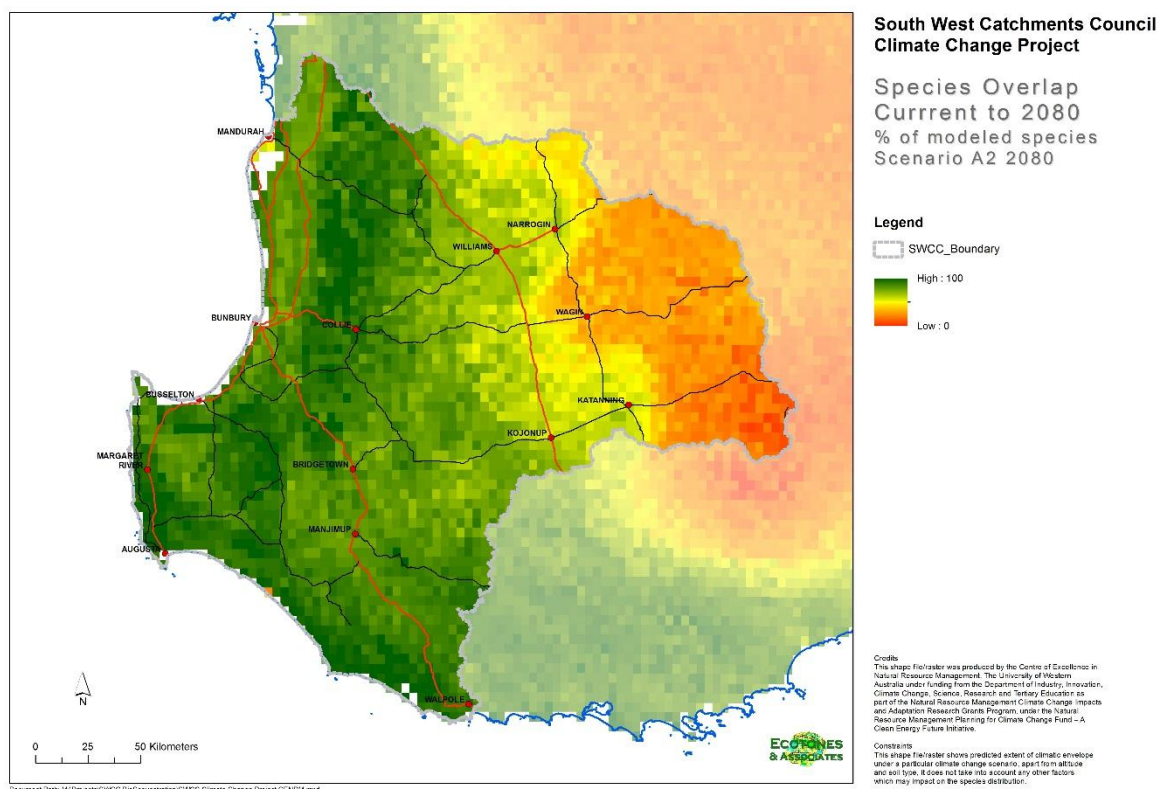


Figure 19: CENRM Plant Species Overlap Map

Species Movement Vectors

It was decided to create an indicator of the direction and distance of species projected range movement. To do this, Ben Ford has calculated the median latitude and longitude of current and projected future climate envelopes for the A2/2080 scenario.

This technique is not perfect (i.e. some end up in ocean) but gives an indication of the direction and magnitude of climate envelope shifts in different parts of SW. The value of this technique is to suggest the direction of change and movement in range, which may be applicable to provision of landscape connectivity and management.

In the SWCC region, the bulk of modeled species are moving in a south-westerly direction; others are moving south along the west coast and west along the south coast. This suggests that the maintenance (or establishment) of linkages in these direction will be beneficial for movement.

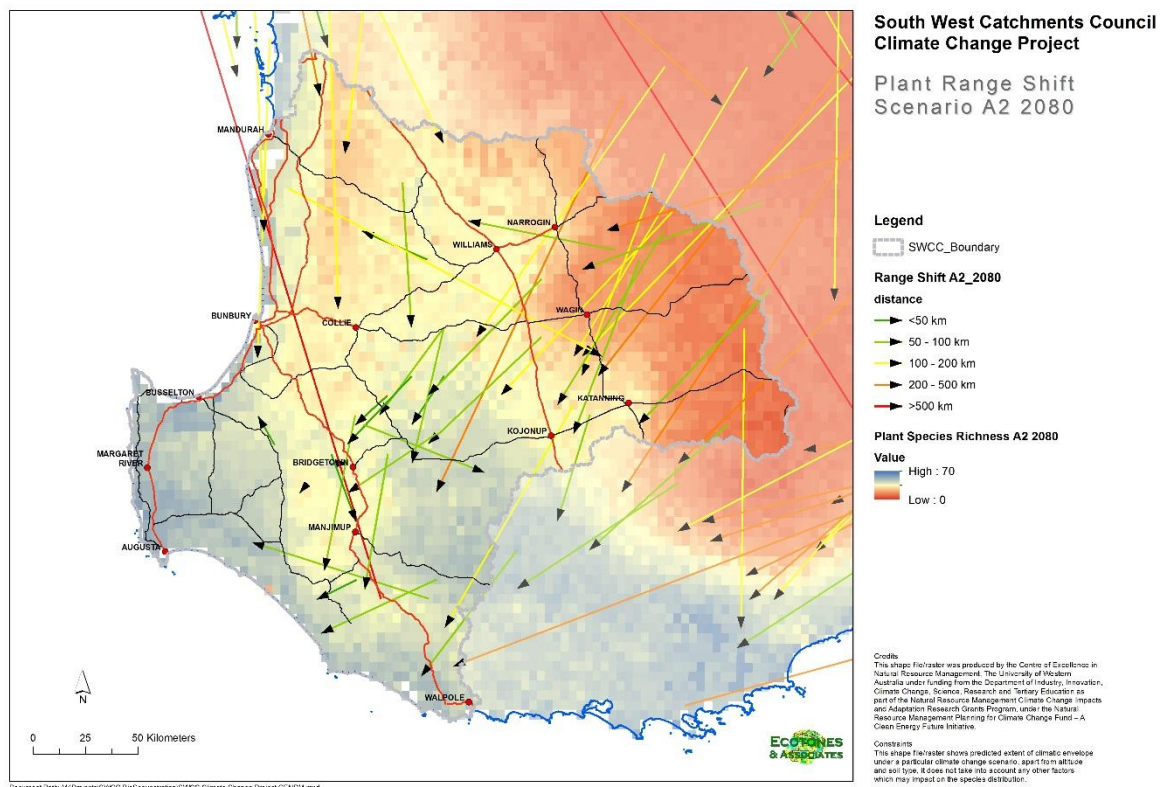


Figure 20: CENRM Plant Range Shift

Climatic Impact MCAS-S Model

Notwithstanding the wide variety of projection products outlined above, we have used a relatively small set of these in indicating the nature of climatic stress on the biodiversity of the SWCC region.

Indicators used are as follows:

- NCCARF Refugia (animals) & CENRM Refugia (plants)

These provide a specific indicator of impacts, through identification of refugia. However due to the method used they identify peak values, and so additional datasets are used:

- Animal & Plant Emigrants %

Identifies the projected loss of existing species, and so acts as a useful indicator of climatic impact.

- Species Stability (both plants and animals)

Combines Animal & Plant Immigrants and Emigrants (%) to identify areas where species composition is likely to remain stable. It was felt important to use this, as additional species may not be consistent with maintenance of the existing community.

Current Species Richness has not been used in the modeling, but could be used to qualify the results of using the above indicators based on the extent to which modeling has actually included local species.

3. SWCC ASSETS

The SWCC assets used here are two datasets: one is a set of existing native vegetation areas (under DPAW control) including national parks & nature reserves. The other is a biodiversity/conservation value assessment produced out of the MCAS-S Biosequestration modeling recently completed (Neville 2014a). Both were used in another recent report to SWCC as identifying assets (Neville 2014b).

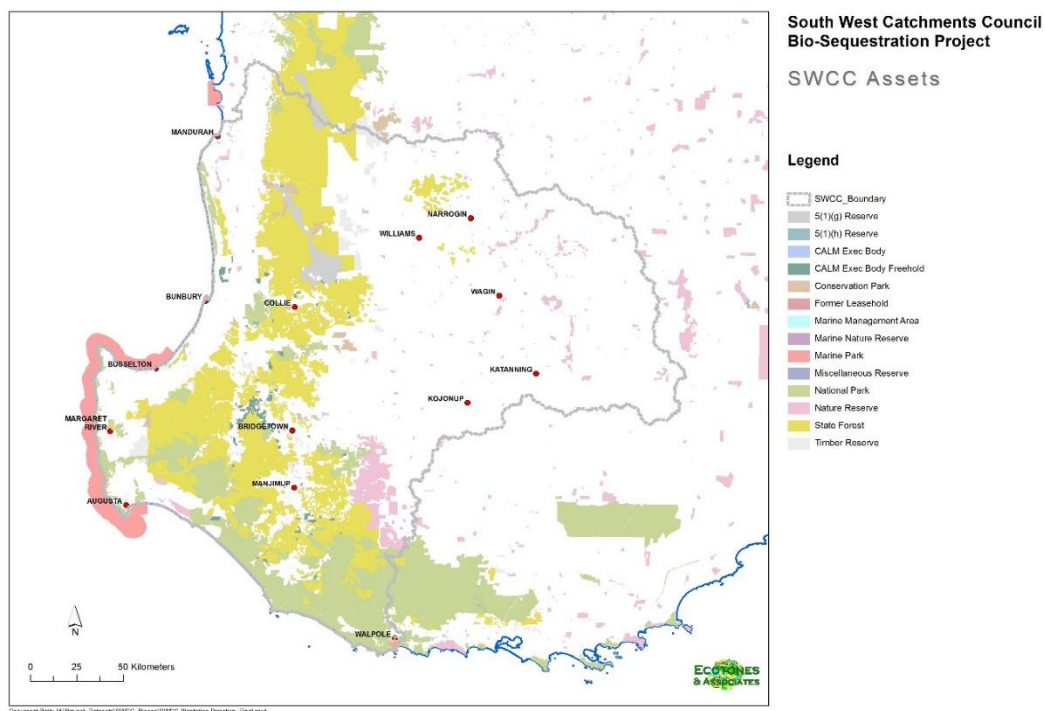


Figure 21 – SWCC Assets 1 – Natural Areas under DPAW management.

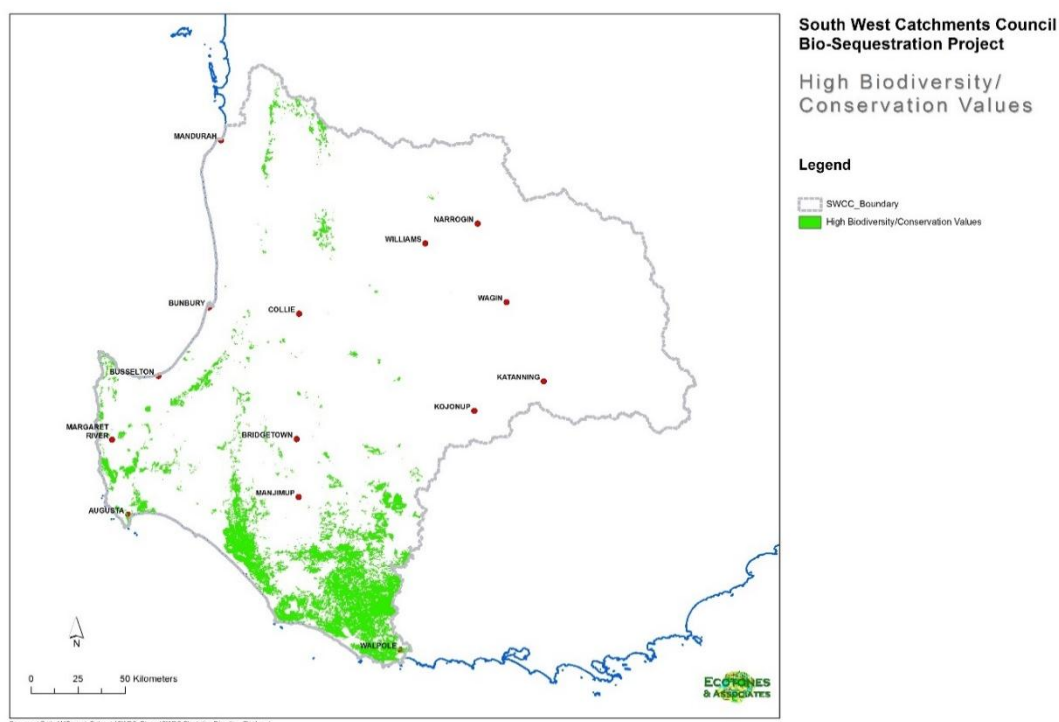


Figure 22 - SWCC Assets 2 –Areas defined as having high Biodiversity/Conservation Value

4. NEW MCAS-S COMPONENTS

The three new MCAS-S models developed here have similar names as MCAS-S models created for Perth Region NRM and South Coast NRM. The frameworks used in the models B2 and B3 are similar but not identical.

Component B2 – Protection afforded under Existing Tenure

Component B2A assesses potential value of land based on the current protections afforded from vesting and management. It is designed to provide assistance in identifying areas for conservation works.

A wide range of possible protections have been given a “protection/security” value in comparison to DPaw reserves and reserve categories (where A Class Nature Reserve has the top value). The map is an effective tool in identifying vegetation security.

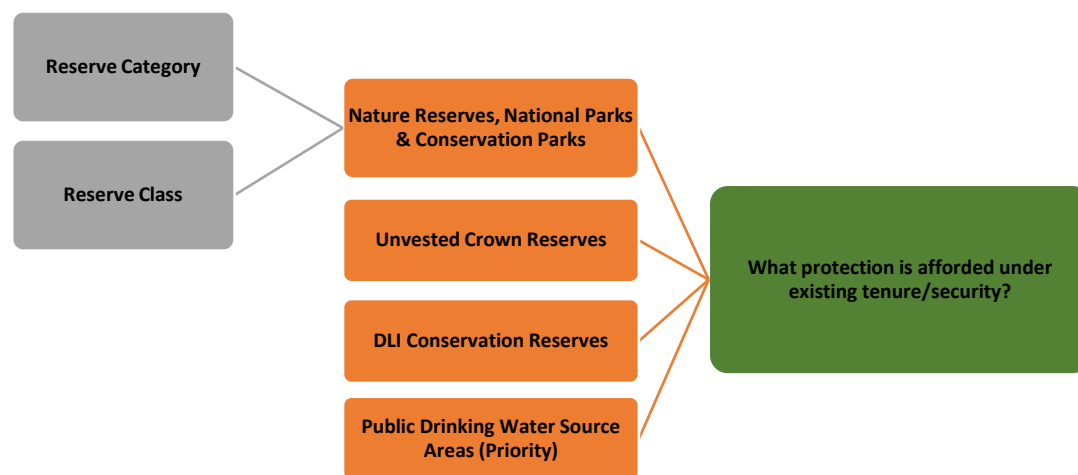


Figure 23: Component B2 - Protection afforded under existing tenure- Model Diagram

Layer 'B2 Protection is afforded under Existing Tenure' is generated from the maximum of a wide range of datasets identifying different kinds of tenure:

- 1 x 'DPaw Reserve Tenure & Security'
- 1 x 'Regional Parks'
- 1 x 'Bush Forever'
- 1 x 'Swan River Trust - Development Control Area'
- 1 x 'TPS - Local Authority Reserves'
- 1 x 'MRS - Parks and Recreation'
- 1 x 'Public Drinking Water Source Areas (Priority)'
- 1 x 'Covenanted Private Land'.

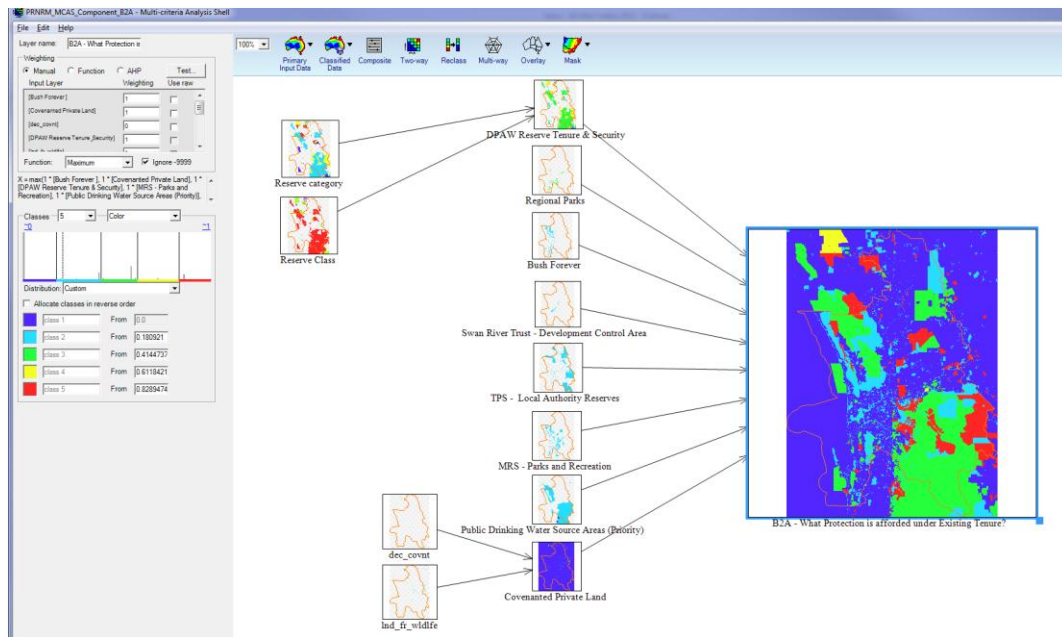


Figure 24: Component B2A MCAS-S Model

Using a maximum function means that the best protection from any source is identified. All input layers were classified on the same notional scale:

- 1 - No Tenure//Management Protection (e.g. Timber Reserve)
- 2 - Low level protection (Local Government Reserves, Voluntary Covenants)
- 3 - Medium Protection (Conservation Park)
- 4 - High Protection (A Class National Park)
- 5 - Highest Protection (A Class Nature Reserve)

DPaW Reserve Tenure & Security

A combination of reserve type and vesting (reserve class) has been used to give the effective security, using values provided by David Mitchell (DPaW) in other NRM processes. The implication is that even a National Park can have low security of tenure and therefore protection. These protection equivalents were used throughout this component.

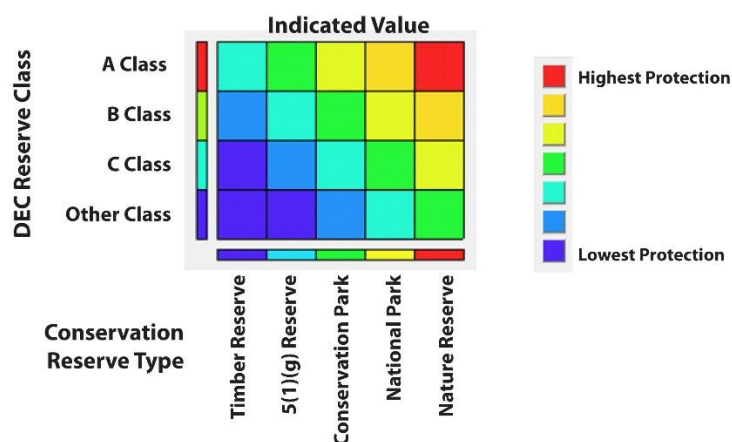
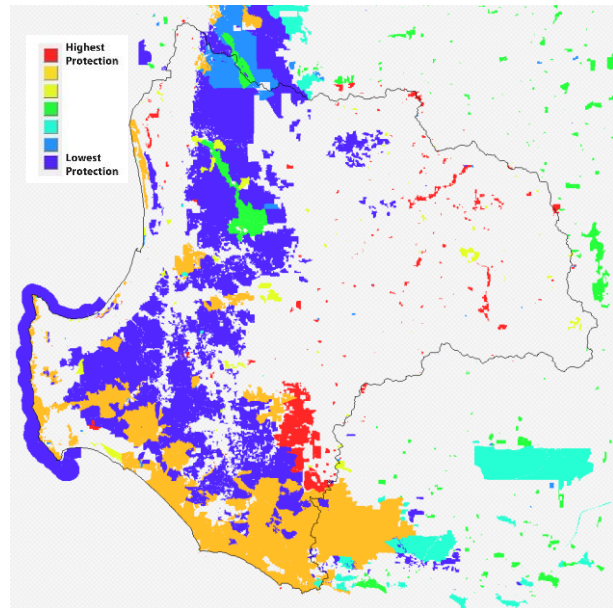


Figure 25: Reserve Tenure & Security 2-Way Matrix

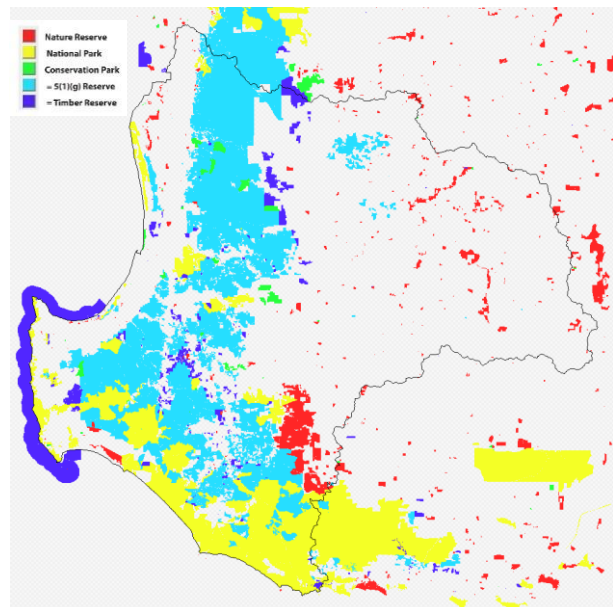
Layer 'DPAW Reserve Tenure & Security' is generated with the Two Way above from 'Reserve category' and 'Reserve Class' producing 7 classes.



Reserve Category

Layer 'Reserve category' is a categorical layer built from 'dec_category1', which is the current reserve category data from DPaW.

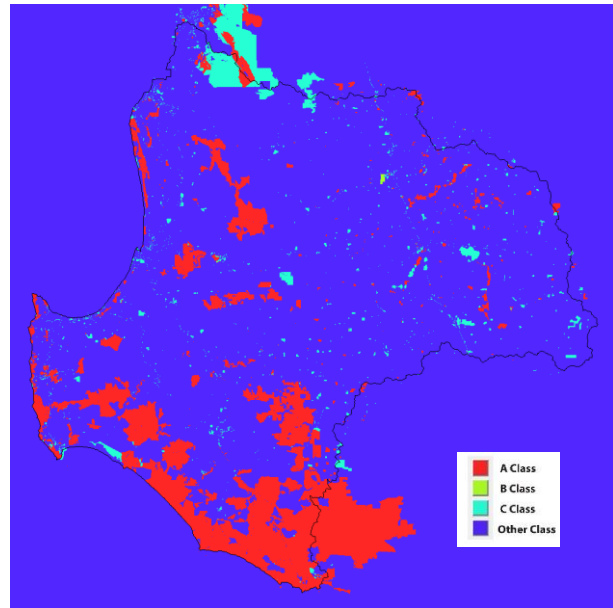
- Class 5 for Nature Reserve [Highest Value]
- Class 4 for National Park
- Class 3 for Crown Freehold - Dept Interest
- Class 3 for Conservation Park
- Class 2 for State Forest
- Class 2 for 5(1)(g) Reserve
- Class 1 for Timber Reserve
- Class 1 for Miscellaneous Reserve
- Class 1 for Marine Park
- Class 1 for 5(1)(h) Reserve



Reserve Class

Layer 'Reserve Class' is a categorical layer with four classes of tenure, sourced from the current reserve data from DPaW.

Class 4 for A Class Reserve [Highest Value]
Class 3 for B Class Reserve
Class 2 for C Class Reserve
Class 1 for NA

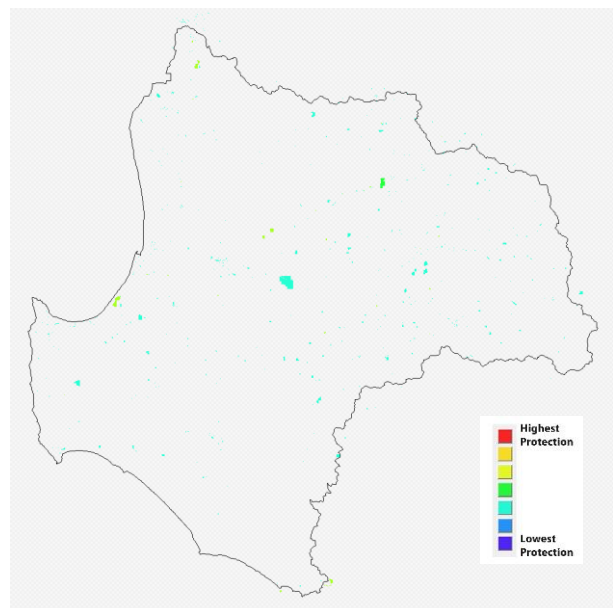


Unvested Crown Reserves

Crown Reserves with no vesting listed at March 2013.

Layer 'Unvested Crown Reserves' is a categorical layer built from 'unvst_crwnres':

Class 3 for Unvested C Class Reserve
Class 4 for Unvested B Class Reserve
Class 5 for Unvested A Class Reserve

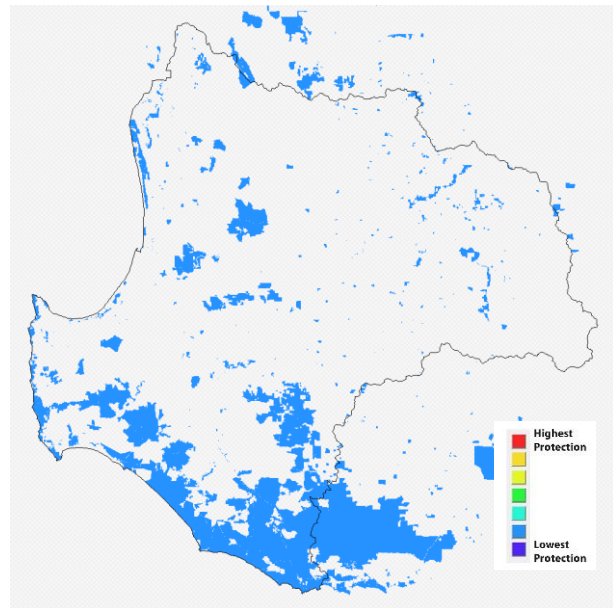


DLI Conservation Reserves

DLI Conservation Reserves – all reserves listed as vested for “Conservation” according to this DLI dataset.

Layer 'DLI Conservation Reserves' is a categorical layer built from 'dli_cons_res'

Class 2 = State Forest or 5(1)(g) Reserve equivalent.



Public Drinking Water Source Areas (Priority)

Layer 'Public Drinking Water Source Areas (Priority)' is a categorical layer built from 'pdws_priority':

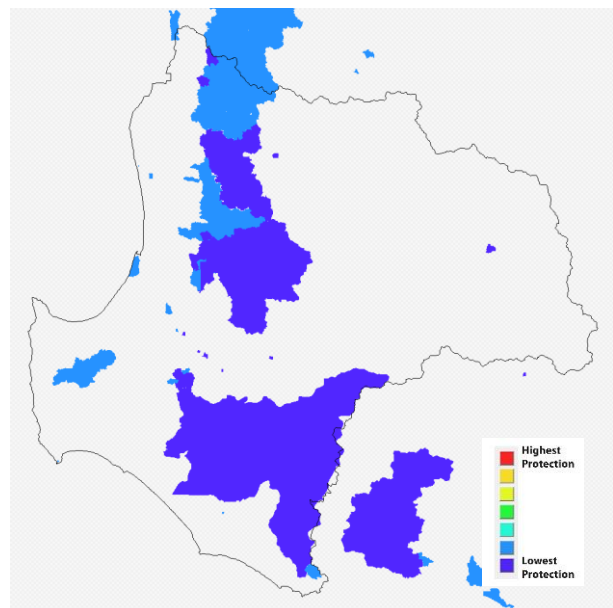
Class 2 for P2

Class 2 for P1

Class 2 for P3

All with = State Forest or 5(1)(g) Reserve equivalent.

Class 1 for Not Assigned



Component B2 Output - Protection afforded under Existing Tenure

The output indicates relative protection through tenure and purpose.

Layer 'B2 Protection afforded under Existing Tenure' is a composite layer producing 7 classes, generated from the maximum of:

- 1 x 'DLI Conservation Reserves'
- 1 x 'DPaW Reserve Tenure & Security'
- 1 x 'pdws_priority'
- 1 x 'Unvested Crown Reserves'

The result is classed using the standard protection equivalents.

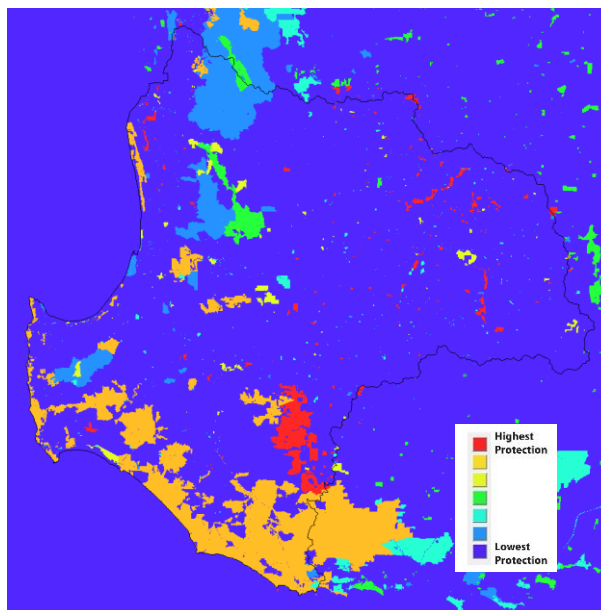


Figure 26: Component B2 Output –Protection afforded under Existing Tenure

Component B3 – Landscape Linkages

This component provides a framework to assist in both plantation establishment for conservation outcomes, as well as the valuation of areas that are in potential or actual landscape linkages.

The model is based on three top-level criteria (or concepts): Cores, Existing Connections and Connectivity.

Cores are the lynch-pins of the system, representing the reservoirs of natural values. They are identified by using distance from areas of high biodiversity/conservation value (from Component A3) and the existing reserve system. This ensures the linkages are grounded in the most suitable and best protected values.

Natural corridors represent existing areas of connectivity, either along rivers or other riparian zones, or within existing vegetation. These are all places of significant movement of animals and sometime plants by natural vectors. Connectivity is the real or potential connectivity in the landscape, characterised by Connectivity Potential – a measure of connectivity between all patches of vegetation. We can also add the existing SWCC Preliminary Ecological Linkages, but as we have been tasked with evaluating these we have created two versions of the linkages, one with and one without.

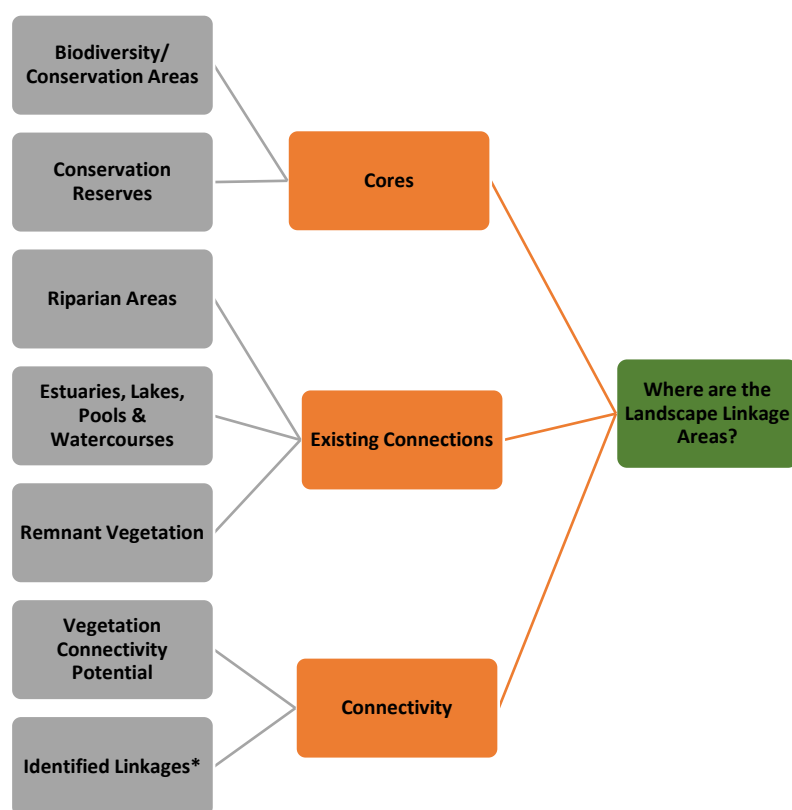


Figure 27: Component B3 –Landscape Linkage/Corridors– Model Diagram

Layer 'B3 Landscape Linkages' is a composite layer generated from the sum of:

2 x 'Cores'

2 x 'Existing Connections'

1 x 'Connectivity'

The result is classed manually so that there is a high connectivity corridor along the west coast, and all other values are in relationship to these values.

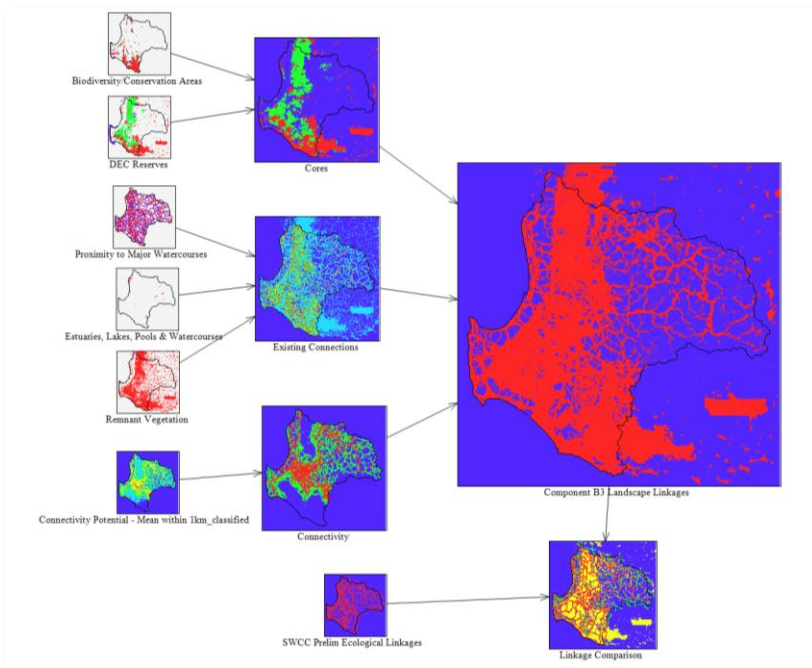


Figure 28: Component B3 MCAS-S Model

Cores

Layer 'Cores' is a composite layer producing 3 classes generated from the maximum of:

1 x 'Biodiversity/Conservation Areas'

2 x 'DEC Reserves'

The result is classed according to this table:

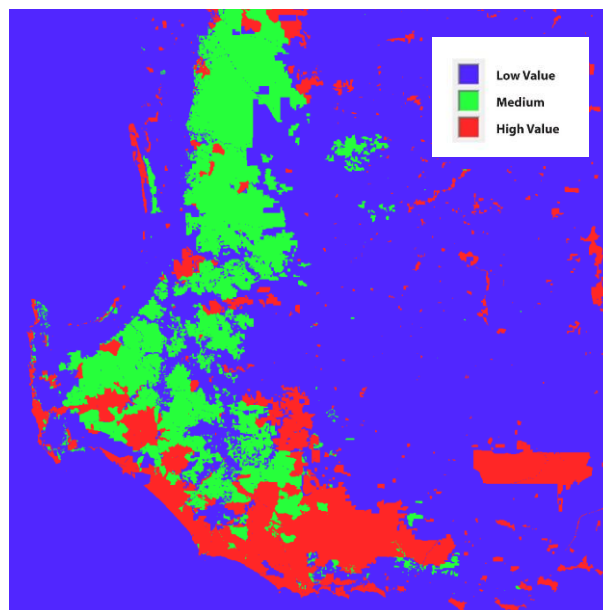
1 - up to 1

2 - up to 1.5

3 - above 1.5

This ensures that all significant reserves or large contiguous area will be defined as a core.

The result is classed using a custom scale that ensures that there is consistent “core” classification for major national parks and reserves, and all other values are in relationship to these values.



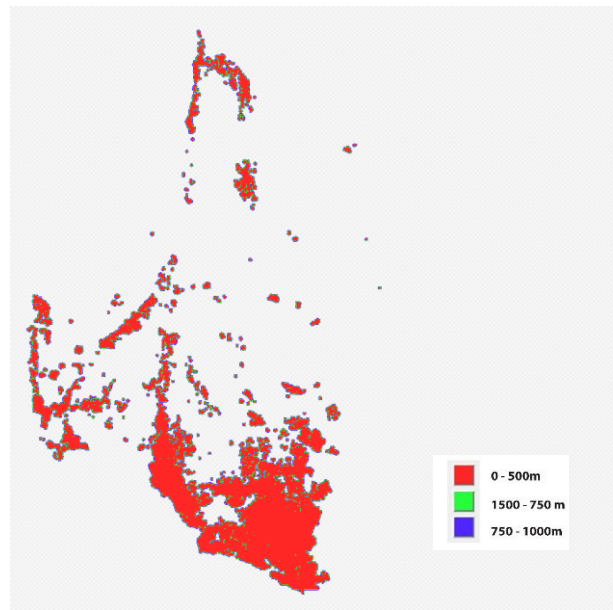
Distance from High Biodiversity/Conservation Areas (Component A3)

High conservation/biodiversity value areas (HCV) according to Component A3 from the previous MCAS-S analysis (Neville 2014a).

The classification values areas close to HCV as follows:

- 3 - < 500m [Highest Value]
- 2 - from 500-750m
- 1 - from 750-1000m

All areas not within 1000m of a HCV area are given no value.



Reserve System

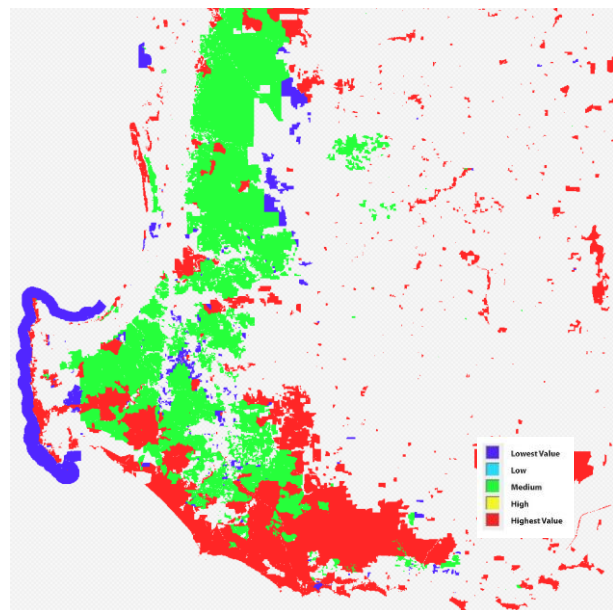
Layer 'Reserve System' is a categorical layer built from the DPaW Managed Lands and Waters.

Nature Reserves, National Parks and Conservation Parks are defined as cores (class 5).

Lower values of reservation are given a value of 3:

- Class 3 for 5(1)(g) Reserve
- Class 3 for 5(1)(h) Reserve
- Class 3 for Miscellaneous Reserve
- Class 3 for State Forest

All other DPaW managed lands are given the value 1.



Existing Connections

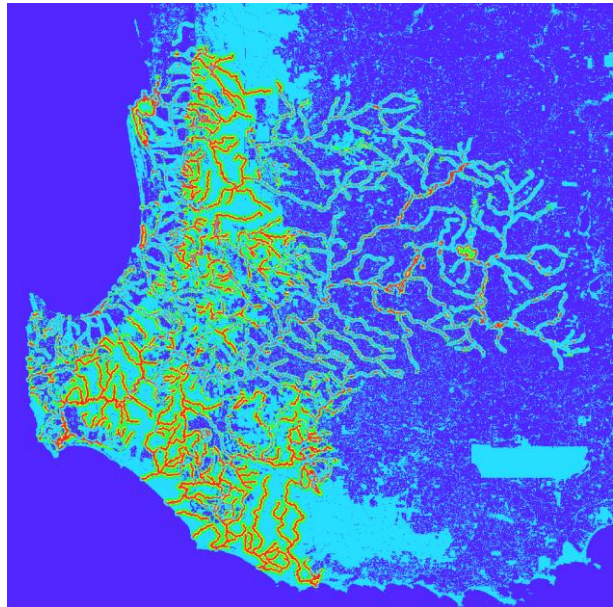
Layer 'Existing Connections' is a composite layer producing 5 classes generated from the sum of:

- 1 x 'Estuaries, Lakes, Pools & Watercourses'
- 1 x 'Proximity to Major Watercourses'
- 1 x 'Remnant Vegetation'

The result is classed using a custom scale.

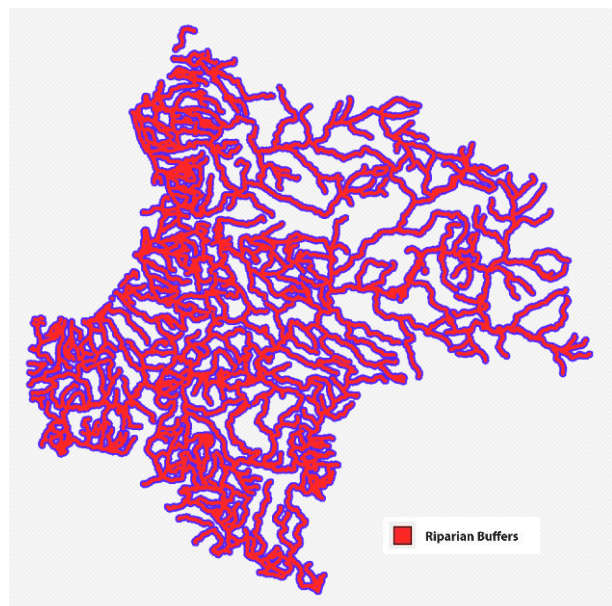
Any existing connection is included in the final layer, but vegetated riparian buffers are the highest weighting.





Proximity to Major Watercourses

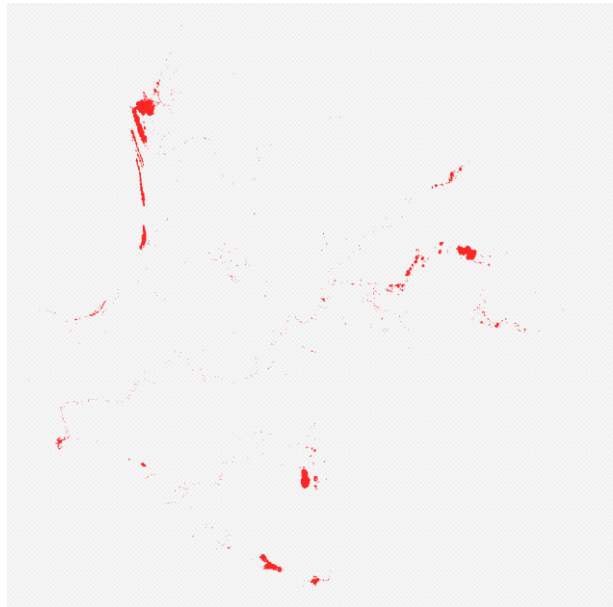
It is recognised that riparian areas provide connectivity for both plants and animals. Major waterways have been buffered out to 1000m and 2000m.



Estuaries, Lakes, Pools & Watercourses

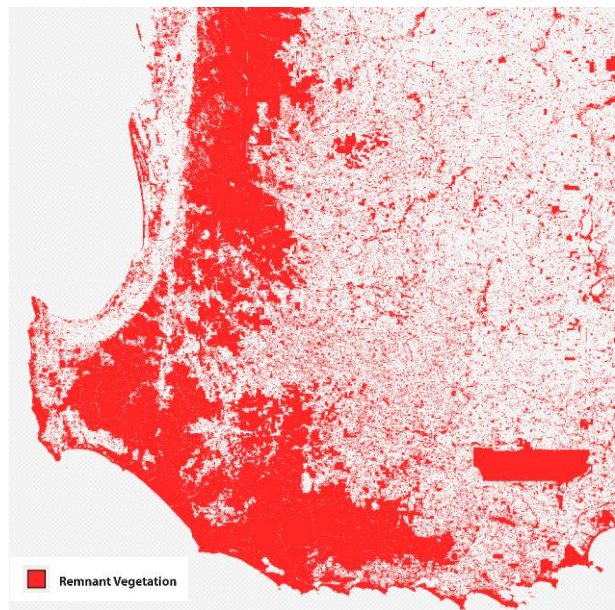
It is recognised that riparian areas provide connectivity for both plants and animals. Estuaries, Lakes, Pools & Watercourses are added to ensure all of these become part of existing connections.

 Riparian Buffers



Remnant Vegetation

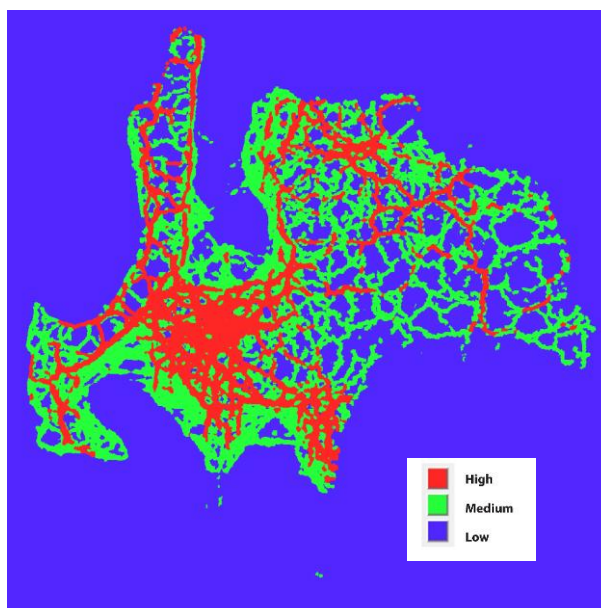
All existing remnant vegetation provides linkage, irrespective of vesting.



Connectivity

Layer 'Connectivity' is a composite layer producing 3 classes generated from the sum of:
2 x 'Connectivity Potential - Mean within
1km_classified'.

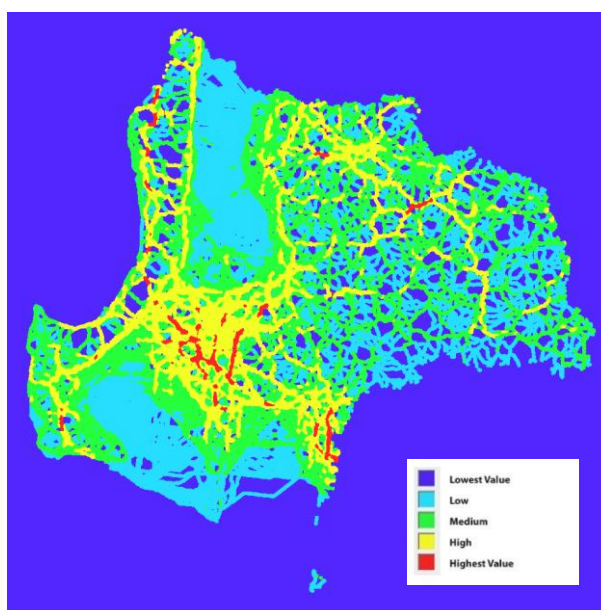
The result is classed with a custom scheme.



Connectivity Potential – Mean within 1km

Connectivity Potential is a dataset from the Australian Government Department of the Environment which identifies all potential linkages between all vegetation patches. This is an empirical indicator of potential connectivity. The specific data used is the maximum number of linkages within 1km of each MCAS-S cell.

The data has previously been classified, and the class system used here simply allocates highest class values to the highest number of connections.



Component B3 Output - Landscape Linkages

Layer 'B3 Landscape Linkages' is a composite layer producing just 2 classes. This ensures that a network of corridors is produced rather than a range of values.

It is our expectation that SWCC will be interested in the network in areas that do not have significant remnant vegetation.

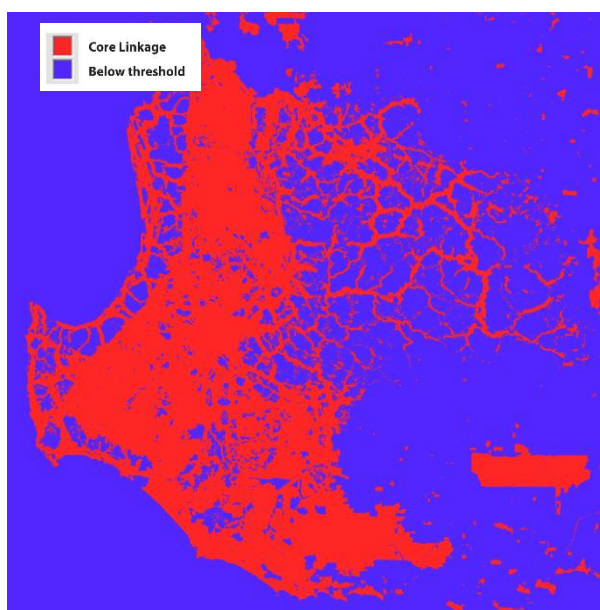


Figure 29: Component B3 Output –Landscape Linkages

Variation of Connectivity – SWCC Prelim Ecological Linkages:

We have also run the model with the inclusion of the SWCC Prelim Ecological Linkages dataset, shown below.

SWCC Prelim Ecological Linkages

Distance from South West Catchment Council Preliminary Ecological Linkages Axis Lines. This is an expanded version of the South West Regional Ecological Linkages (SWREL) Axis Lines.

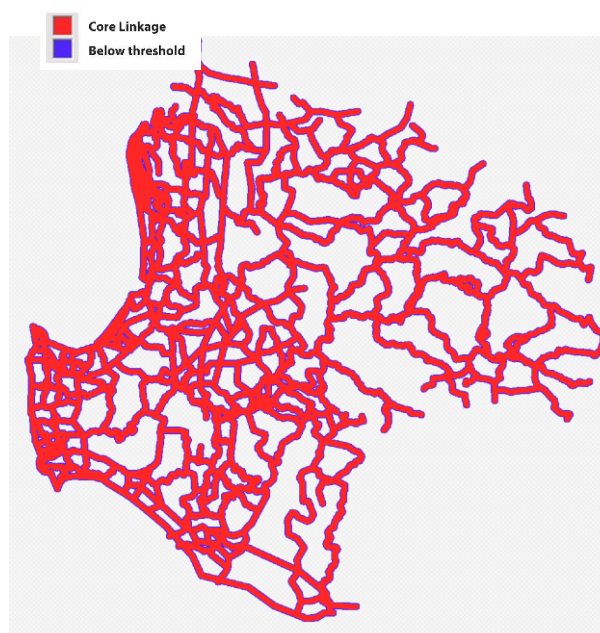
Layer 'SWCC Prelim Ecological Linkages' is generated from primary data 'swcc_dist'

Split into 2 classes

2 - from 0

1 - from 1500

Areas >2000m have no value.



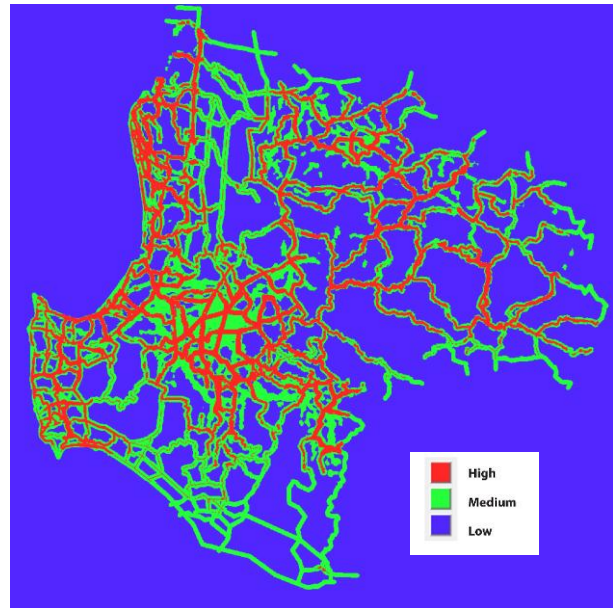
This dataset modifies connectivity as shown:

Connectivity (modified)

Layer 'Connectivity' is a composite layer producing 3 classes generated from the sum of:
2 x 'Connectivity Potential - Mean within 1km_classified'

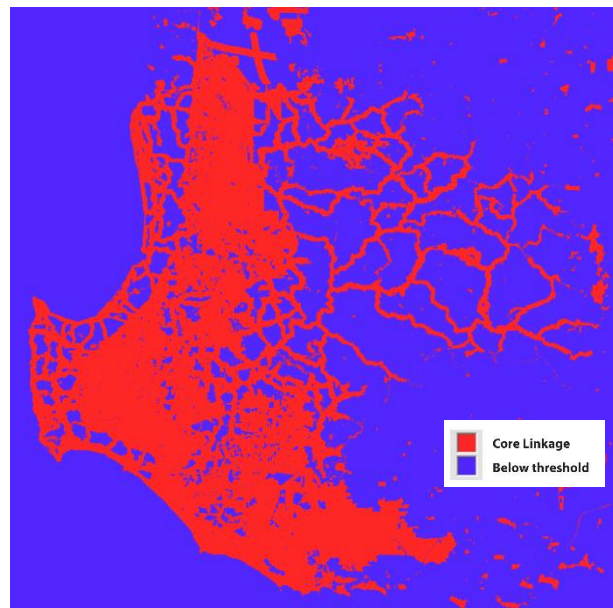
2 x 'SWCC Prelim Ecological Linkages '

The result is classed with the same custom scheme. The result is a much 'tighter' connectivity layer, as the SWCC Linkages dataset is essentially a network of lines that focus the output layer.



Component B3 - Modified Landscape Linkages

The inclusion of the existing linkage layer makes only a minor difference to the final output:



Evaluating the SWCC Preliminary Ecological Linkages dataset

As mentioned above, the South West Catchment Council Preliminary Ecological Linkages are an expanded version of the South West Regional Ecological Linkages (SWREL) Axis Lines. Part of the brief in this project was to assess these ecological linkages in light of the new Landscape Linkages framework. We have done this using a simple 2-way analysis, comparing the Preliminary Ecological Linkages Axis Lines with the output of the landscape linkage component. The following map shows the result:

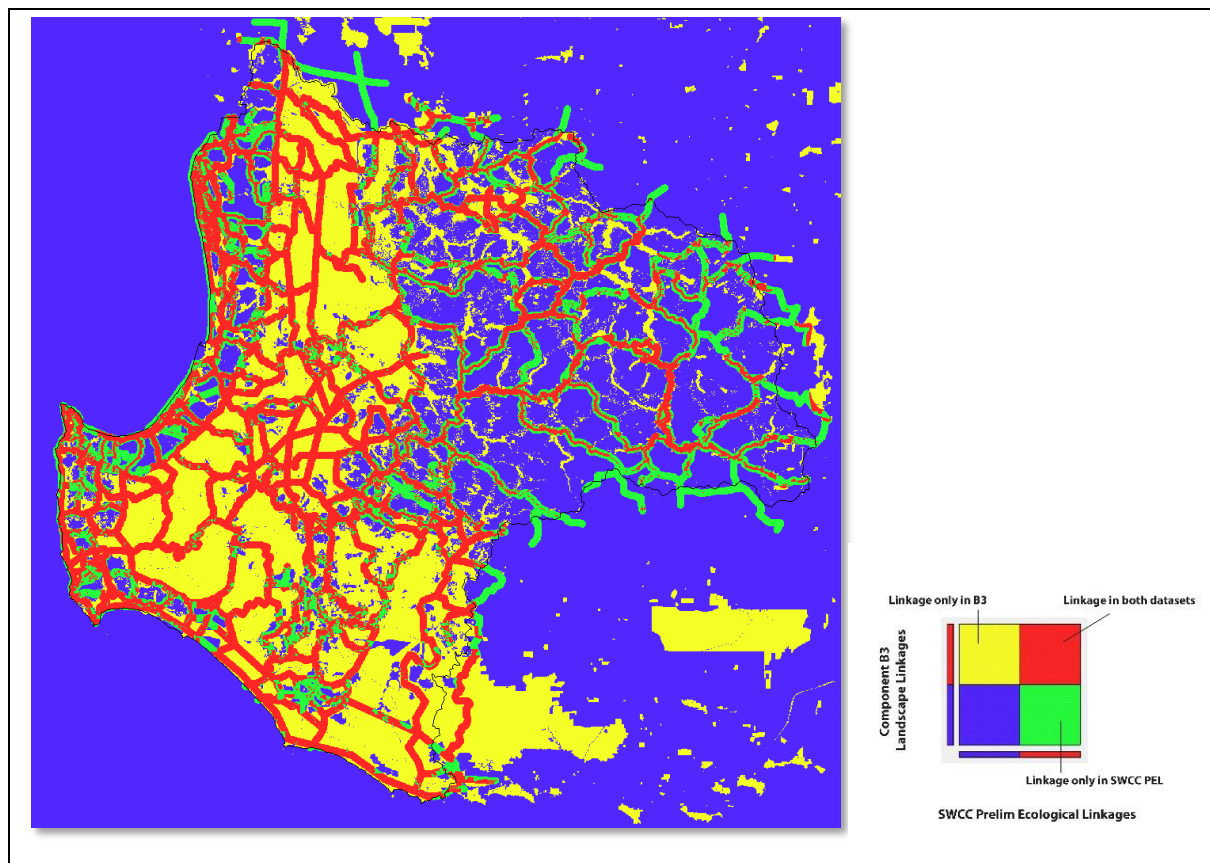


Figure 30: Comparison of B3 Landscape Linkages and SWCC Preliminary Ecological Linkages

In the figure above (Figure 30) areas in red illustrate agreement between the two linkage datasets. Areas in green show where component B3 does not cover the SWREL linkages and areas in yellow where the Landscape Linkages framework indicates linkages are not shown in the SWREL dataset. Although a large amount of yellow is shown, this is to be expected given that the SWREL linkages are lines, whereas the Landscape Linkages framework component is created from a range of broad-scale datasets. Accounting for this, there is a great deal of similarity of overall similarity.

Significant differences exist in the level of detail provided by the Landscape Linkages framework, where some finer scale linkages exist. One of the values of the Landscape Linkages framework output is to give this fine-scale direction. In addition, the framework can be modified to two or three levels of linkage priority, so that higher-value linkages can be discerned. The advantage of the SWREL dataset is that it is clean, having been reduced to a single set of lines. A further stage of work for SWCC could be to produce a similar set of lines based on the Landscape Linkages work. However leaving the work in the current state provides additional information about the relative strength of linkages in the landscape.

Component C1A – Climate Impacts on Biodiversity

The intention of this component is to combine the available bioclimatic indicators into a single index of climate impact specifically relating to biodiversity. This does not include climate projections directly, but has them as directed through the bioclimatic modeling carried out by CENRM and NCCARF. Three major criteria are used:

- Low Refugia status – is the cell projected to be a low ranked refuge based on maintaining and attracting species? Note that this is used without considering the implications of immigration of existing populations
- High Projected Species Loss – is the cell projected to have a large percentage of loss of existing species?
- Low Species stability – is the cell projected to maintain its existing species assemblage? Looking for areas with low emigration and low immigration.

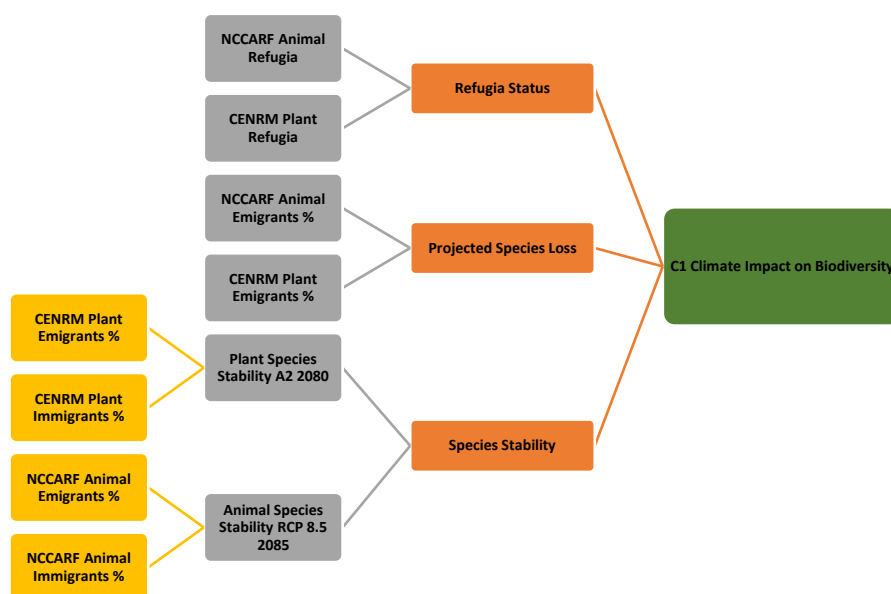


Figure 31: Component C1A - Climate Impact on Biodiversity Model Diagram

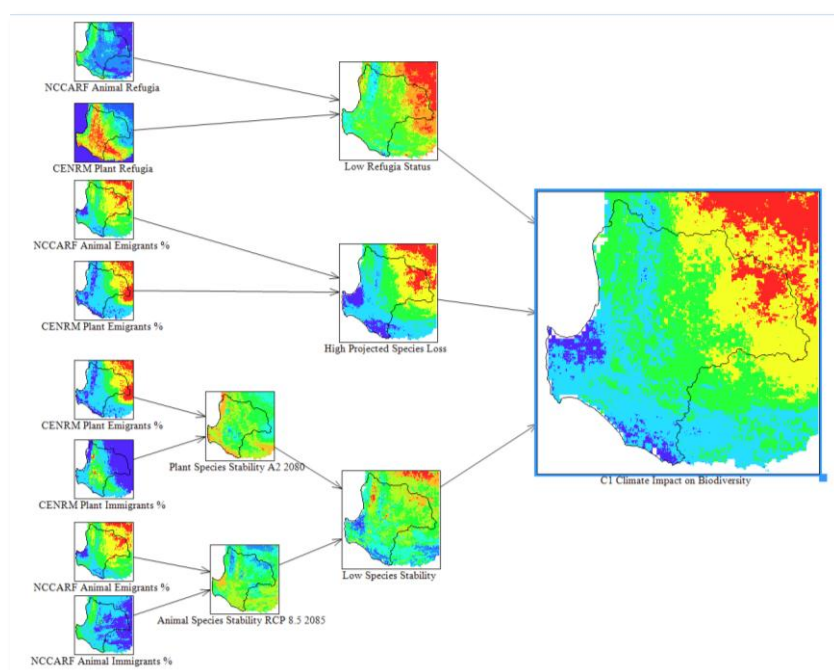


Figure 32: Component C1A – MCAS-S Model

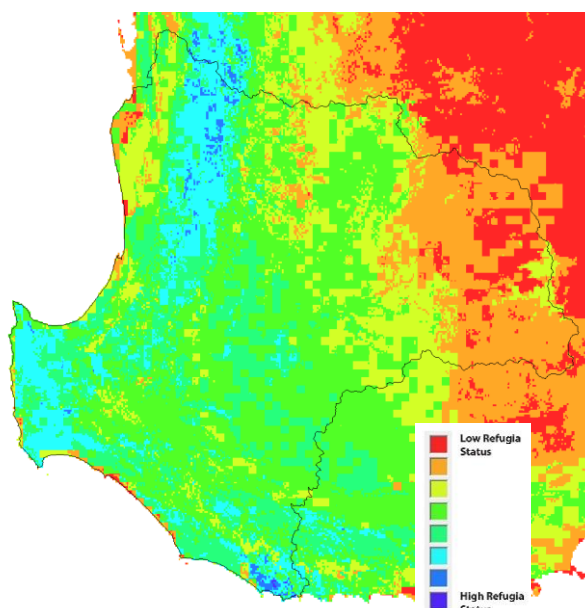
Low Refugia Status

Layer 'Low Refugia Status' is a composite layer producing 8 classes generated from the sum of:

- 1 x 'CENRM Plant Refugia'
- 1.5 x 'NCCARF Animal Refugia'

The result is classed using an equal interval scale – which produces sufficient classes to deal with the complexity of the two inputs. The scale is reversed, so that the highest input scores (best refugia) receive the lowest output scores, as this is identifying LOW refugia status.

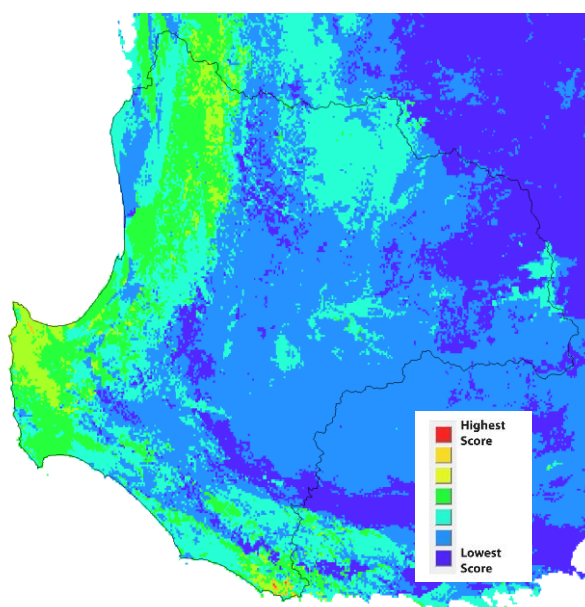
The Animal Refugia layer is given a higher weighting (1.5) due to the much larger number of species, and the more representative nature of these species than the plant species.



NCCARF Animal Refugia

Layer 'NCCARF Animal Refugia' is a categorical layer built from 'nccarf_rfugia'. The refugia score has been classified into 7 classes, where 0 = the lowest refugia score. This classification is used in Low Refugia Status in reverse.

Note that very few cells in the SWCC region score higher than 4 out of 7.

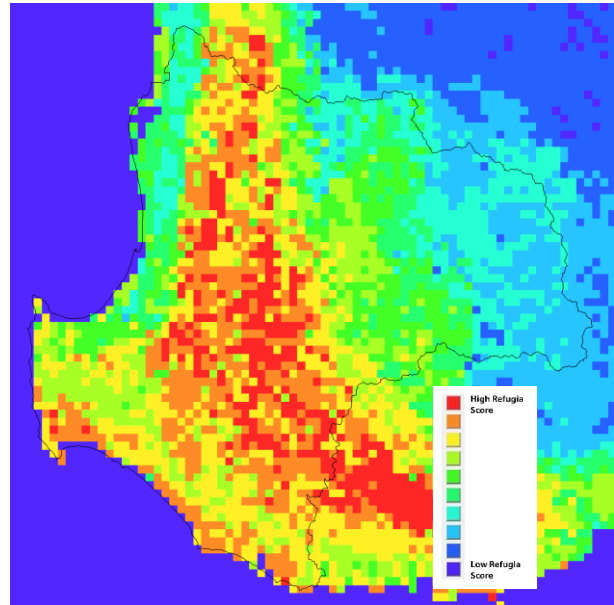


CENRM Plant Refugia

Layer 'CENRM Plant Refugia' is generated from primary data 'refugia_a2_80'.

The refugia scores have been classified into 10 classes, one for each refugia score – where 0 = the lowest refugia score. This classification is used in Low Refugia Status in reverse.

This map shows very high scores, as the south west corner of WA is the best area in WA for plant refugia under this technique.



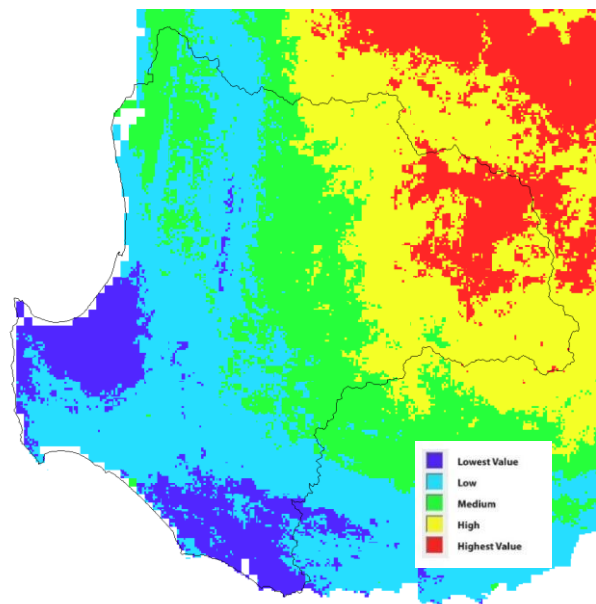
High Projected Species Loss

Layer 'High Projected Species Loss' is a composite layer generated from the sum of:

- 1 x 'CENRM Plant Emigrants %'
- 1.5 x 'NCCARF Animal Emigrants %'

The Animal Emigrants layer is given a higher weighting (1.5) due to the much larger number of species, and the more representative nature of these species than the plant species.

The result is classed according to an equal interval scale.

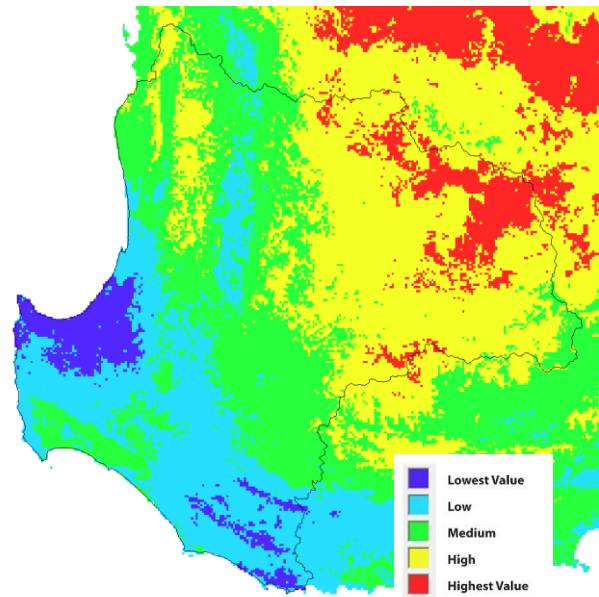


NCCARF Animal Emigrants %

Layer 'NCCARF Animal Emigrants %' is generated from primary data 'em_pr_85_2085'. It highlights areas with a high projected loss of species by 2085.

Split into 5 classes using an equal interval scale:

- 1 - from 0.23%
- 2 - from 0.28%
- 3 - from 0.32%
- 4 - from 0.37%
- 5 - from 0.41% [Highest Value]



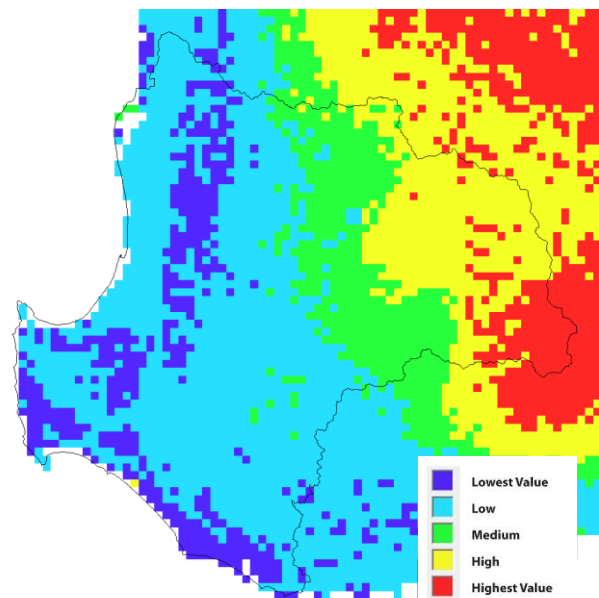
CENRM Plant Emigrants %

Layer 'CENRM Plant Emigrants %' is generated from primary data 'em_pr_a2_2080'. It highlights areas with a high projected loss of species by 2080.

Split into 5 classes:

- 1 - from 0-18%
- 2 - from 18 – 36%
- 3 - from 36 – 54%
- 4 - from 54 – 72%
- 5 - from 72 – 100% [Highest Value]

Note that the small number of species in the study dataset contributes to the large % emigrants.

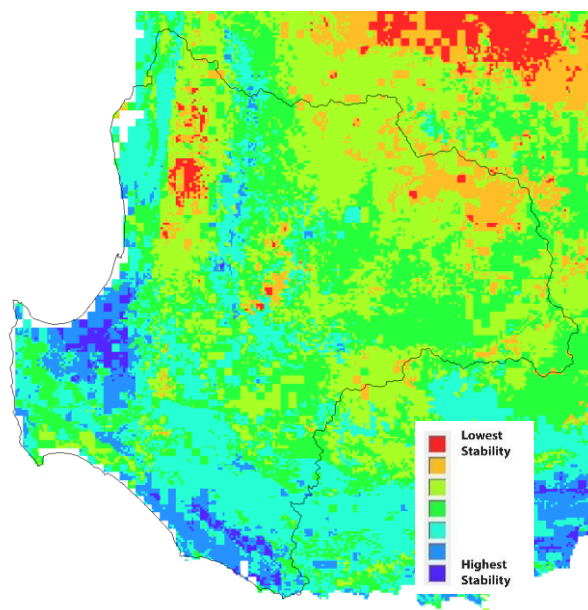


Low Species Stability

Layer 'Low Species Stability' is a composite layer producing 7 classes generated from the sum of:

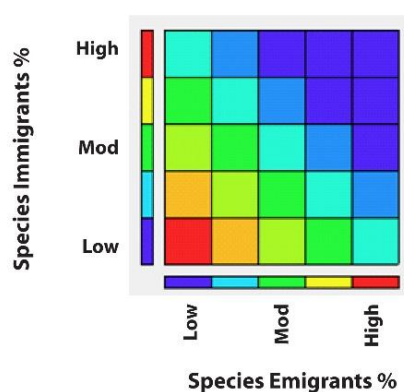
- 1.5 x 'Animal Species Stability RCP 8.5 2085'
- 1 x 'Plant Species Stability A2 2080'

This layer combines the two indicators of stability. The result is classed according to an equal interval scale.

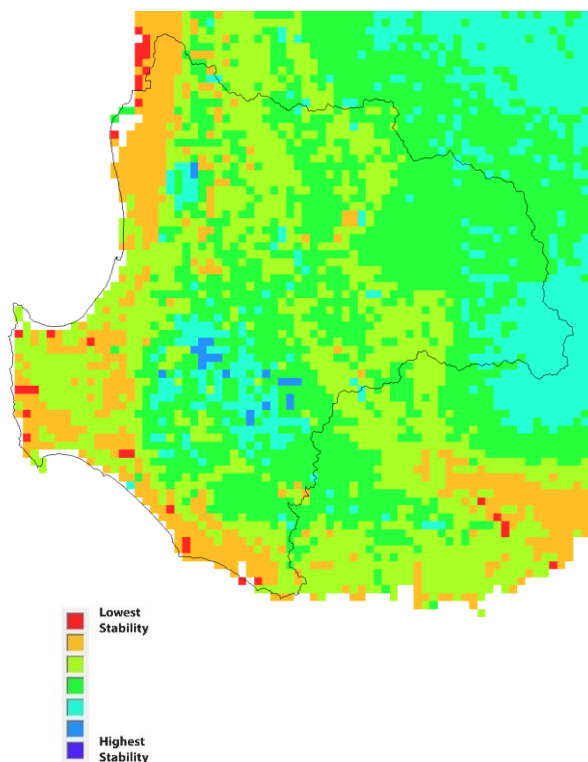


Plant Species Stability A2 2080

Layer 'Plant Species Stability A2 2080' is generated with a Two Way from 'CENRM Plant Emigrants %' and 'CENRM Plant Immigrants %' producing 7 classes:



The highest values are given to cells which combine low emigration AND low immigration (stability).

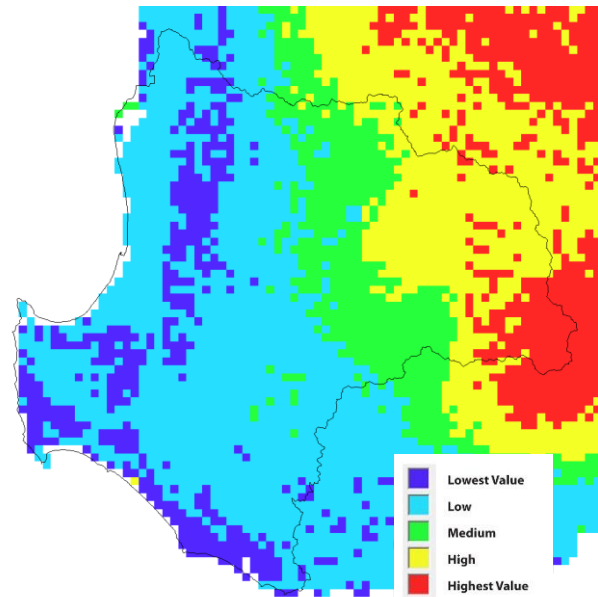


CENRM Plant Emigrants %

Layer 'CENRM Plant Emigrants %' is generated from primary data 'em_pr_a2_2080'. The numbers refer to the number of emigrant species as a % of the existing modelled species richness. The small number of modelled species in some cells has a large bearing on the high percentages.

Split into 5 classes using an equal interval scale:

- 1 - from 0 – 18%
- 2 - from 18 – 36%
- 3 - from 36. – 54%
- 4 - from 54 – 72%
- 5 - over 72% [High Values]



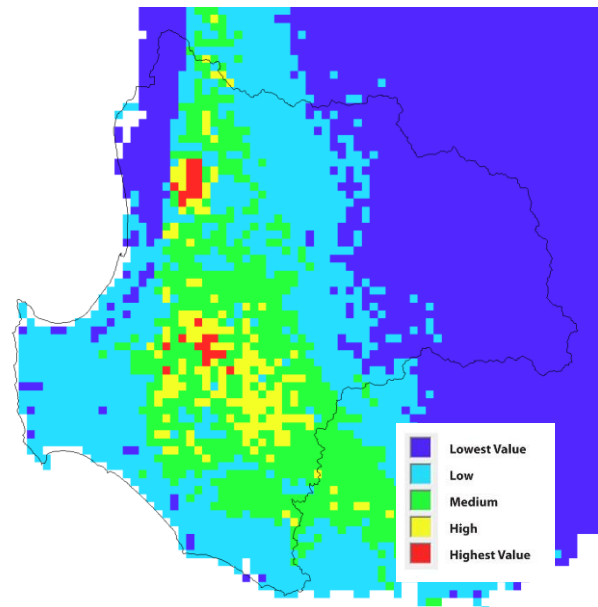
CENRM Plant Immigrants %

Layer 'CENRM Plant Immigrants %' is generated from primary data 'im_pr_a2_2080'.

The numbers refer to the number of immigrant species as a % of the existing modelled species richness. The small number of modelled species in some cells has a bearing on the high percentages.

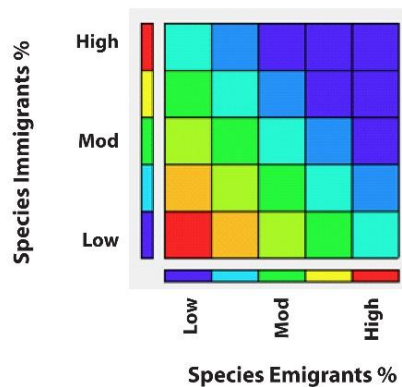
Split into 5 classes using an equal interval scale:

- 1 - from 2 – 24%
- 2 - from 24 – 47%
- 3 - from 47 – 69%
- 4 - from 69 – 92%
- 5 - over 92% [High Values]

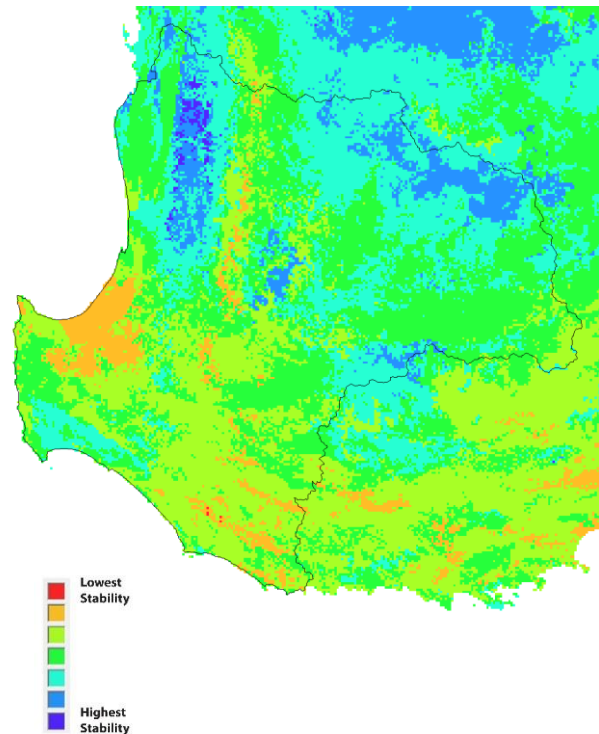


Animal Species Stability RCP 8.5 2085

Layer 'Animal Species Stability RCP 8.5 2085' is generated with a Two Way from 'NCCARF Animal Emigrants %' and 'NCCARF Animal Immigrants %' producing 7 classes:



The highest values are given to cells which combine low emigration AND low immigration (stability).



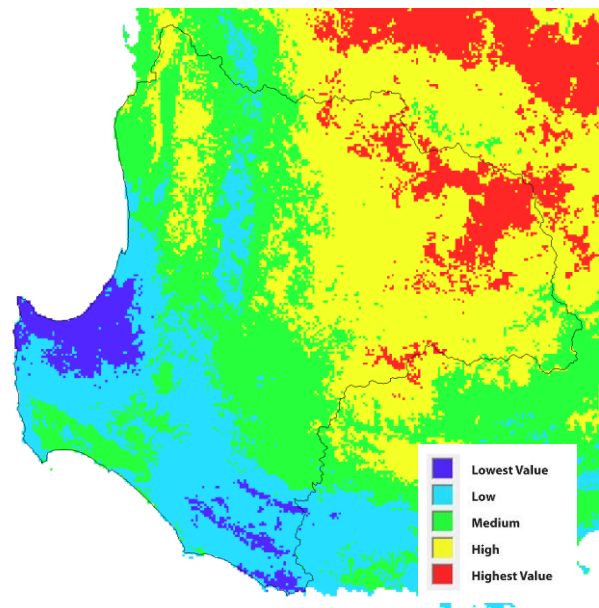
NCCARF Animal Emigrants %

Layer 'NCCARF Animal Emigrants %' is generated from primary data 'em_pr_85_2085'.

Split into 5 classes

- 1 - from 23 – 28%
- 2 - from 28 – 32%
- 3 - from 32 – 37%
- 4 - from 37 – 41%
- 5 – over 41% [Highest Value]

Clearly the animal emigration percentages are in a more constrained scale than the plant reductions, due to much large sample size and more diverse species selection.



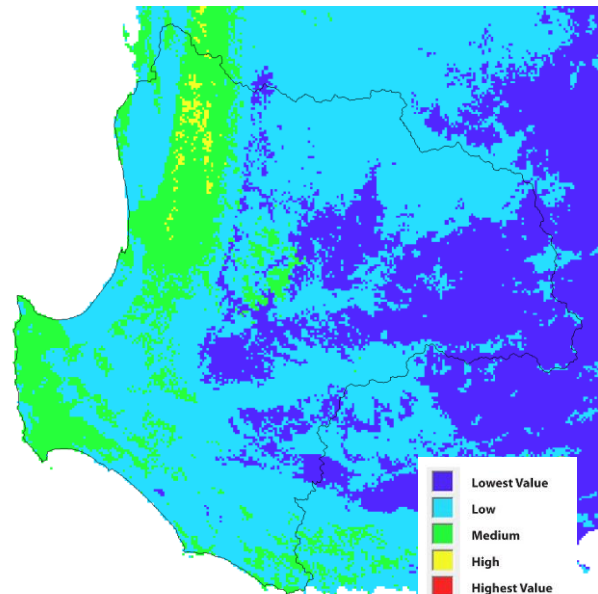
NCCARF Animal Immigrants %

Layer 'NCCARF Animal Immigrants %' is generated from primary data 'im_pr_85_2085'.

Split into 5 classes

- 1 - from 21 – 31%
- 2 - from 31 – 42%
- 3 - from 42 – 53%
- 4 - from 53 – 63%
- 5 – over 63% [Highest Value]

The classification used here reflects a wider range than exists in the SWCC region, indicating that on an Australia-wide scale the SWCC region has few areas likely to attract a high proportion of new species.



Component C1 Output - Climate Impact on Biodiversity

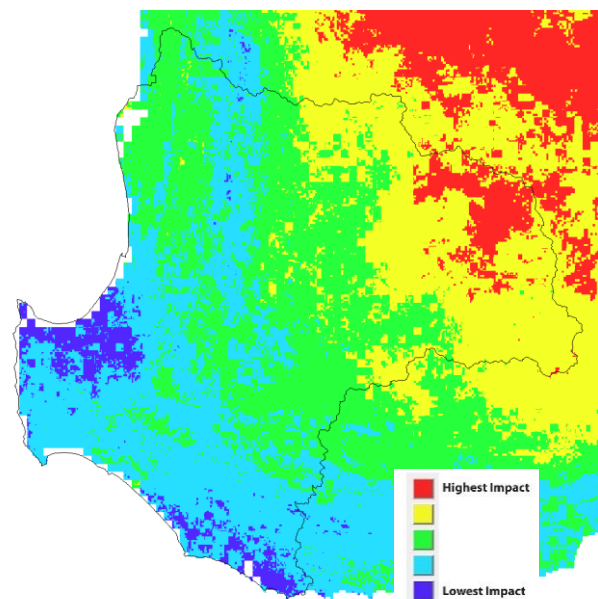
Layer 'C1 Climate Impact on Biodiversity' is a composite layer producing 5 classes.

The composite function is generated from the sum of:

- 1 x 'High Projected Species Loss'
- 1 x 'Low Refugia Status'
- 1 x 'Low Species Stability'

The weightings used are nominal: because of the interrelationships between these dataset, the final result is not very sensitive to variation in weightings. In other words, while the three criteria reflect different measures, they are ultimately mapping the same data.

The result is classed using an equal interval scale.



5. RESULTS

New Components

The following maps show maps for the three new components.

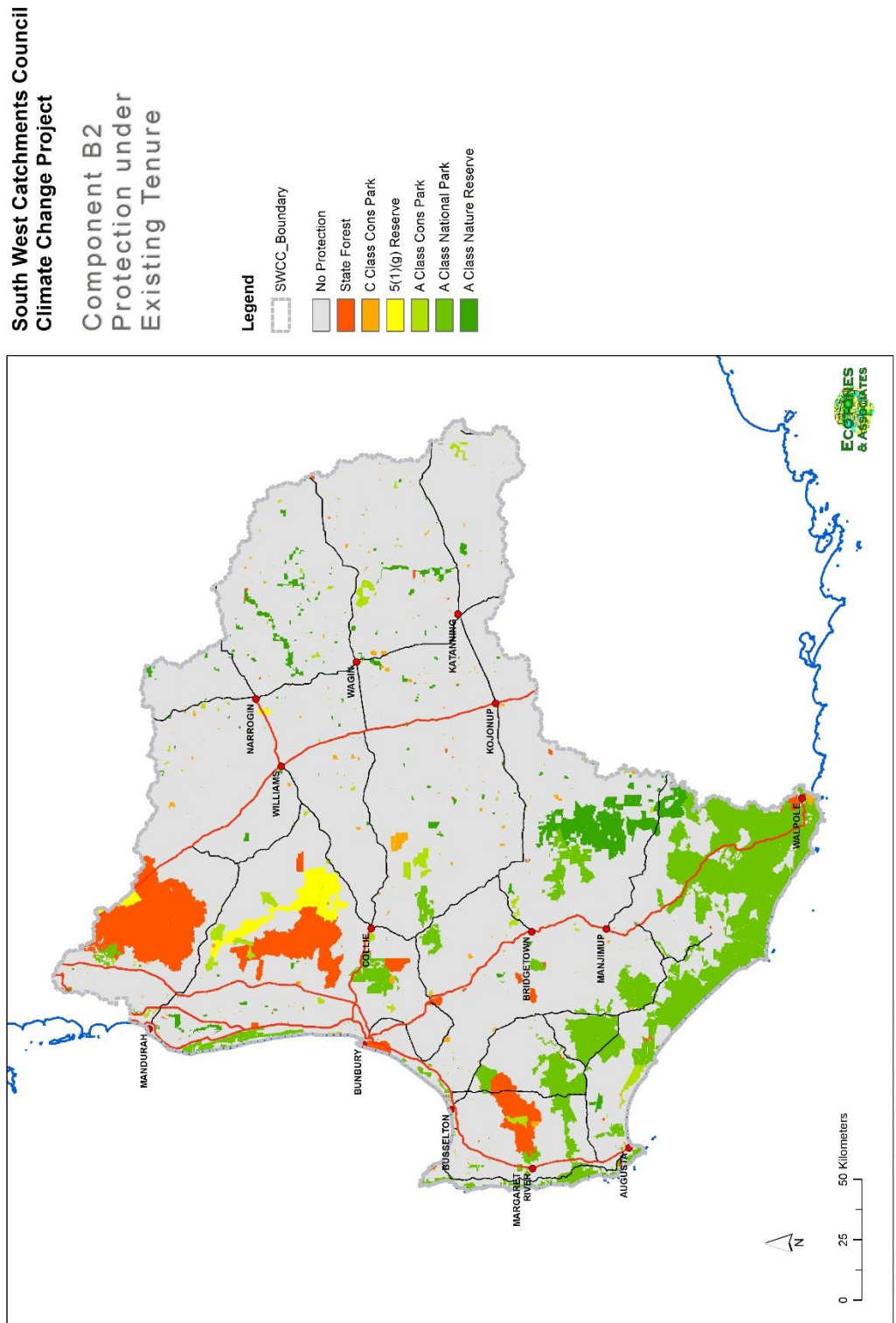


Figure 33: Component B2 – Protection under Existing Tenure and Security

South West Catchments Council
Climate Change Project
Component B3
Landscape Linkages

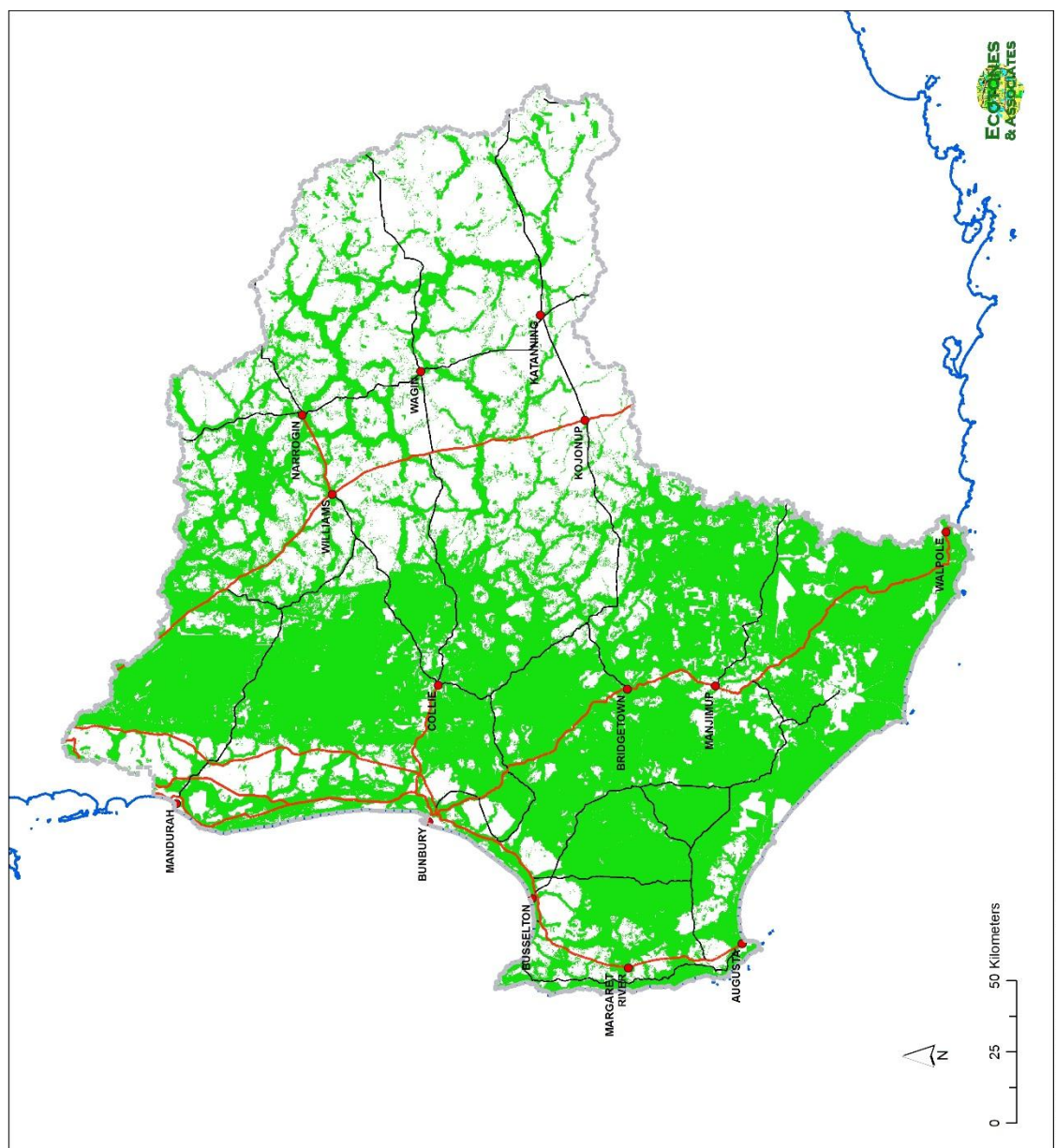


Figure 34: Component B3 – Landscape Linkages

South West Catchments Council
Climate Change Project
Component C1
Climate Impact
on Biodiversity

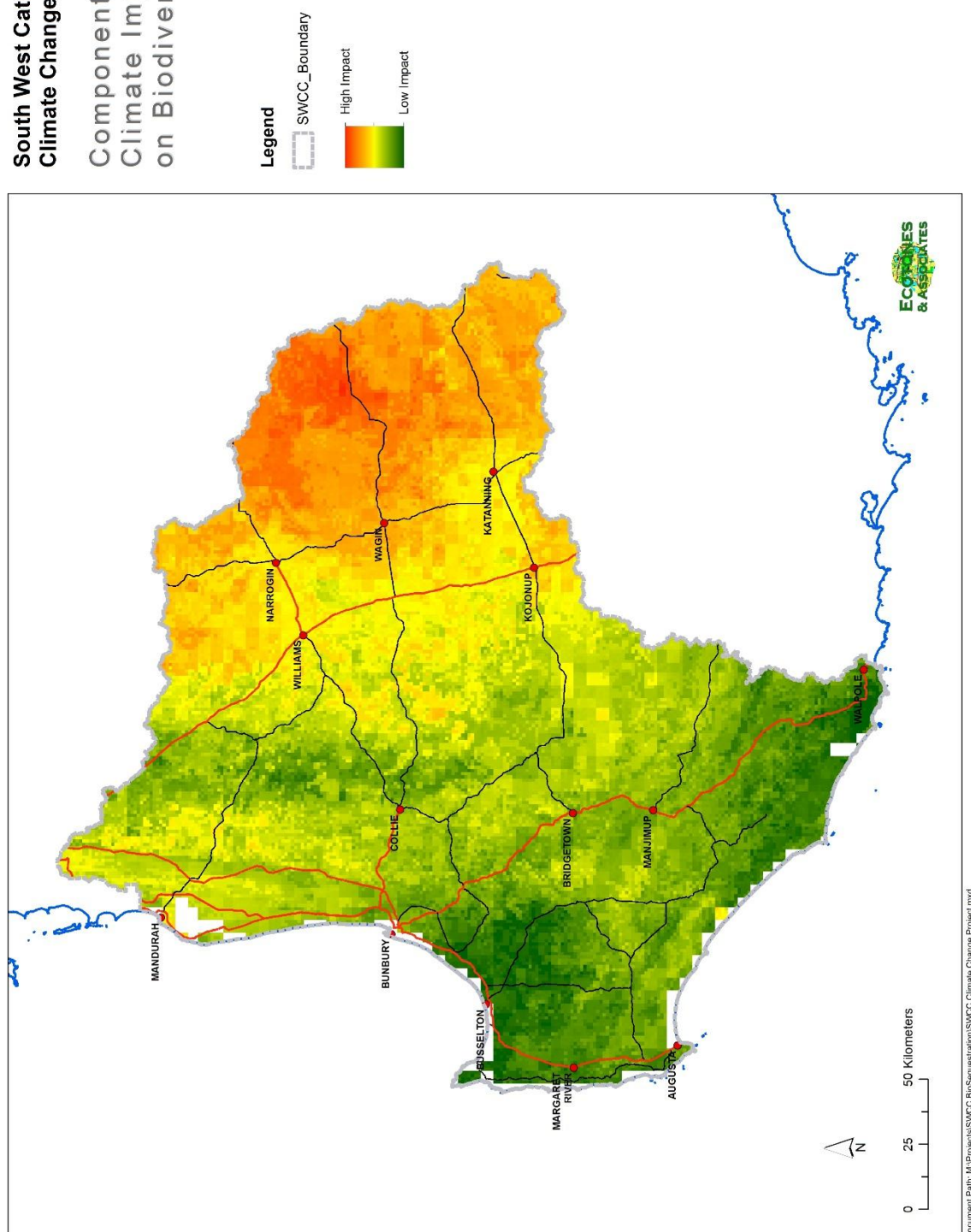


Figure 35: Component C1 – Climate Impacts on Biodiversity

Component B4 – Combinations for Conservation/Biodiversity prioritisation

We have developed an MCAS-S Component (B4) to combine the outputs produced in this work with the previous Component 3 – Conservation/Biodiversity values (Neville 2014a). This has allowed the production of maps that may be useful for specific aspects of biodiversity conservation in respect to protection and linkages. It must be noted that these are intended only as indications of what the outputs may be used for.

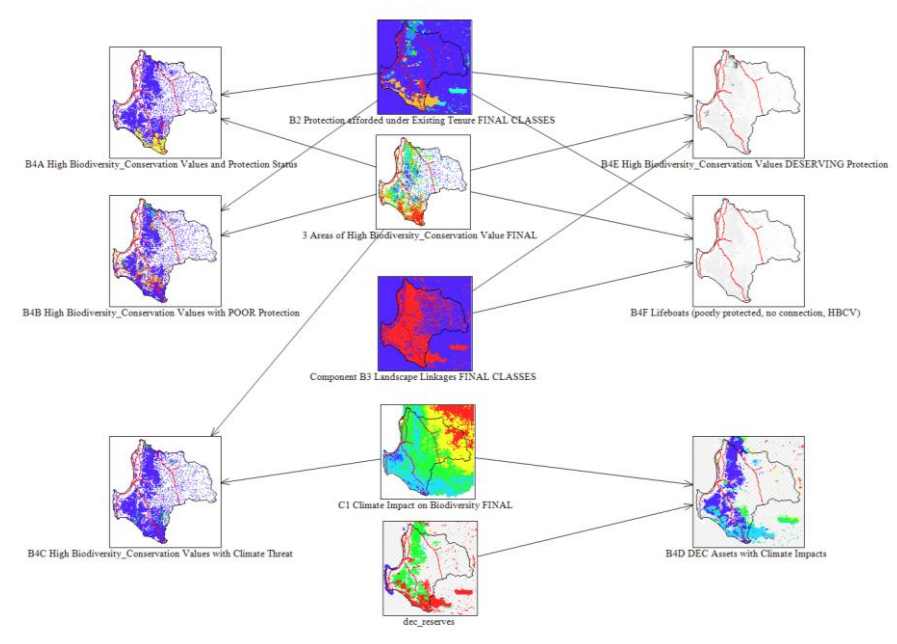


Figure 36: Component B4 – Combinations of Theme B Components

The outputs from Component B4 indicate:

- B4A & B4B - The protection status of High Biodiversity/Conservation values;
- B4C – Where high Biodiversity/Conservation values may be threatened by climate change;
- B4D – Where DPaW assets may be threatened by climate change;
- B4E - Where High Biodiversity/Conservation Values exist in areas with poor protection but with good linkage values (= deserving protection); and
- B4F - “Lifeboat Areas” – area with high Biodiversity/Conservation values that are poorly protected and with poor linkage potential. These have been described as “lifeboat areas” – collect seed/specimens but do not invest. A harsh but probably accurate reflection of their fate, unless they have high resilience along the lines of an OCBIL classification of Stephen Hopper (Hopper, 2009).

Indicative Theme B results

B4A - High Conservation/Biodiversity Values with Protection Status

This map identifies areas with ‘high’ Biodiversity/Conservation value (using the highest class value from the output of Component 3), with their current level of protection from tenure and vesting. It indicates that the bulk of high biodiversity values identified currently have protection through either national park or nature reserve.

B4B - High Conservation/Biodiversity Values with Poor Protection Status

This map shows areas in the two highest Biodiversity/Conservation classes (using the class values from the output of Component 3), which have either very low or no protection from tenure and vesting. It indicates that significant areas of high biodiversity values identified currently have either low or no protection.

B4C - High Conservation/Biodiversity Values with climate threat

This map shows areas with 'high' Biodiversity/Conservation value with an indication of the potential level of threat from climate-driven biodiversity change. It suggests that whilst no areas of the highest biodiversity values are at the highest threat level, there are areas of the second highest class that are – these occur in a few areas, especially the east of the region.

B4D – DPaW assets with climate threat

This map shows areas of DPaW reserve classes (assets) with an indication of the potential level of threat from climate-driven biodiversity change. It suggests that there are significant areas of high-level DPaW assets that are at the highest threat level. These occur in the east of the region, and are notable outside the region further east.

B4E High Conservation/Biodiversity Values Deserving Protection

Map B4E uses three criteria to identify all areas that combine high or very high biodiversity value and high landscape linkage value but without tenured/security protection. We have used the descriptor “deserving protection” due to this intersection of values. Additional reservation, protection through covenants, or even biodiversity plantings to provide better connectivity and to augment current smaller areas would assist in meeting multiple objectives of protection of biodiversity and landscape re-connection. Notable is a concentration of land that meets these criteria in the north of the region (state forest areas).

B4F “Lifeboat Areas” – High Biodiversity areas outside linkages and without protection

This is an exploratory map of areas that meet a different set of criteria: high biodiversity values and poor protection combined with not being in landscape linkages. The areas identified are small and mainly isolated, and in these cases have fewer reasons for investment, and even if given better protection is likely to remain isolated. Unless these areas are extremely robust (ie OCBILS according to Hopper, 2009) they are likely to continue to decline over time. The suggestion of a “lifeboat” is that we would consider forms of off-site conservation (ie relocation of species) but not invest additional resources.

**South West Catchments Council
Climate Change Project**

Component B4A

High Conservation/Biodiversity
Values and Protection Status

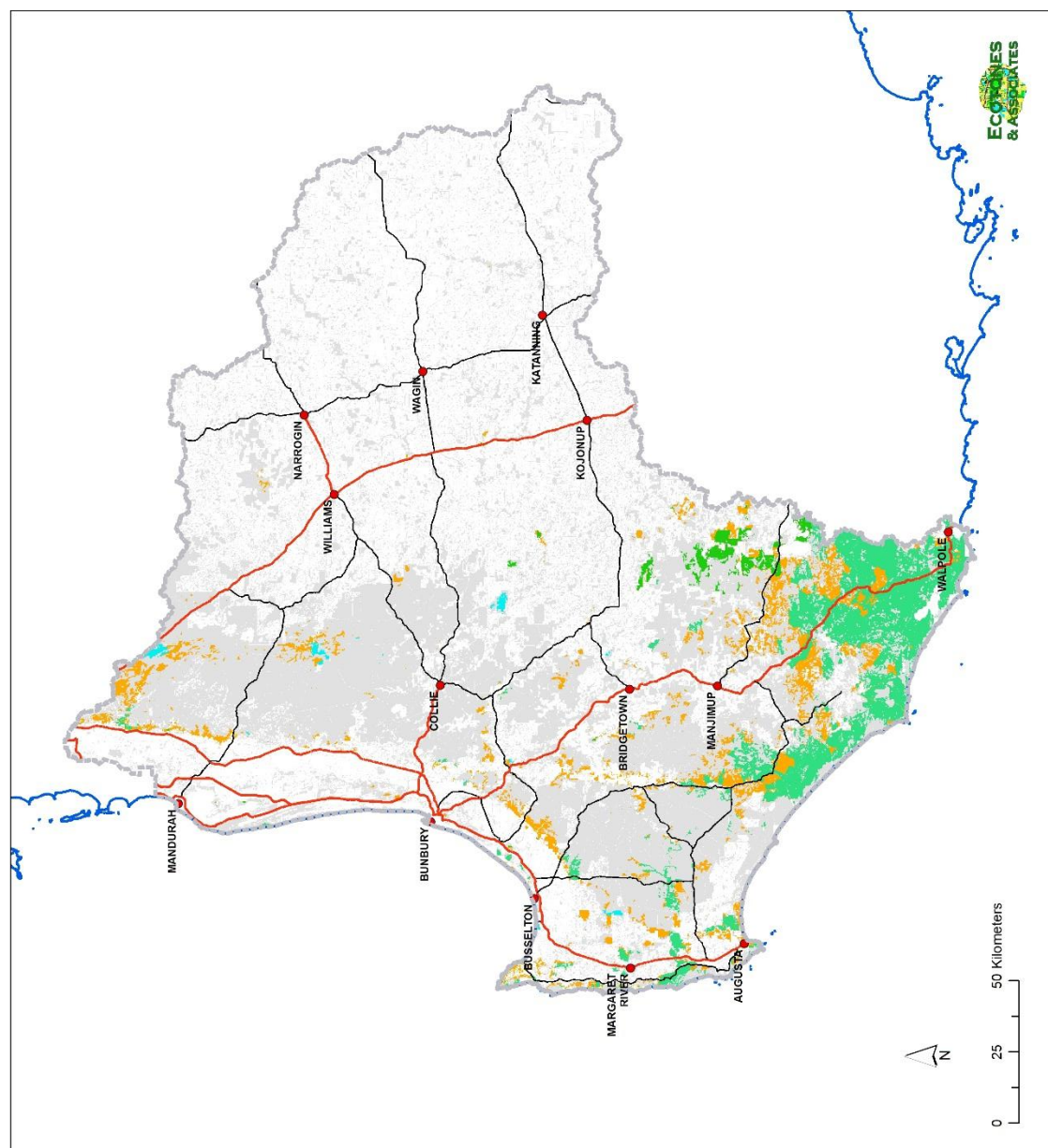


Figure 37: Component B4A – High Conservation/Biodiversity Value Areas with Protection Status

**South West Catchments Council
Climate Change Project**

Component B4B

High Conservation/Biodiversity
Values with Poor Protection

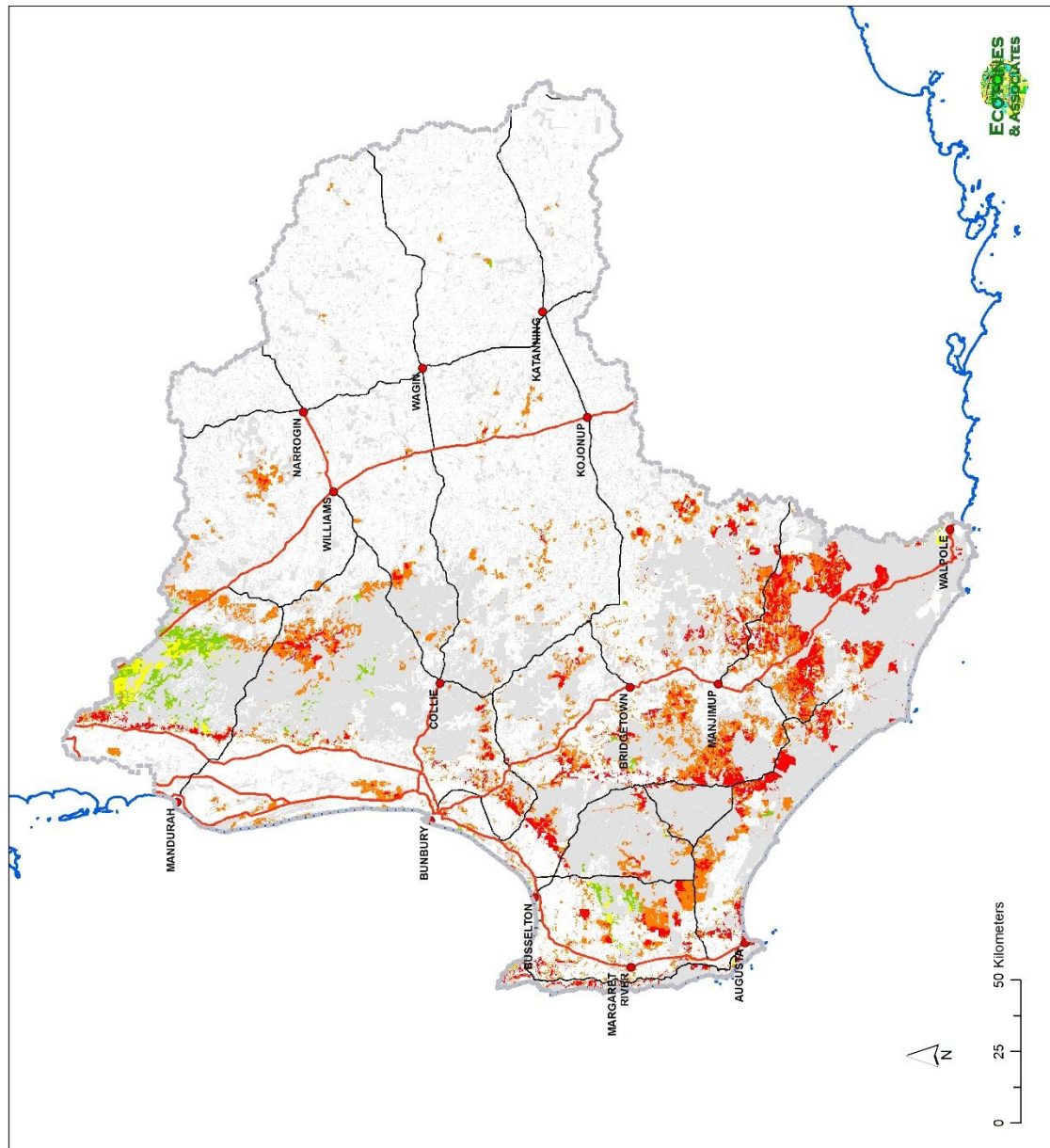


Figure 38: Component B4B – High Conservation/Biodiversity Value Areas with Poor or No Protection

**South West Catchments Council
Climate Change Project**

Component B4C
High Conservation/Biodiversity
Values with Climate Threat

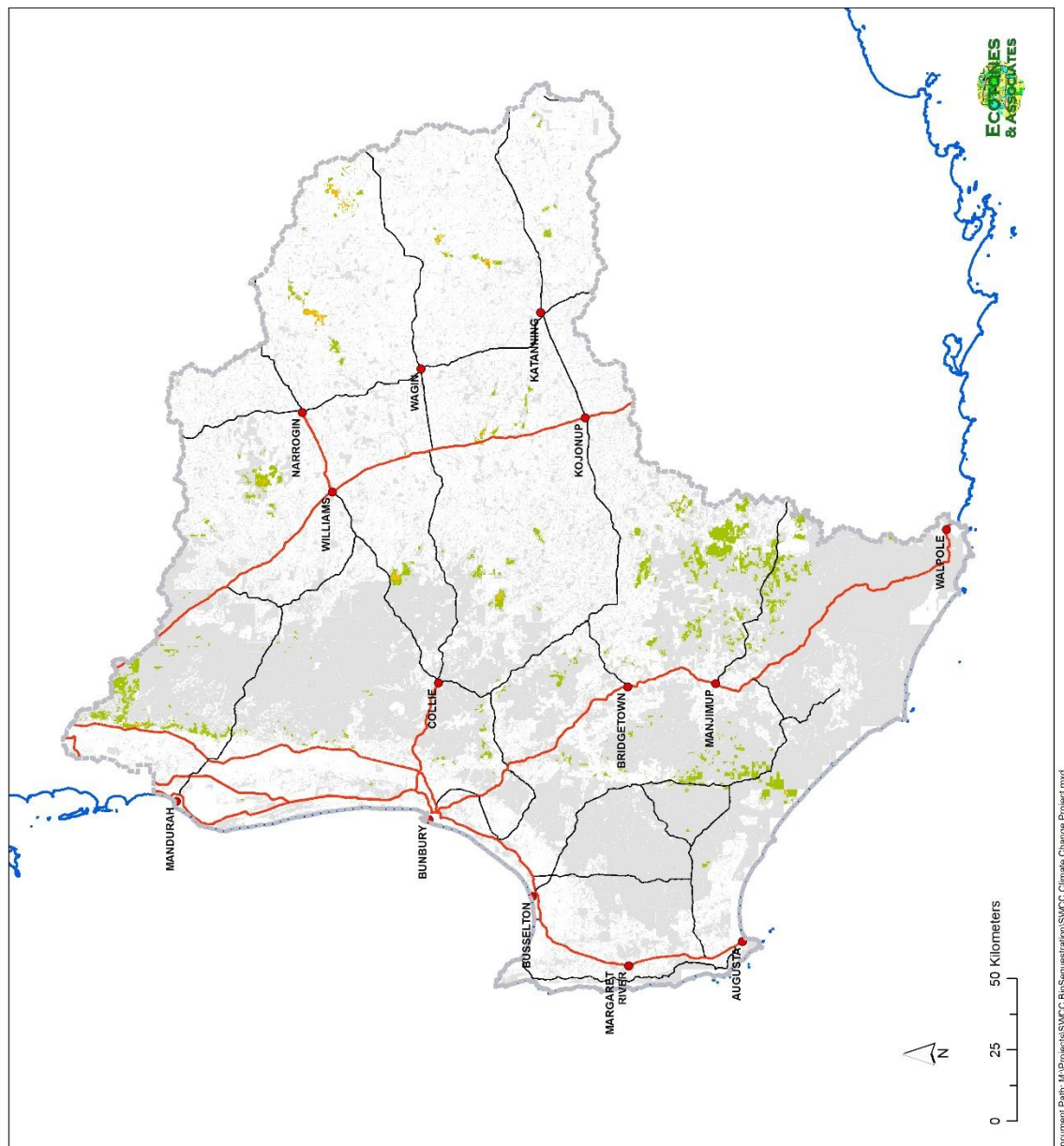


Figure 39: Component B4C – High Conservation/Biodiversity Value Areas with Climate Threat

South West Catchments Council
Climate Change Project

Component B4D
DPaW Assets with
Climate Threat

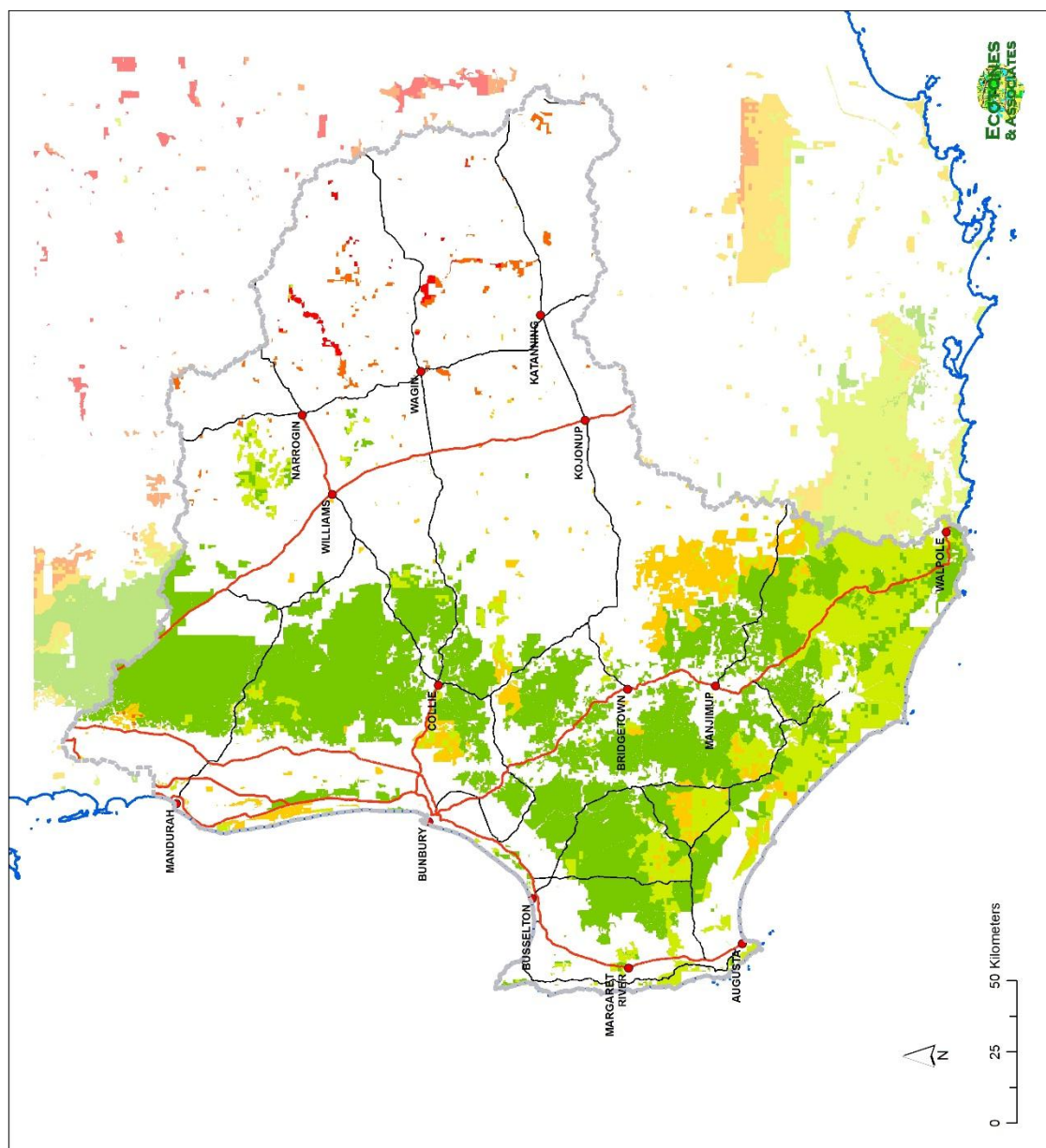


Figure 40: Component B4D – DPaW Assets with Climate Threat

**South West Catchments Council
Climate Change Project**

Component B4E

High Conservation/Biodiversity
Values, in Linkages,
without Protection

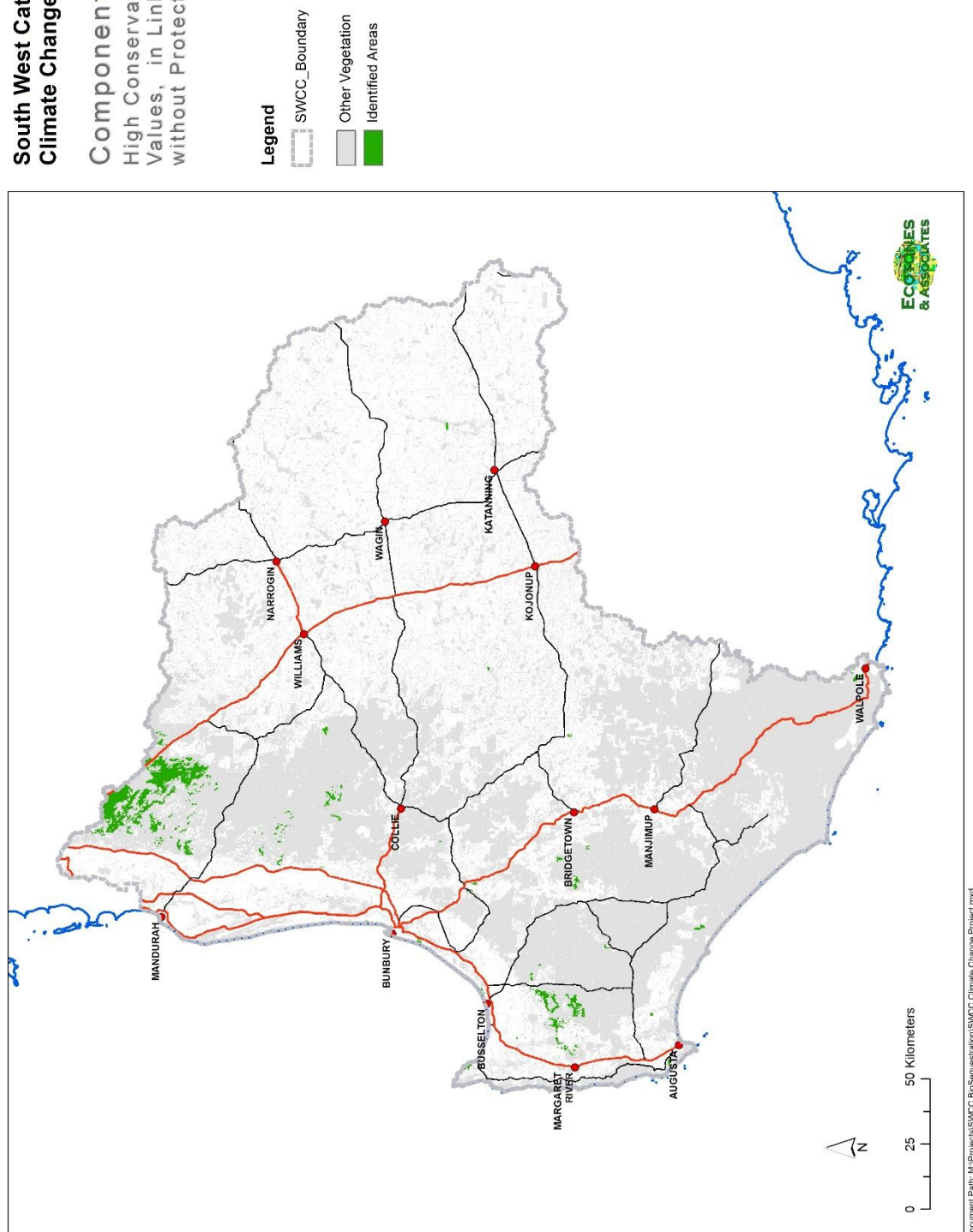


Figure 41: Component B4E – High CBV Areas in Linkages without Protection

**South West Catchments Council
Climate Change Project**

**Component B4F
'Lifeboat Areas'**

High Conservation/Biodiversity
Values outside Linkages
and Poorly Protected

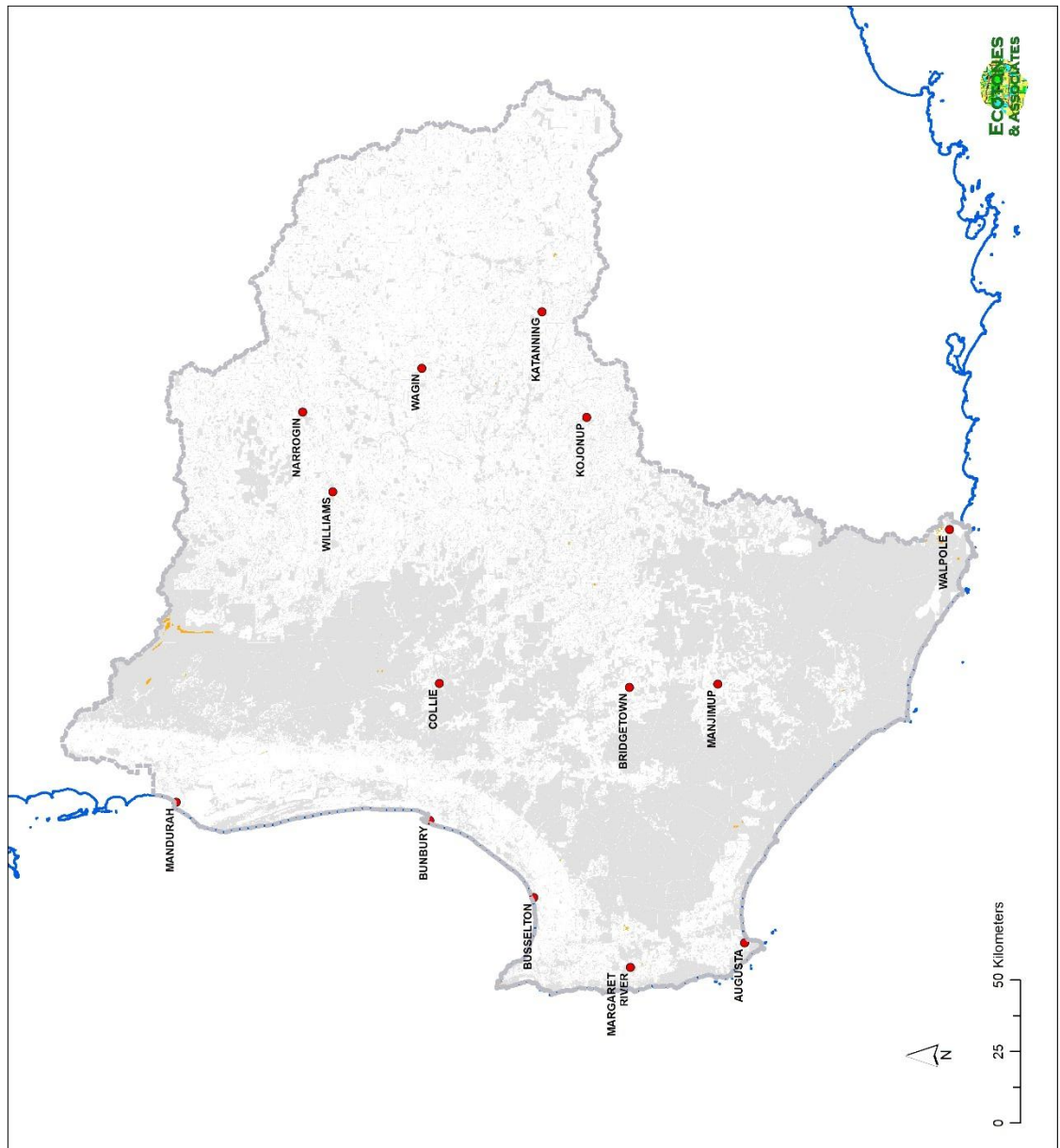
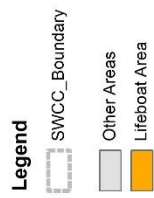


Figure 42: Component B4F – 'Lifeboat' Areas

Component B5 – Combinations for Conservation prioritisation

We have developed a further small MCAS-S Component (B5) to combine the outputs produced in this work with a simple indicator of conservation value (B5A – Critical Conservation Values). This varies from Component 3 in that it does not use biodiversity (diversity) indicators or area (naturalness) criteria. Instead it uses three conservation (rarity) criteria:

- % of each Vegetation Association within DEC Reserves (2012)
- Vegetation Association - Reduction in area (%) to 2014
- Vegetation Patch - % of remaining association area – 2014

Each of these criteria is derived from Heddle/Beard Datasets (DEC) & current vegetation remaining dataset (DAFWA). The reason for this is that the biodiversity component primarily selects vegetation that is in the main vegetation (forest) belts. Whereas the most severe climate impacts are indicated as being in the east and north east of the SWCC region, so we wanted to highlight conservation values in that part of the region.

This has allowed the production of a map that may be useful for specific aspects of conservation in respect to climate impacts. It must be noted that this is another simple indicator of what the outputs may be used for.

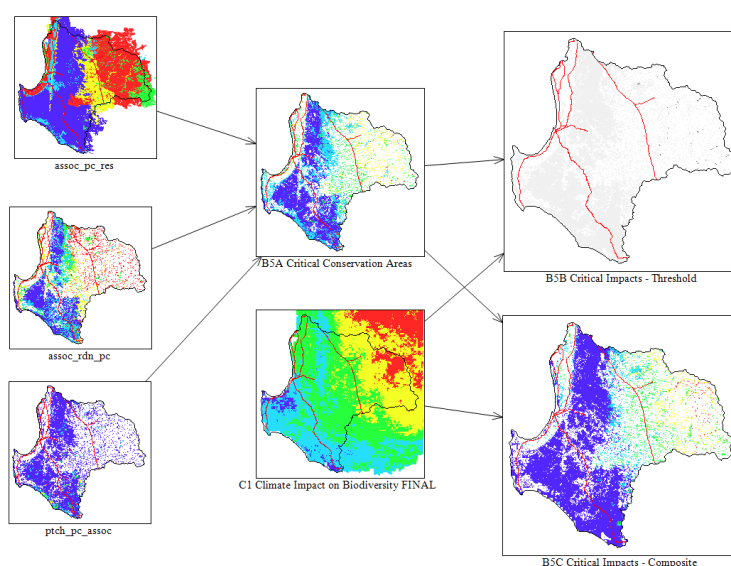


Figure 43: Component B5 – Climate Impact on Critical Conservation Areas

The outputs from Component B4 indicate:

- B5A – The location of Critical Conservation values;
- B5B – Where Critical Conservation values may be threatened by climate change (Threshold method);
- B5C – Where Critical Conservation values may be threatened by climate change (Composite method);

B5A indicates a number of small areas in the east of the SWCC region as having significant conservation value. B5A and B5B indicate that many small areas in the east of the region coincide with indicated high climate change impacts. This combination may be useful in management of these small remaining areas of natural vegetation.

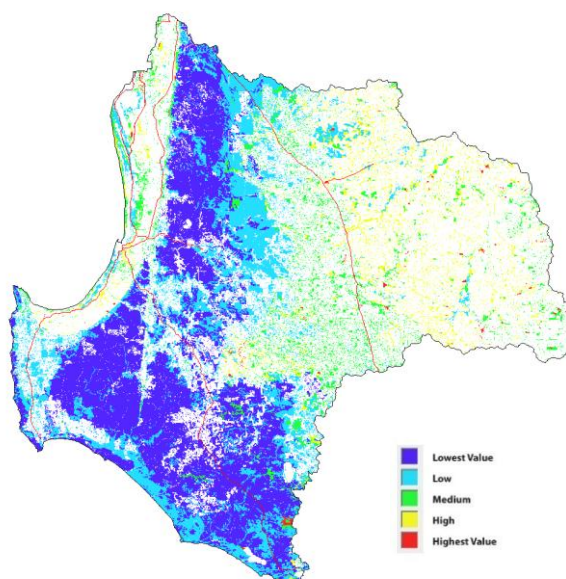
B5A Critical Conservation Areas

Layer 'B5A Critical Conservation Areas' is a composite layer producing 5 classes

The composite function is generated from the of:

- 1 x ' % of each Vegetation Association within DEC Reserve'
- 1 x 'Vegetation Association - Reduction in area (%) to 2014'
- 1 x 'Vegetation Patch - % of remaining association area - 2014'

The result is classed according to a custom classification that highlights a small number of the highest value areas.



% of each Vegetation Association within DEC Reserve

Layer ' % of each Vegetation Association within DEC Reserve' is generated from primary data 'assoc_pc_res'

Split into 5 classes

5 - from 0 – 10% [Highest Value]

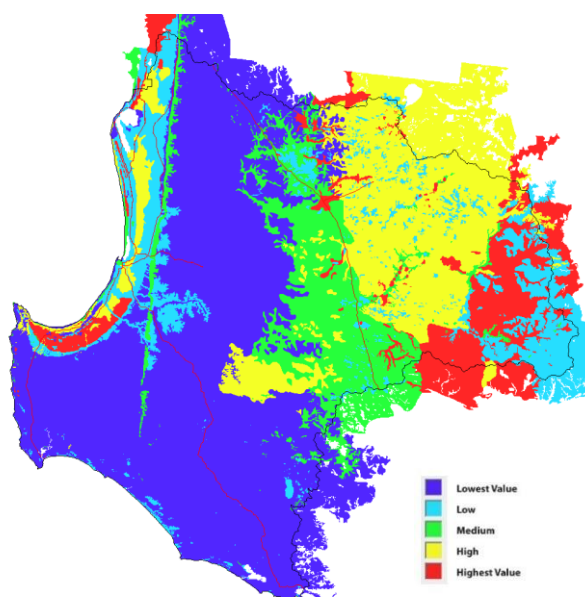
4 - from 10 – 17%

3 - from 17-30%

2 - from 30-50%

1 - from 50-100%

The highest value class indicates very poor reservation, class 2 shows reservation below international standards.

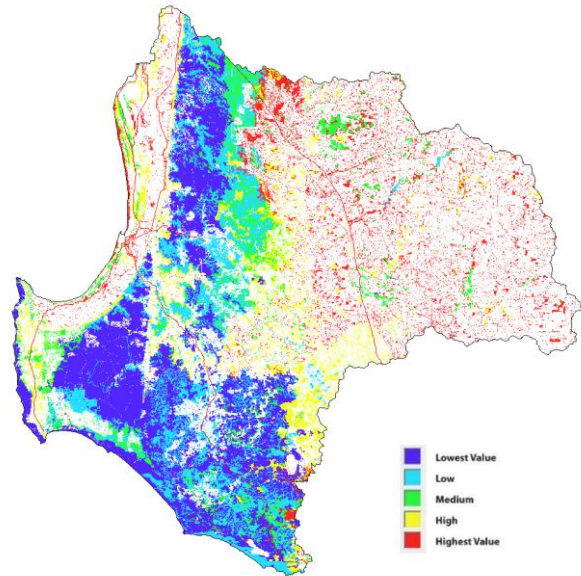


Vegetation Association - Reduction in area (%) to 2014

Layer 'Vegetation Association - Reduction in area (%) to 2014' is generated from primary data 'assoc_rdn_pc'

Split into 5 classes

- 1 - from 0-20%
- 2 - from 20-40%
- 3 - from 40-60%
- 4 - from 60-80%
- 5 - from 80-100% [Highest Value].



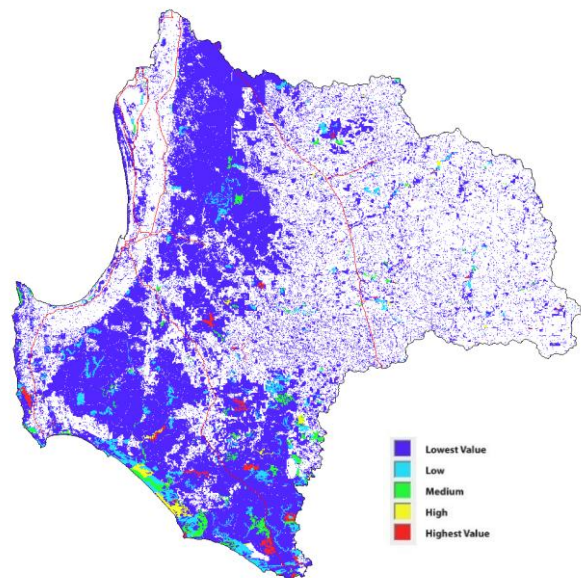
Vegetation Patch - % of remaining association area - 2014

Layer 'Vegetation Patch - % of remaining association area - 2014' is generated from primary data 'ptch_pc_assoc'

Split into 5 classes

- 1 - from 0-10%
- 2 - from 10-20%
- 3 - from 20-35%
- 4 - from 35-50%
- 5 - from 50-100% [Highest Value]

The highest class indicates patches which are more than 50% of the remaining vegetation type.



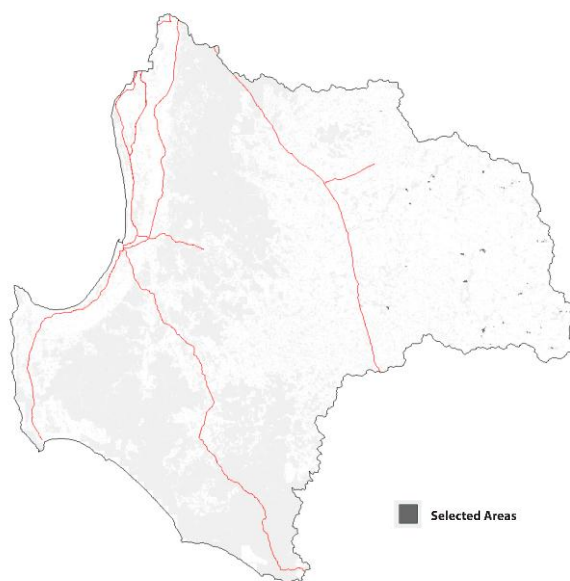
B5B Critical Impacts - Threshold

Layer 'B5B Critical Impacts - Threshold' is generated with a multi-way mask function

The mask is generated with the following criteria:

- Layer 'C1 Climate Impact on Biodiversity FINAL' having a classified value between 4 and 5
- Layer 'B5A Critical Conservation Areas' having a classified value of 5.

This component output is only those areas with the identified critical conservation values and climate impacts in the highest two classes.



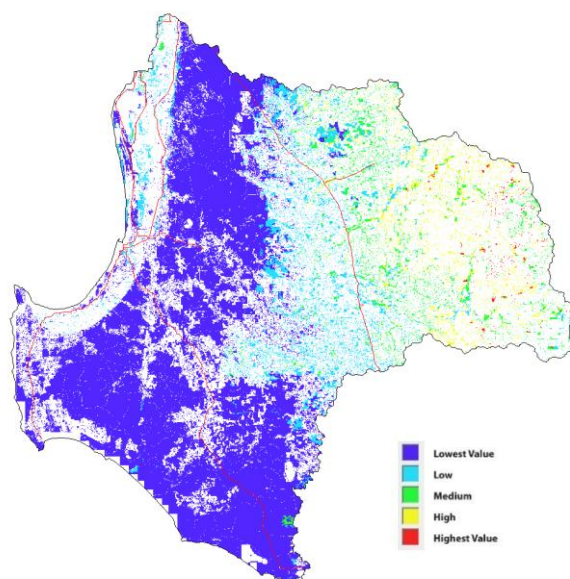
B5C Critical Impacts - Composite

Layer 'B5C Critical Impacts - Composite' is a composite layer producing 5 classes

The composite function is generated from the sum of:

- 1 x 'B5A Critical Conservation Areas'
- 1 x 'C1 Climate Impact on Biodiversity FINAL'

The result is classed according to a custom class system that selects a small number of key areas.



South West Catchments Council
Climate Change Project
Component B5A
Critical Conservation Area

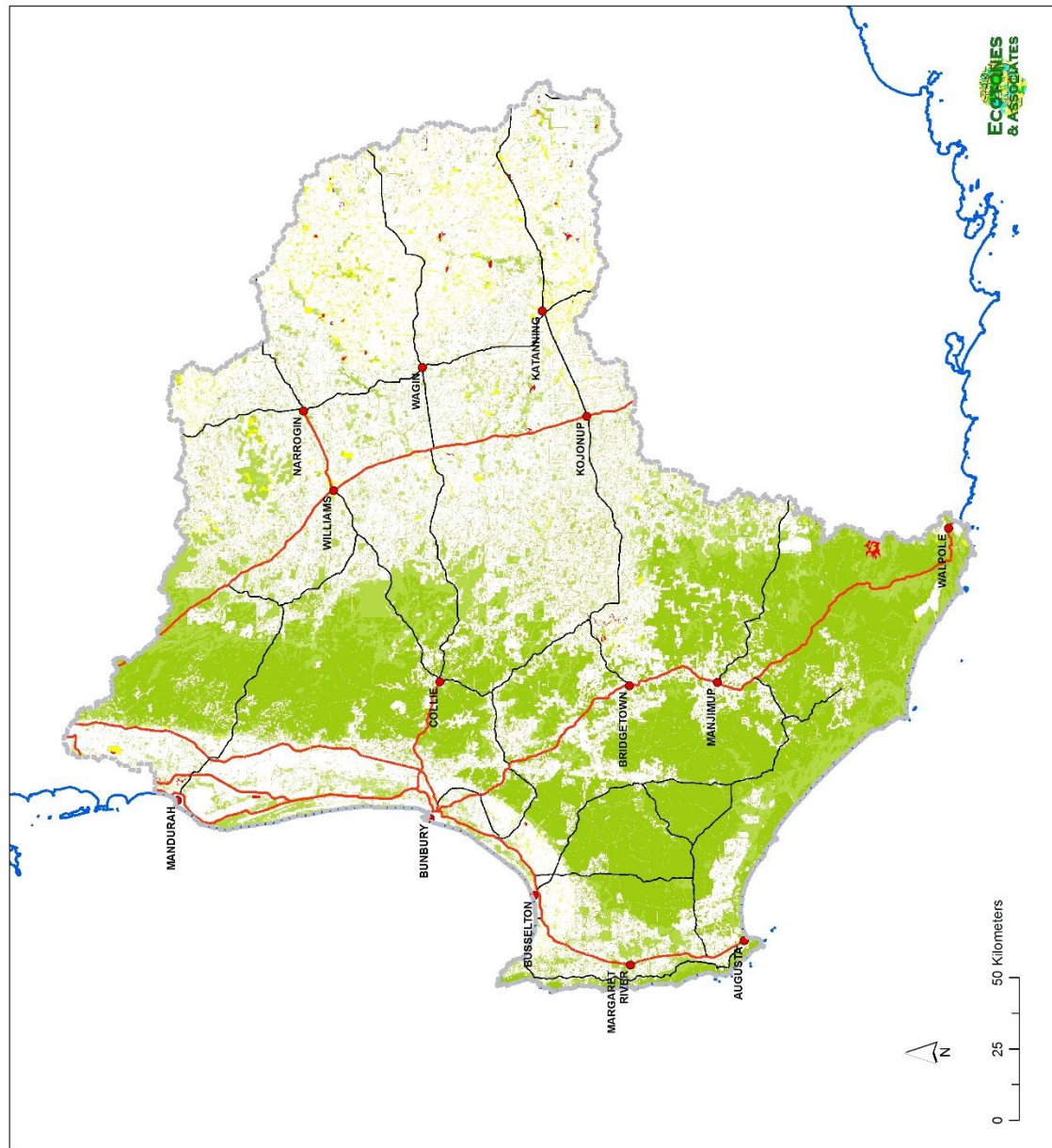


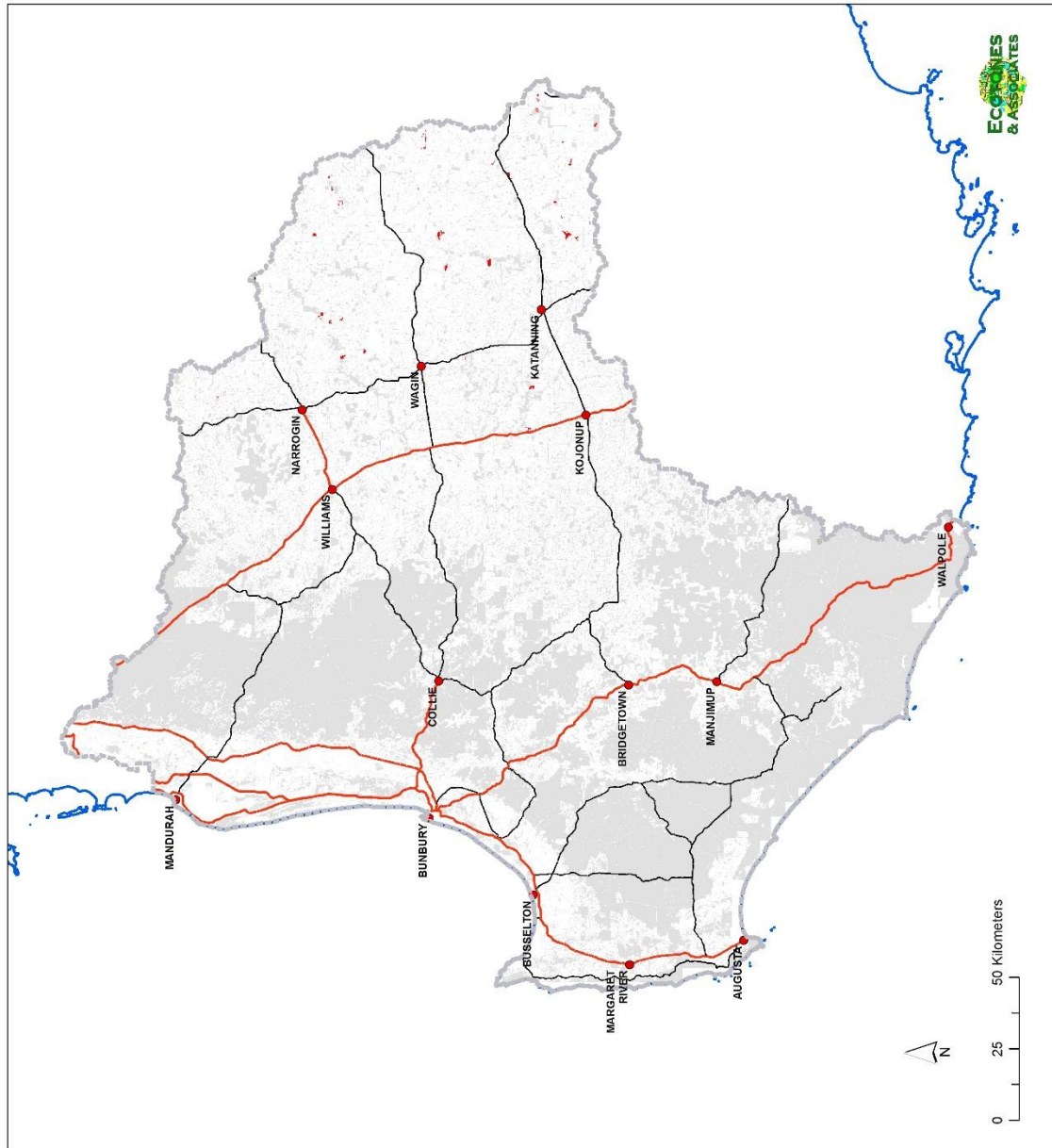
Figure 44: Component B5A – Critical Conservation Areas

**South West Catchments Council
Climate Change Project**

**Component B5B
Critical Impacts
Threshold Method**

Projected impacts of climate
change on critical conservation areas

Legend



Document Path: M:\Projects\SWCC Box\Sequestration\SWCC Climate Change Project.mxd

Figure 45: Component B5B – Critical Conservation Impacts – Threshold method

South West Catchments Council
Climate Change Project

Component B5C
Critical Impacts
Composite Method

Projected impacts of climate
change on critical conservation areas

Legend

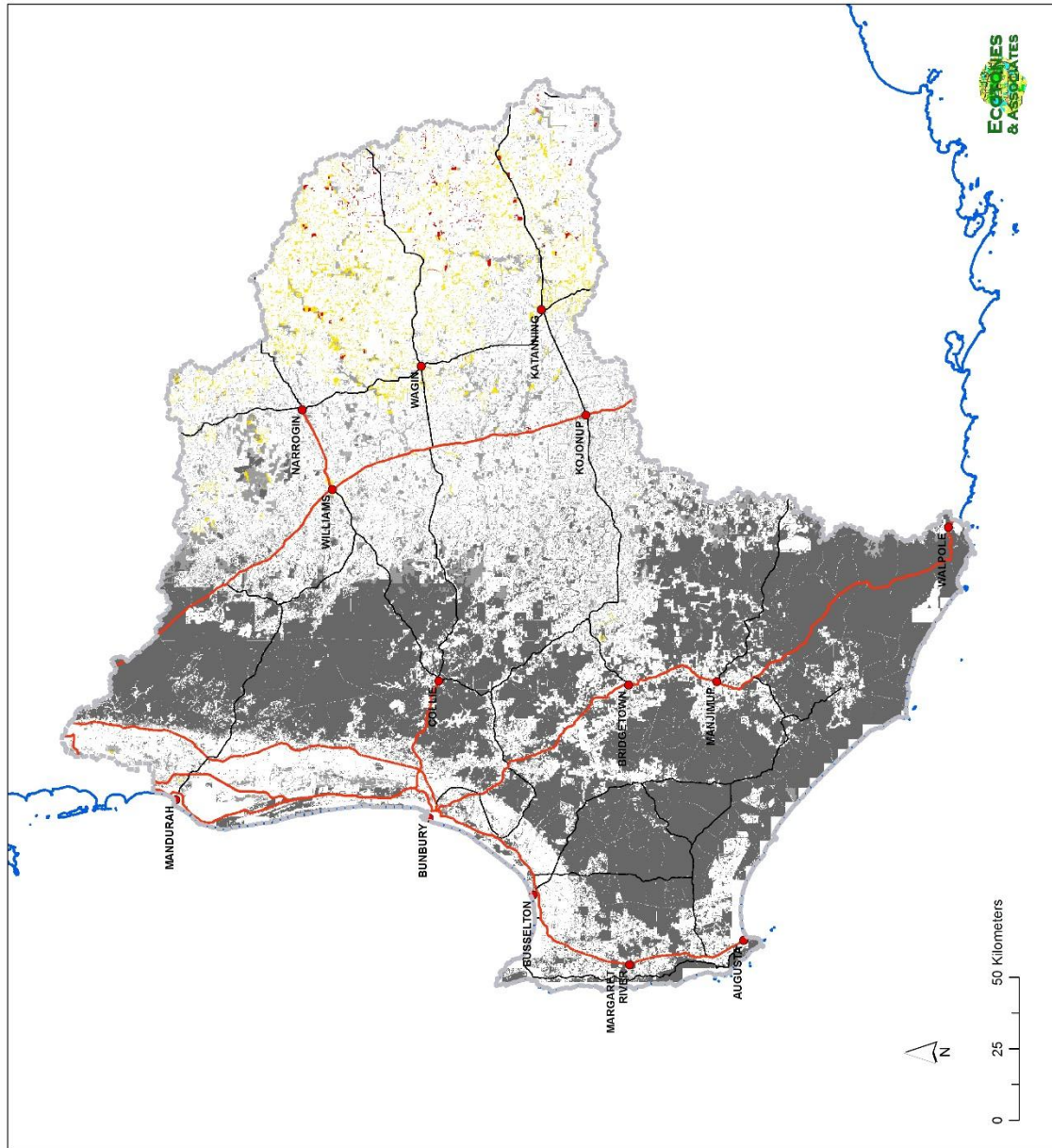
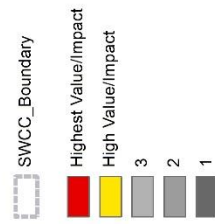


Figure 46: Component B5C – Critical Conservation Impacts – Composite method

6. REFERENCES

- Reside, AE, VanDerWal, J, Phillips, B, Shoo, LP, Rosauer, DF, Anderson, BJ, Welbergen, J, Moritz, C, Ferrier, S, Harwood, TD, Williams, KJ, Mackey, B, Hugh, S, Williams, SE (2013) *Climate change refugia for terrestrial biodiversity: Defining areas that promote species persistence and ecosystem resilience in the face of global climate change*, National Climate Change Adaptation Research Facility, Gold Coast.
- Neville, SD (2014a) Spatially representing South West Catchments Council priorities for biosequestration plantations and high biodiversity planting under climate change. Consultant's report for South West Catchments Council. Ecotones & Associates, Denmark., WA.
- Neville, SD (2014b) Projected climate change impacts for SWCC – discussion of rainfall & temperature change in relation to SWCC assets. Consultant's report for South West Catchments Council. Ecotones & Associates, Denmark., WA.
- James Cook University (2013) Climate Change and Biodiversity Report for South West Region. Prepared by the James Cook University eResearch Centre and Centre for Tropical Biodiversity and Climate Change. <http://tdh-tools-2.hpc.jcu.edu.au/climas/reports>.

7. APPENDIX 1 – CENRM SDM MODELING – SPECIES LISTS & GROUPS

Species listed by Vegetation Groups

These groups are how the species were characterised when selected for the modeling, and so are in part the reasons for each selection (ie iconic or threatened species).

Group: Threatened Flora

Scientific Name	Common Name
<i>Acacia cochlocarpa</i> subsp. <i>velutinos</i>	Velvety Spiral Pod Wattle
<i>Acacia unguicula</i>	A shrub
<i>Banksia anaton</i>	Cactus Dryandra
<i>Banksia aurantia</i>	Orange Dryandra
<i>Banksia fuscobracea</i>	Dark-bract Banksia
<i>Banksia serratuloides</i> subsp. <i>perissa</i>	Northern Serrate Dryandra
<i>Brachyscias verecundus</i>	A herb
<i>Caladenia lodgeana</i>	Lodge's spider-orchid
<i>Caladenia melanema</i>	Ballerina Orchid
<i>Caladenia procera</i>	Carbunup King Spider Orchid
<i>Calectasia cyanea</i>	Blue Tinsel Lily
<i>Conostylis setigera</i> subsp. <i>dasys</i>	Boscabel Conostylis
<i>Darwinia foetida</i>	Muchea Bell
<i>Dasymalla axillaris</i>	Native Foxglove
<i>Daviesia glossema</i>	Maroon-flowered Daviesia
<i>Eremophila rostrata</i> subsp. <i>trifida</i>	A shrub
<i>Gastrolobium diabolophyllum</i>	Bodallin Poison
<i>Gastrolobium luteifolium</i>	Yellow-leafed Gastrolobium
<i>Grevillea brachystylis</i> subsp. <i>grandis</i>	Large-flowered short-styled grevillea
<i>Guichenotia seorsiflora</i>	A shrub
<i>Gyrostemon reticulatus</i>	Net-veined Gyrostemon
<i>Haloragis platycarpa</i>	Broad-fruited Haloragis
<i>Hemigenia ramosissima</i>	Branched Hemigenia
<i>Hibbertia priceana</i>	A shrub
<i>Hybanthus cymulosus</i>	Ninghan Violet
<i>Isopogon robustus</i>	Robust Coneflower
<i>Lysiosepalum abollatum</i>	Woolly Lysiosepalum
<i>Muehlenbeckia horrida</i> subsp. <i>abdit</i>	Remote Thorny Lignum
<i>Paragoodia crenulata</i>	A pea
<i>Philothea falcata</i>	Sickle-leaved Waxflower
<i>Reedia spathacea</i>	A sedge
<i>Scaevola macrophylla</i>	Large-flowered Scaevola
<i>Tetratheca nephelioides</i>	A shrub
<i>Verticordia apecta</i>	Scruffy Verticordia

Group: Reveg Species

Scientific Name	Common Name
<i>Acacia assimilis</i>	A wattle
<i>Acacia assimilis</i> subsp. <i>atroviridis</i>	A wattle
<i>Acacia consobrina</i>	A wattle
<i>Acacia dictyoneura</i>	Musa Scented Wattle
<i>Acacia harveyi</i>	A wattle
<i>Acacia microbotrya</i>	Manna Wattle
<i>Acacia myrtifolia</i>	Myrtle Wattle
<i>Acacia pulchella</i>	Prickly Moses
<i>Acacia pulchella</i> var. <i>goadbyi</i>	A wattle
<i>Acacia redolens</i>	Vanilla Wattle
<i>Eucalyptus annulata</i>	Open-fruited Mallee
<i>Eucalyptus ecostata</i>	A Eucalypt
<i>Eucalyptus flocktoniae</i>	Merrit
<i>Eucalyptus thamnoides</i>	A Eucalypt
<i>Eucalyptus thamnoides</i> subsp. <i>thamnoides</i>	A Eucalypt
<i>Eucalyptus uncinata</i>	Hook-leaved Mallee
<i>Gastrolobium parviflorum</i>	Box Poison
<i>Gastrolobium spinosum</i>	Prickly Poison
<i>Hakea corymbosa</i>	Cauliflower Hakea
<i>Hakea laurina</i>	Pincushion Hakea
<i>Hakea nitida</i>	Frog Hakea
<i>Hakea pandanicaarpa</i>	A Hakea
<i>Hakea pandanicaarpa</i> subsp. <i>crassifolia</i>	A Hakea
<i>Melaleuca acuminata</i>	A Melaleuca
<i>Melaleuca hamata</i>	A Melaleuca
<i>Melaleuca thymoides</i>	Sand Wattle-Myrtle
<i>Templetonia retusa</i>	Cockies Tongues

Group: Coastal Vegetation

Scientific Name	Common Name
<i>Acacia cochlearis</i>	Rigid Wattle
<i>Acacia cyclops</i>	Coastal Wattle
<i>Acacia lasiocarpa</i>	Panjang
<i>Acacia littorea</i>	Wattle 1
<i>Acacia rostellifera</i>	Summer-Scented Wattle
<i>Acacia spathulifolia</i>	Wattle 2
<i>Acacia xanthina</i>	White-stemmed Wattle
<i>Actites megalocarpus</i>	Dune Thistle
<i>Adenanthos cygnorum</i>	Common Woollybush
<i>Adenanthos sericeus</i>	Woollybush
<i>Agonis flexuosa</i>	Peppermint
<i>Allocasuarina humilis</i>	Dwarf Sheoak
<i>Allocasuarina trichodon</i>	Sheoak 1
<i>Alyogyne huegelii</i>	Lilac Hibiscus
<i>Ammophila arenaria</i>	Marram Grass
<i>Angianthus cunninghamii</i>	Coast Angianthus
<i>Atriplex isatidea</i>	Coast Saltbush
<i>Banksia armata</i>	Prickly Dryandra
<i>Banksia grandis</i>	Bull Banksia
<i>Banksia heliantha</i>	Oak-leaved Dryandra
<i>Banksia media</i>	Southern Plains Banksia
<i>Banksia menziesii</i>	Firewood Banksia
<i>Banksia sessilis</i>	Parrot Bush
<i>Calothamnus pinifolius</i>	Dense Clawflower
<i>Calothamnus quadrifidus</i>	One-sided Bottlebrush
<i>Carpobrotus virescens</i>	Coastal Pigface
<i>Clematis linearifolia</i>	Slender Clematis
<i>Dodonaea aptera</i>	Coast Hop-bush
<i>Eucalyptus angulosa</i>	Ridge-fruited Mallee
<i>Eucalyptus conferruminata</i>	Bald Island Marlock
<i>Eucalyptus globata</i>	Port Lincoln Mallee
<i>Eucalyptus utilis</i>	Coastal Moort
<i>Exocarpos sparteus</i>	Broom Ballart
<i>Ficinia nodosa</i>	Knotted Club Rush
<i>Hakea oleifolia</i>	Dungyn
<i>Hardenbergia comptoniana</i>	Native Wisteria
<i>Hibbertia cuneiformis</i>	Cutleaf Hibbertia
<i>Jacksonia cupulifera</i>	A pea
<i>Lepidosperma gladiatum</i>	Coast Sword-sedge
<i>Leucophyta brownii</i>	Cushion Bush
<i>Melaleuca cardiophylla</i>	Tangling Melaleuca
<i>Melaleuca cuticularis</i>	Salt Paperbark
<i>Melaleuca huegelii</i>	Chenille Honeymyrtle
<i>Melaleuca pentagona</i>	A Melaleuca
<i>Melaleuca raphiophylla</i>	Swamp Paperbark
<i>Melaleuca systena</i>	A Melaleuca
<i>Myoporum insulare</i>	Blueberry Tree
<i>Nuytsia floribunda</i>	Christmas Tree
<i>Oxypetalum</i>	A shrub
<i>Olearia axillaris</i>	Coastal Daisybush
<i>Pelargonium capitatum</i>	Rose Pelargonium
<i>Pimelea clavata</i>	A shrub
<i>Pimelea ferruginea</i>	A shrub
<i>Scaevola crassifolia</i>	Thick-leaved Fan-flower
<i>Scaevola nitida</i>	Shining Fanflower
<i>Senecio pinnatifolius</i>	Coast Groundsel
<i>Spinifex hirsutus</i>	Hairy Spinifex
<i>Spinifex longifolius</i>	Beach Spinifex
<i>Spyridium globulosum</i>	Basket Bush
<i>Tetragonia decumbens</i>	Sea Spinach
<i>Trachypogon divaricata</i>	Dune Onion Weed

Group: Iconic Vegetation

Scientific Name	Common Name
<i>Acacia acuminata</i>	Jam
<i>Acacia aneura</i>	Mulga
<i>Acacia lasiocalyx</i>	Silver Wattle
<i>Acacia saligna</i>	Orange Wattle
<i>Acacia tetragonophylla</i>	Kurara
<i>Allocasuarina campestris</i>	Tamma
<i>Allocasuarina huegeliana</i>	Rock Sheoak
<i>Banksia attenuata</i>	Candle Banksia
<i>Casuarina obesa</i>	Swamp Sheoak
<i>Corymbia calophylla</i>	Marri
<i>Eucalyptus accedens</i>	Powder bark Wandoo
<i>Eucalyptus astringens</i>	Brown Mallet
<i>Eucalyptus brevistylis</i>	Rate's Tingle
<i>Eucalyptus decipiens</i>	Limestone Marlock
<i>Eucalyptus diversicolor</i>	Karri
<i>Eucalyptus eremophila</i>	Eastern Goldfields Horned Mallee
<i>Eucalyptus gomphocephala</i>	Tuart
<i>Eucalyptus guilfoylei</i>	Yellow Tingle
<i>Eucalyptus jacksonii</i>	Red Tingle
<i>Eucalyptus longicornis</i>	Red Morrel
<i>Eucalyptus loxophleba</i>	York Gum
<i>Eucalyptus marginata</i>	Jarrah
<i>Eucalyptus occidentalis</i>	Flat-topped Yate
<i>Eucalyptus patens</i>	Blackbutt
<i>Eucalyptus platypus</i>	Moort
<i>Eucalyptus rudis</i>	River Gum
<i>Eucalyptus salmonophloia</i>	Salmon Gum
<i>Eucalyptus salubris</i>	Gimlet
<i>Eucalyptus staeri</i>	Albany Blackbutt
<i>Eucalyptus todtiana</i>	Coastal Blackbutt
<i>Eucalyptus wandoo</i>	Wandoo
<i>Leptospermum erubescens</i>	Roadside Teatree
<i>Melaleuca preissiana</i>	Modong
<i>Melaleuca strobophylla</i>	A Paperbark
<i>Persoonia longifolia</i>	Snottygobble

Species listed by Refugia Modeling Groups

Analysis was done to identify the various climate drivers at work in species distributions. These groups list the species that responded most strongly to the specific climate drivers and were used in the developing the CENRM plant refugia index.

Altitude	Mean Summer Temperature	Winter Rain
<p>Acacia_cochlearis</p> <p>Allocasuarina_trichodon</p> <p>Atriplex_isatidea</p> <p>Carpobrotus_virescens</p> <p>Casuarina_obesa</p> <p>Clematis_linearifolia</p> <p>Dodonaea_aptera</p> <p>Eucalyptus_gomphocephala</p> <p>Exocarpos_sparteus</p> <p>Leucophyta_brownii</p> <p>Melaleuca_huegelii</p> <p>Myoporum_insulare</p> <p>Olearia_axillaris</p> <p>Pelargonium_capitatum</p> <p>Scaevola_crassifolia</p> <p>Spinifex_hirsutus</p> <p>Spinifex_longifolius</p> <p>Spyridium_globulosum</p> <p>Tetragonia_decumbens</p> <p>Trachyandra_divaricata</p>	<p>Acacia_aneura</p> <p>Acacia_consobrina</p> <p>Acacia_dictyoneura</p> <p>Acacia_harveyi</p> <p>Acacia_lasiocalyx</p> <p>Acacia_tetragonophylla</p> <p>Allocasuarina_huegeliana</p> <p>Eucalyptus_astringens</p> <p>Eucalyptus_conglobata</p> <p>Eucalyptus_occidentalis</p> <p>Eucalyptus_platypus</p> <p>Eucalyptus_staeri</p> <p>Eucalyptus_thamnoides</p> <p>Eucalyptus_uncinata</p> <p>Hakea_corymbosa</p> <p>Hakea_nitida</p> <p>Hakea_pandanicarpa</p> <p>Hakea_pandanicarpa_subsp._crassifolia</p>	<p>Acacia_acuminata</p> <p>Acacia_lasiocarpa</p> <p>Acacia_microbotrya</p> <p>Acacia_pulchella</p> <p>Acacia_pulchella_var._goadbyi</p> <p>Acacia_saligna</p> <p>Adenanthos_cygnorum</p> <p>Agonis_flexuosa</p> <p>Allocasuarina_campestris</p> <p>Allocasuarina_humilis</p> <p>Banksia_armata</p> <p>Banksia_attenuata</p> <p>Banksia_grandis</p> <p>Banksia_menziesii</p> <p>Banksia_sessilis</p> <p>Calothamnus_quadridius</p> <p>Corymbia_calophylla</p> <p>Eucalyptus_accedens</p> <p>Eucalyptus_decipiens</p> <p>Eucalyptus_flocktoniae</p> <p>Eucalyptus_loxophleba</p> <p>Eucalyptus_marginata</p> <p>Eucalyptus_patens</p> <p>Eucalyptus_rudis</p> <p>Eucalyptus_todtiana</p> <p>Eucalyptus_wandoo</p> <p>Gastrolobium_spinosum</p> <p>Hardenbergia_comptoniana</p> <p>Leptospermum_erubescens</p> <p>Melaleuca_preissiana</p> <p>Melaleuca_rhaphiophylla</p> <p>Melaleuca_strobophylla</p> <p>Melaleuca_systema</p> <p>Melaleuca_thymoides</p> <p>Nuytsia_floribunda</p> <p>Persoonia_longifolia</p>
Maximum Summer Temperature	Summer Rainfall	
<p>Acacia_cyclops</p> <p>Acacia_littorea</p> <p>Acacia_myrtifolia</p> <p>Adenanthos_sericeus</p> <p>Eucalyptus_angulosa</p> <p>Eucalyptus_diversicolor</p> <p>Hakea_oleifolia</p> <p>Hibbertia_cuneiformis</p> <p>Lepidosperma_gladiatum</p> <p>Melaleuca_cuticularis</p> <p>Pimelea_ferruginea</p> <p>Scaevola_nitida</p> <p>Templetonia_retusa</p>	<p>Acacia_assimilis</p> <p>Acacia_assimilis_subsp._atroviridis</p> <p>Acacia_redolens</p> <p>Ammophila_arenaria</p> <p>Banksia_heliantha</p> <p>Banksia_media</p> <p>Calothamnus_pinifolius</p> <p>Eucalyptus_annulata</p> <p>Eucalyptus_brevistylis</p> <p>Eucalyptus_conferruminata</p> <p>Eucalyptus_ecostata</p> <p>Eucalyptus_eremophila</p> <p>Eucalyptus_guilfoylei</p> <p>Eucalyptus_jacksonii</p> <p>Eucalyptus_longicornis</p> <p>Eucalyptus_salmonophloia</p> <p>Eucalyptus_salubris</p> <p>Eucalyptus_utilis</p> <p>Gastrolobium_parviflorum</p> <p>Hakea_laurina</p> <p>Melaleuca_acuminata</p> <p>Melaleuca_hamata</p> <p>Melaleuca_pentagona</p> <p>Olax_phyllanthi</p> <p>Pimelea_clavata</p>	
Soil Properties		
<p>Acacia_rostellifera</p> <p>Acacia_spathulifolia</p> <p>Acacia_xanthina</p> <p>Alyogyne_huegelii</p> <p>Angianthus_cunninghamii</p> <p>Jacksonia_cupulifera</p> <p>Melaleuca_cardiophylla</p>		

APPENDIX 2 - NEW MCAS LAYERS

Datasets

CENRM SDM

CENRM Current Plant Species Richness
CENRM Plant Emigration % under Climate Change - A2 2080
CENRM Plant Immigration % under Climate Change - A2 2080
CENRM Plant Species Overlap % under Climate Change - A2 2080
CENRM Plant Refugia under Climate Change - A2 2080

NCCARF_SDM

NCCARF Animal Refugia under Climate Change
NCCARF Animal Emigration % under Climate Change - RCP8.5 2085
NCCARF Animal Immigration % under Climate Change - RCP8.5 2085

Classified Outputs

Component Outputs

B2 Protection afforded under Existing Tenure
Component B3 Landscape Linkages
C1 Climate Impact on Biodiversity

Composite Outputs

B4A High Biodiversity_Conservation Values and Protection Status
B4B HBCV with POOR Protection
B4C HBCV with Climate Threat
B4D DEC Assets with Climate Impacts
B4E HBCV DESERVING Protection
B4F Lifeboats (poorly protected, no connection, HBCV)
B5A Critical Conservation Areas
B5B Critical Impacts – Threshold
B5C Critical Impacts – Composite