Gilbert's potoroo. *Pic. Dick and Judy Walker.*

Climate Change Adaptation & Biodiversity

South Coast Region of Western Australia

A background paper for the Climate Adaptation Addendum to Southern Prospects 2011 -2016.

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SOUTHCOAST NATURAL RESOURCE MANAGEMENT

Australian Government

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Contents

1 - Forward

The background papers to the *Climate Adaptation Addendum of Southern Prospects 2011-16* are a series of detailed technical documents on the potential impacts of the South Coast region's changing climate and how people are adapting to it.

They papers were commissioned by South Coast NRM in 2014 and were part of the Regional Natural Resource Management Planning for Climate Change - Stream 1 project of the Australian Government.

The background papers synthesise the current information on the effect of climate change on each natural resource theme, community capacity to adapt and how people are already adapting. They also document some of the gaps. The papers provide useful background for community consultation through South Coast NRM reference groups. The reference groups have used the papers to develop climate adaptation goals and outcomes for *Southern Prospects 2011-2016*.

South Coast NRM recommends the papers are best read in conjunction with *Fry (2015) A Changing Climate- South Coast of Western Australia* and information on the CSIRO and Bureau of Meteorology Climate Change in Australia website *www.climatechangeinaustralia.gov.au/en/*.

Climate change planning at South Coast NRM will be flexible and adaptive and so information on climate and its impacts will be continually reviewed.

- Kaylene Parker, Climate Change Project Leader, 2015

Terminology

In climate change terminology, the treatment of risks is generally referred to as 'adaptation'. Climate change adaptation can be defined as actions in response to actual or projected climate change impacts that lead to a reduction in risks or realisation of benefits.

Adaptation represents a planned, active response to climate change. In ecological terms adaptation is an alteration or adjustment in structure or habits, often hereditary, by which a species or individual improves its condition in relationship to its environment.

In this report the term adaptation (or adapted to) is used in reference to its ecological definition and climate adaptation refers to the former definition.

2 - Introduction

Understanding the impacts of climate change on biodiversity and developing actions which effectively mitigate these impacts, are major challenges for researchers and managers in the immediate future (5-10 years) and beyond.

However, despite a vast number of recommendations for biodiversity management responses and a wealth of information about climate change impacts in the scientific literature, systematic approaches to identifying and evaluating on-ground management actions are lacking *(Williams et al. 2008; Heller and Zavaleta 2009, Prober et al. 2012, Dunlop et al. 2012).*

It has been recognised effective climate change management may require non-traditional approaches, and attempting to maintain idealised ecosystem states may not be attainable *(Heller and Hobbs 2014).*

Also, managers need to proactively decide whether to adopt a deterministic (risk tolerant), or an indeterministic (risk averse), approach to mitigating the impacts of climate change *(Heller and Zalaveta 2009).*

Southern Prospects 2011-2016 includes a section discussing climate change as a threat to biodiversity within the South Coast region. This section draws largely from information provided in the region.

The *Threatened Species & Ecological Communities Regional Strategic Management Plan (SCTSMP) (DPaW 2009)*, discusses climate change in the South Coast NRM region, specifically how climate change may impact on threatened species by identifying the level of risk to them from climate change, describing potential effects of climate change on other key threats in the region and summarising actions for incorporating climate change into threatened species recovery.

Although focused on listed threatened and priority species and communities, the *SCTSMP* took a landscape approach, providing strategies and actions to manage whole landscapes containing threatened species.

Therefore its approach lends itself to developing strategies and actions incorporating all biodiversity at a landscape or ecosystem scale.

Thus, using the *SCTSMP* section on climate change as a foundation, this background paper aims to:

- Review and update recent relevant knowledge and management or research achievements since 2007-2008.
- Revise the aspirations, goals and strategies related to climate change impacts on biodiversity outlined in the *SCTSMP* and *Southern Prospects 2011 - 2016.*
- Provide updated or new aspirations and goals which are targeted, realistic and achievable.

This report does not repeat the information provided in the *SCTSMP* on climate change impacts on biodiversity.

Readers are referred to the climate change section of the *SCTSMP, Coffey (2009) and Dunlop et al. (2012)* for a detailed discussion about potential and known impacts of climate change on biodiversity.

2.1 - Relevant Major Documents Since 2007

A number of documents focusing on the impacts of climate change on biodiversity have been produced since 2007 at local and commonwealth level.

Major documents include those listed in *Table 1 on page 6.* Most of these were completed in 2009. A state strategy for mitigating the impacts of climate change on biodiversity has not been produced.

All of these provide general strategies for dealing with climate change impacts on biodiversity and at a broad level are useful in guiding areas of action (Table 1).

These strategies generally fall into the following categories:

- Creating landscapes that maximise adaptation opportunities (connectivity, refugia).
- Enhancing resilience in ecological systems at all levels by reducing the impact of threatening processes, particularly those that may be exacerbated by climate change.
- Identifying and targeting the most vulnerable species (undertake specific in situ conservation and undertake ex-situ in some cases).
- Expanding and augmenting the reserve system.

A component of the Coffey 2009 project *(Table 1)* was a workshop involving all stakeholders with the outcome of producing priority risks and possible actions for adaptation mitigation of climate change impacts on biodiversity.

Risks were given a priority score out of 10, with 10 being highest, generally assigned a rating of 10 due to the loss of habitat or species, a rating of 9 to decreases, increases and changes and a rating of 7 - 8 for changes resulting in displacement.

Priority actions were identified to overcome the perceived deficiencies in the existing programs relating to managing the impact of climate change on biodiversity in the South Coast NRM region.

Of the 12 actions identified, six were seen as high priority, two were assigned a medium priority and the balance were either assigned a lower priority or not assigned a priority. The majority of the measures had significant budgetary implications (upwards of $100,000).

Coffey et al. (2009) stated these actions need to be considered in terms of cost, benefit and *"other priorities, including the costs associated with not acting (asset versus risk)"*. This part of the process was not carried out by *Coffey et al. (2009)*.

Jurisdiction	Name	Year	Main Content
Commonwealth	Australia's Biodiversity and Climate Change *(Steffen et al. 2009)* www.climatechange.gov.au/climate-change.	2009	• Extensive review of climate change impacts on biodiversity. • Build on long-established foundation of strategies developed to deal with non-climatic threats.
	The Biodiversity Conservation Strategy (Australian Government).	2009	Identifies conservation connectivity and building resilience as key strategies to ensure natural systems have the capacity to adapt to shifting climatic zones.
	The implications of climate change for Australia's biodiversity conservation and protected areas (June 11, 2010, updated February 14, 2014) csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/adapt-national-reserve-system.aspx.	2010	Australia-wide assessment of the impacts of climate change on biodiversity and the focus of the National Reserve System, is on the reserve system, but the following recommendations are stated with respect to off-reserve: • Additional criteria for selecting priority areas of habitat, including connectivity at multiple scales and refuges, will help enable landscape-scale ecological processes that build the resilience of biodiversity to climate change. • Given the increased level of threat and the dynamics of species, areas of habitat outside the NRS will be increasingly important in combination with the NRS, to provide habitat for species and to support ecological processes across whole landscapes.
South Coast Region	Climate Change: Whole of Landscape Analysis of the Impacts and Options of the South Coast Region. *Coffey Environments.*	2009	Identified the potential risks and impacts of climate change and seasonal variability on natural resource assets, landscapes and seascapes, industries and communities of the South Coast region, to allow the community to develop actions and set priorities to minimise the impacts of climate change on the environment and the community.

2.2 - Recent Knowledge Gains Concerning the Responses of South Coast Region Species & Ecosystems to Climate Change

The predicted response of species and communities to climate change have been well reviewed. In general, there are four aspects of species biology and ecology which are expected to respond to climate change *(Steffen et al. 2009; Chambers et al. 2013).*

If species are unable to respond in any of these ways they have a high risk of local or broad-scale extinction.

- **Changes in demography** - changes in breeding success, survival of young.
- **Changes in phenology** - changes in the relationship between the timing of life-cycle events and seasonal climatic patterns. These changes can lead to shifts in species distributions, population viability and reproductive successes and on an ecosystem level, to changes in ecological interactions such as predator-prey and plant-pollinator dynamics and the epidemiology of infectious diseases.
- **Changes in phenotypic plasticity in-situ** - changes in physiology, morphology or behaviour.
- **Evolutionary change (genetic)** - changes in community composition, species loss/gain.
- **Changes in dispersal and movement** resulting in changes in distribution. Species can either move according to their ecological requirements or they can persist in pockets of favourable habitat (refugia) (range shift or contraction). This can include changes in small-scale movements in some fauna in order to seek out refuges that provided short-term relief from weather extremes.

There is clear evidence globally, that the relatively modest climatic changes over the past century have already caused shifts in species distributions towards the poles and upwards in elevation and shifts in phenology (earlier fruiting and flowering times, and earlier reproduction in amphibians and birds in response to warmer temperatures).

Within Australia, similar evidence is lacking due largely to the lack of long-term datasets *(Dunlop et al. 2012).*

There are some recently documented trends of species distribution changes offering circumstantial evidence of climate change impacts in Australia but these may also have an important non-climatic component *(reviewed in Stephen et al. 2009).*

The geological and ecological characteristics making the biodiversity of the south-west of WA, including the South Coast region, vulnerable to climate change are:

- Southern Australia in general is vulnerable to climate change impacts due to the generally high degree of fragmentation.
- There is a strong relationship between climate and distributions patterns of species and communities.
- Climate dynamism over the past 2 million years leading to periodic waxing and waning, isolation and colonisation of plant populations, forcing many plants into small fragmented populations.
- Species that evolved in the climate fluctuations of the past few million years may be able to adapt or have flexibility in their response to climate. Persistence through changing climatic conditions also implies species may have broader climatic tolerances than indicated by their current climatic envelope.
- Refugial/relictual species that have evolved little during the climate dynamism have a limited capacity to adapt. Most species show patterns of high levels of genetic divergence between local populations, indicating they have persisted in patchy, localised refugia rather than moving long distances to major refugia.
- The presence of many plant taxa with small distributions that are often restricted to particular rock or soil types.
- High level of endemism and restricted distributions in flora and some fauna groups (e.g. some invertebrates).

At the time the *SCTSMP* was produced, knowledge of specific impacts on, or responses to, climate change within South Coast species and communities was limited. Predicted impacts were based on biological attributes of species that may hinder a species or communities resilience to climate change or its ability to adapt to change. These attributes include:

- Poor dispersal ability.
- Low reproductive capability/fecundity.
- Susceptibility to *Phytophthora cinnamomi* (eg. its spread may increase with a rise in summer rainfall).
- Susceptibility to seasonal variability (e.g. requirement for winter rain).
- Dependence on fire for regeneration strategy (e.g. opportunities for regeneration are likely to be limited by the fire interval).
- Dependence on late stage ecosystems (eg. long periods since fire or long juvenile period).

Since the production of the *SCTSMP*, additional knowledge has been gained on the specific responses of and impacts on, species and communities to climate change which can be used to progress the development of a resilience strategy for managing climate change impacts.

2.2.1 - Plant Germination & Recruitment Experiments & Observations

Recent work on temperature thresholds for recruitment in south-west WA flora has demonstrated a range of responses of species to differing temperature regimes.

Cochrane and Daws (2008) demonstrated that for five of the ten species studied from the Stirling Range. *(Banksia brownii, Calothamnus crassus, Velleia foliosa, Kunzea montana* and *Eucalyptus megacarpa),* the optimal seed germination temperature was lower than the optimal temperature for seedling growth. Therefore changes in temperature associated with climate change may potentially impact on recruitment of these species.

Little difference in germination temperature profiles existed for those species assessed from mountain and coastal habitats *(e.g. Banksia brownii). Cochrane et al. (2011)* demonstrated high temperatures are not a limiting factor for germination in some species restricted to the mountain tops of the Stirling Range, signifying a lack of relationship between geographic range size and breadth of the germination niche.

In contrast other restricted species, in particular *Sphenotoma drummondii,* was at risk of recruitment failure as a consequence of warming. Seeds of this species showed a strong negative relationship between percentage germination and increasing temperature above a relatively low optimum constant temperature (13°C).

MaxEnt (software used for species distribution and environmental niche modelling,) modelling of two south-west WA flora species also revealed two differing responses to germination under climate change emission scenarios. The temperature profile for germination for *Banksia media* and *B. dryandroides* with an overlay of the forecast mean annual temperature for the location at the low, medium and high emission scenarios for 2070 at the locations where the seed was collected.

Banksia media has a wide range of temperatures for germination and so under the high emission 2070 scenario temperature it would appear that this species would be able to germinate. However, *B. dryandroides*, under the same scenario would not *(Anne Cochrane, unpublished data).*

2.3 - Climate Refugia

The identification and protection of places providing respite from global warming temperature is increasingly seen as an important climate adaptation strategy *(Schut et al. 2014).* These places can be either ephemeral refuges (transient places with low maximum temperatures which provide respite from high temperatures and are important for mobile species and in maintaining meta population structure) or stable refugia (cool places with a stable environment and are isolated; important for persistence of low mobility species over a long timeframe) *(Gollan et al. 2013).*

2.3.1 - Granite Outcrops as Climate Refugia

Current work by the Climate Change Refugia Research Group (Curtin University) and DPaW's Climate Change Unit is determining and quantifying the extent to which granite outcrops in the south-west have acted as refugia in the past and will be able to do so under predicted future climate change *(Schut et al. 2014).*

Granite outcrops provide extraordinary diversity, including a wide range of taxa, vegetation types and habitats in the Southwest Australian Floristic Region (SWAFR). *Schut et al. (2014)* used Light Detection and Ranging (LiDAR) data and red green and blue (RGB) imagery mapping approach, enabling the integration of site-based biotic assessment with structural vegetation types for the rapid delineation and prioritisation of key refugia.

They found water gaining sites around granite outcrops are characterised by taller and denser vegetation in all areas. The strong relationship between rainfall, soil-depth and vegetation structure allowed comparisons of vegetation structure between current and future climate.

Significant shifts in vegetation structural types were predicted and mapped for future climates. Water-gaining areas below granite outcrops were identified as important putative refugia. A reduction in rainfall may be offset by the occurrence of deeper soil elsewhere on the outcrop.

2.3.2 - Plant Refugia

In the south-west, persistence in localised refugia has been the major response of flora species over the past 700,000 years during periods of climate extremes.

Therefore species are not likely to respond to future climate change by migration. Persistence through changing climatic conditions also implies species may have broader climatic tolerances than indicated by their current climatic envelope *(Byrne 2010).*

Although known to exist, the nature of these places remains cryptic. The climate stability of a refugium is often facilitated by high spatial heterogeneity and diversity resulting in micro-climatic variation and decoupling from the regional climate.

In the south-west's undulating landscapes places of high topographic complexity with large numbers of short range endemics such as the Barrens, Ragged, Ravensthorpe and Stirling ranges may act as refugia, but fine-scale modelling of species distributions under the influence of climate change is needed to confirm this hypothesis.

A DPaW Science Division project is aiming to elucidate the nature of these plant refugia by using a recently collected high resolution species distribution dataset for the Ravensthorpe Range.

This project will model the distribution of short range endemics in the range under the influence of projected climate change and develop fine-scale microclimatic, radiation and micro-topographic surfaces for the range by deploying weather stations. An array of 100 micro-climatic sensors across the range will collect temperature and relative humidity data over a 12-month period *(Neil Gibson and Colin Yates, DPaW, Science Project Concept Plan)*

2.3.3 - Refugial & Short-range Endemic Invertebrates

Within the South Coast region, many terrestrial invertebrates have survived in isolated and small, relictual Gondwanan habitats such as deep gullies or mountain peaks.

Due to their limited distribution, many are considered short-range endemic species (SRE). *Framenau et al. (2008)* found SRE invertebrates along the entire South Coast NRM region, with the highest concentration of species occurring in Karri *(Eucalyptus diversicolor)* forest, isolated granite outcrops and mountain peaks. A drying climate associated with climate change was identified by *Framenau et al. (2008)* as a key threatening process to the SREs occurring on the higher peaks of the Stirling Range and in litter in Karri forest habitats.

Moir et al. (2009) identified areas of high species richness and endemism for millipedes within the south-west to assist with conservation planning and the environmental factors which have influenced biogeographic patterns in millipedes. This is important in gauging the level of threat posed by global climate change.

The study identified five areas in the south-west displaying the greatest endemism and richness of millipede species: Stirling Range (east), Cape Le Grand, Cape Arid, Walpole region and Porongurup.

Important environmental variables of biogeographic patterns in millipedes were elevation and present-day rainfall, therefore the decline in rainfall predicted to occur for the south-west through global climate change may see a decline in the availability of moist refugia required by many species of millipedes.

2.4 - Freshwater Ecosystems

Knowledge of the impacts of climate change on freshwater biodiversity is limited. For example, large uncertainties remain regarding which processes (eg. biophysical processes such as water temperature or nitrogen enrichment) will have the greatest impact on biodiversity in freshwater ecosystems and whether the sum of the individual stressor effects are greater than any stressor alone (eg. a synergistic interaction) *(Mantyka-Pringle et al. (2014)).*

Stewart et.al. (2013) found variable upper thermo tolerances of key taxonomic groups of freshwater fauna from the south-west and conclude thermal shifts created by climate change will likely create novel faunal assemblages by replacement of less thermo tolerant species by more thermo-tolerant species.

The background aper C*limate Change and Water Resources in the South Coast Region (Gunby 2014),* produced in conjunction with this report outlines impacts of climate change on river and wetland ecosystems and recent advances in knowledge.

2.5 - Phenotypic Plasticity in Plants Implication for Seed Provenance in Restoration Plantings

Traditional revegetation and restoration practices have a strong focus on sourcing seeds from local plant populations. In a changing climate this may no longer be desirable, as local populations highly adapted to past or present climatic conditions ,may lack the capacity to cope with a changing climate.

There is evidence in some widespread eucalypt species *(e.g. E. salubris)*, however, for plastic response as well as genetic adaptation to climate, indicating that widespread eucalypts are therefore likely to be able to adjust to a changing climate to some extent. Widespread species may provide the answer as they grow under a range of climatic conditions and may therefore improve the climate resilience of restored ecosystems *(Byrne et al. 2013)*.

2.6 - Species Distribution Modelling

Species distribution modelling (SDM) is currently being used for predicting the impacts of projected climate change on south-west species and communities. While these models on their own do not predict a species response to climate change, they can act as starting point in targeting potential habitats where species may move to and making sure suitable habitats are managed.

It is important to note the accuracy of species distribution data used, and caution should be used in conclusions based on these distribution models alone, without considering the demography of the species and/or the increasing impacts of other threatening processes under climate change. For example, although the habitat of the glossy black cockatoo *(Calyptorhynchus lathami)* on Kangaroo Island is predicted to decrease under high impact scenarios, incorporation of the bird's life history characteristics (survival, fecundity and age of first breeding) suggest the factor likely to have a more profound impact upon its survival is successful management of the brush-tail possum *(Trichosurus vulpecula) (Harris et al., 2012)*.

The incorporation of demographic and management variables into SDM provide greater resolution predictions and are vital for predicting likely outcomes of climate change on taxa. The following SDM has been carried out for South Coast species.

Centre of Excellence in Natural Resource Management, University of Western Australia (CENRM).
CENRM has carried out modelling on 61 species of coastal flora, 35 species of "iconic" flora, 37 species of threatened fauna (including 19 birds species), 34 species of threatened flora and 27 species used in revegetation under the Gondwana Link program *(Ben Ford and Barbara Cook pers. com.)*.

CENRM has also provided a review of SDM models for south-west taxa, based on both unlimited and zero dispersal abilities of the species *(Table 2)*.

The general predicted response of south-west taxa to climate change for taxa modelled to date is range contraction and/or distribution shifts, typically to the south and west, with magnitude of impact increasing with scenario severity *(Ford et al. 2013)*.

Table 2: Summary of SDM used to predict potential changes of south-west taxa under climate change scenarios *(Ford et al. 2013.*

Author	Year	Species/Group	Emission Scenarios
Fitzpatrick et al	2008	Banksia	B1, A1B, A1F
Coffey Environments	2009	Frogs/reptiles/birds,/mammals	Unknown
Gibson et al	2010	Quokka	B1, A1B, A1Fl
Yates et al	2010	Banksia	B1, A1B, A1Fl
Davies	Unpub.	Frogs	A1B, A2a, B2a
Davies	Unpub.	Freshwater fishes	A1B,A2a, B2a
Davies	Unpub.	Aquatic invertebrates	A1B, A2a, B2a
Molloy et al	2014	Western ringtail possum	A2a
Prober et al	2012	Great Western Woodlands	B1, A1B, A1Fl

Some examples include:
1. *Gibson et al. (2010)* modelled the distribution of the quokka with Maxent using records of occurrence and a combination of historical climate (1961-1990) and habitat variables. Future projections of this distribution were then examined assuming two simple dispersal scenarios (zero and full migration) and three climate-change scenarios of increasing severity for 2030, 2050 and 2070.

Except for the low-severity climate-change scenario under the full dispersal assumption, the future projected distribution of quokkas was shown to contract over time. The extent of range contraction tended to increase with the severity of the climate-change scenario, with the species predicted to lose almost all range by the year 2070 under the most extreme climate-change scenario.

The authors emphasise the importance of identifying potential refuges for the quokka (eg. areas where the species is predicted to persist) and defining management strategies to protect these areas from threatening processes.

2. *Fitzgerald et al. (2008)* simulated migration of 100 banksia (proteaceae) using Maxent and compared projected impacts with those under the assumptions of 'full migration' and 'no-migration.'

Across all climate/migration scenarios, 66 per cent of species were projected to decline, whereas only 6 per cent were projected to expand or remain stable. Between 5 per cent and 25 per cent of species were projected to suffer range losses of 100 per cent by 2080, depending mainly on climate scenario.

Species losses were driven primarily by changes in current precipitation regimes, with the greatest losses of species projected to occur in a transition zone between wet coastal areas and interior arid regions. This zone is projected to become more arid in the future.

The data provided by Cochrane on germination of banksia species under different climate scenarios is valuable information that can be used in conjunction with this SDM to further understand how banksia (and other genera) species may respond to climate change. *Lester et al. (2014)* used space-for-time substitution to enable prediction of ecological response of future climate-related change where large data sets are not available ('the target domain') using data from analogous systems that span a well-studied climate gradient in another location (the 'gradient domain').

They used the estuaries of the South Coast where rainfall, as well as ocean-estuary connectivity, tend to decrease towards the east and are well-studied, as the gradient domain to predict the ecological response of estuaries under climate change in Victoria.

This approach may be useful in determining responses of South Coast species or communities to climate change, by substituting space-for-time in well-studied analogous species or communities.

3 - Recent Management Relevant to Climate Change Impacts on Biodiversity

3.1 - Recovery Plans

Integration of climate change adaptation strategies into recovery plans and interim recovery plans is continuing. New recovery plans and interim recovery plans produced since 2007 are listed in *Appendix 1*. Generally the strategies and action relating to climate change for those considered vulnerable to its impact are:

Fauna - eg. Western ringtail possum and quokka: Undertake climate change modelling to assess the potential effects on the distribution and abundance of the western ringtail possum and identify refuges or future suitable habitat to mitigate the climate pressures.

Undertake genetic and demographic modelling to complement habitat modelling, and to inform climate change adaptation.

Flora

In recently produced interim recovery plans (IRP) for threatened flora climate change is listed as a threat, or discussed briefly. However, there are no associated actions listed.

The IRP generally state: "*The intent of this plan is to provide actions that will deal with immediate threats to the habitat of (species). Although climate change may have a long-term effect on the habitat, actions taken directly to prevent the impact of climate change are beyond the scope of this plan*".

For example, the IRP for *Gastrolobium luteifolium* states: "*G. luteifolium is likely to be vulnerable to drying trends associated with climate change, such trends may result in, among other things, an increase in fire frequency.*

"As the species occurs in a mountain habitat, an area of higher rainfall, it is already at the limit of its climatic range. Continuing drying trends would put strain on the continuing existence of the species in the wild. However, the threat of climate change is beyond the scope of this IRP, and so cannot be addressed under the listed actions."

Landscapes

The South Coast Threatened Birds Recovery Plan (see *Appendix 1)* and the Fitzgerald Biosphere Recovery Plan *(DPaW 2012)* take an integrated approach to the recovery of threatened species across a landscape (six threatened bird species and all threatened species and communities within the biosphere, respectively). Climate change is listed as a major or key threat in both of these plans.

3.2 - Revegetation & Restoration

Revegetation and restoration work is currently being carried out within the South Coast region by several organisations under a number of programs:

Bush Heritage Australia purchased seven properties between 2002 - 2014 within the Gondwana Link Fitz-Stirling Operational Area (Beringa, Chereninup, Monjebup West, Monjebup North, Yarrabee and Monjebup Creek).

Some of these were bought jointly with Greening Australia WA, to contribute to the realisation of the Gondwana Link vision of a 1,000km swathe of protected and reconnected country from Margaret River to the edge of the Nullarbor.

Together with partner properties these reserves cover almost 9,500ha in between the Stirling Range and Fitzgerald River national parks.

They include around 6,600ha of undisturbed native vegetation comprising a diverse mosaic of mallee heath, eucalypt woodlands and riparian vegetation.

Since purchase, around 2,840ha has been protected from grazing and clearing 1,100ha of which is regenerating naturally. About 1,738ha has been revegetated, with a further 66ha planned by Bush Heritage for 2014 *(Angela Sanders, ecologist, BHA).*

Gondwana Link promotes its vision and has produced a tool for identifying priority remnants within the Fitz-Stirling Operational Area using the software MCAS-S (Multi-Criteria Analysis Shell for Spatial Decision Support) which guides the strategic placement of restoration work.

South Coast NRM under the Restoring Gondwana Program (part of the Australian Government Clean Energy Biodiversity Fund) is funding Greenskills and a number of catchment groups to carry-out revegetation work which will increase connectivity on private land .

3.3 - Knowledge & Baseline Information on Ecology of South Coast Species, Communities & Ecosystems.

Since 2007 several projects and programs have contributed to an increased understanding of basic ecology and baseline information of species, communities or ecosystems.

These include:

- Development of systematic vegetation mapping at a scale suitable for strategic planning and management (Albany Regional Vegetation Surveys 1 and 2).
- Increasing knowledge of ecology and management of fire sensitive communities and species *(Barrett et al. (2009).*
- Increasing knowledge of the ecology predator prey relationships and predator control (DPaW Feral Predator Program).
- Impacts of plant diseases on habitat functionality (aerial canker).
- Ecological outcomes monitoring in the Fitz-Stirlings operational area (baseline data, wallabies, birds vegetation and water quality), Bush Heritage Australia.
- Monitoring the effectiveness of fencing and revegetation carried out under the South Coast NRM Restoring Gondwana project using one of the target species in the conservation action plans developed for Gondwana Link areas (black-gloved wallaby monitoring protocol) *(Gilfillan 2014).*

3.4 - Managing Climate Vulnerable Species

3.4.1 - The Noisy Scrub-bird

The noisy scrub-bird is a refugial species of Gondwanan origin, hence establishing new populations in higher rainfall areas to the west is predicted to improve the resilience of the species to predicted climate change.

Unfortunately, although translocations to areas close to its current range have been successful, a number of translocations to areas to the west of this range have not been successful to date *(Comer et.al 2011).*

Comer et.al (2011) recommend where suitable unoccupied habitat is lacking, mechanisms which increase resilience, such as improving connectivity, management of fire and feral predator control, are likely to play a greater role in the long term conservation of this and other threatened species on the South Coast.

3.4.2 - Drought Impacts on the Survival of Threatened Flora

DPaW flora conservation officer Sarah Barrett has outlined observations in the management of climate vulnerable plant species.

Survival in translocation sites is being significantly impacted by summer drought. For example, there were excellent survival rates for *Banksia brownii* (CR) in its first summer after planting in Torndirrup with typical summer rainfall.

However, this was followed by significant mortality in summer 2014 when there was minimal summer rainfall. Other translocation sites and species have undergone similar declines in health and survival in 2014 (eg. *Gastrolobium luteifolium* CR).

If this trend of low summer rainfall is to continue it will be very difficult to establish translocations even if optimal sites and micro-sites are selected *(S Barrett/R Dillon pers. comm.).*

The only known natural population of *Banksia ionthocarpa ssp. ionthocarpa* (CR) is also threatened by climate change.

This population is in steady decline with minimal recruitment occurring. Survival of seedlings after an experimental burn in 2003 was negligible, although irrigated plants had better survival rates than non-irrigated plants in initial years. Survival of seedlings after mass germination after a flood in 2005 was also negligible by the second summer and similarly there has been minimal survival of seedlings that germinated after a wet spring 2013.

Multiple plantings of *B. ionthocarpa* at a translocation site have also undergone significant declines through summers over the years. While the poor 'fitness' of offspring may also relate to genetic factors, environmental stress i.e. drought would appear to be the primary stressor.

3.5 - Managing Other Threatening Processes

Climatic changes have major ramifications for a number of the threatening processes already operating in the South Coast region. Recent progress concerning the knowledge and management of these threatening processes are outlined below.

3.5.1 - Fire

Climate change may affect fire regimes across the Australian landscape through changes to temperature, rainfall, humidity, wind and the amount of carbon dioxide in the atmosphere.

Climate change is expected to have greater effects on fire regimes in regions where fire weather factors like temperature and wind strength determine fire occurrence and fire intensity, such as the south-west of Australia *(Williams et al. (2009).*

Barrett et al. (2009) produced a detailed report outlining the fire responses of South Coast species and communities. This is a valuable resource for addressing how climate change will interact with fire and the subsequent impacts on species and communities.

A proposed 20 year burning regime for the Gondwana Link Fitz-Stirling Operational Area has been produced for Bush Heritage Australia by Ayesha Tulloch from the University of Queensland.

The report outlines an approach to determine how much of the landscape managers should burn and at what frequency fire should occur to maintain biodiversity.

3.5.2 - Plant Disease *(Pc)*

Phytophthora cinnamomi

Predicted responses of *Pc* to climate change on the South Coast outlined in the *SCTSMP* are:

- Change in climatically suitable area for *Pc*.
- Increased flood events may increase *Pc* spread.
- Climatically stressed plants may be more vulnerable to *Pc*.
- Increase in summer rainfall will create optimal conditions for pathogen to reproduce and spread.

Thompson et al. (2014) demonstrated through modelling that temperature and rainfall changes associated with possible climate futures in south western USA have confounding impacts on the range of *Pc* suggesting projections of future pathogen dynamics and ranges should account for multiple pathways of climate-pathogen interaction.

This study suggests the impacts of climate change on *Pc* may be complex and further work is needed to establish the relationship between it and climate change in the south-west.

Canker

A number of threatened flora (eg. *Lambertia fairallii, Persoonia micranthera, Daviesia ovata, Banksia verticillata, l. orbifolia ssp orbifolia, Banksis anatona, B. brownii*) are experiencing significant impacts (declining health and plant mortality) due to aerial canker causing fungi in natural and translocated population.

Many of these fungi are considered to be relatively benign and are not primary pathogens, however it would appear environmental factors (drought and temperature) may be increasing the susceptibility of plant species to the fungi *(Crane et al. 2012)*.

Opportunistic sampling and observations suggest an increase in canker incidence and severity across the region is possibly related to changing climate. Concurrent studies of cankers in the region document the increasing incidence and severity of the pathogen in stressed environments and the role it may play in a drying climate is of great concern *(Crane et al. 2012)*.

Concurrent studies of the influence of climate on canker disease in proteaceae in the SWAFR has shown *L. shearii* is one of the causal organisms frequently isolated from aggressive cankers. *Neofusicoccum australe, N. macroclavatum* and *Cryptodiaporthe melanocraspeda*, along with *L. shearii*, are forming a disease complex that is having an increasing impact across many proteaceous species in the region *(Crane et al. 2012)*. This increasing impact has so far been positively correlated with minimum temperatures (*Crane et al. 2012)* and the complex appears to be an emerging disease issue in a changing environment.

3.5.3 - Weeds

An Australian-wide strategy for managing weeds under climate change is in draft form *(Scott et al. 2014)*. This will provide guidance to NRM regions in the knowledge, processes and tools for climate adaptation planning for invasive species and weeds.

With such a large threat already in Australia and global trade representing an increased risk for further introductions, weed management will increase in importance and change in the future. A main driver of this will be climate change *(Scott et al. 2014)*. The main climate change drivers of invasive plants are:

- Increased temperatures, changed precipitation, increasing CO2 levels, more extreme weather, more frequent frosts, changed phenology and land-use change (from human adaptation.

Work in Victoria indicates species with more southern distributions are likely to become less of a problem under climate change. Whilst conditions across a large part of the state will remain suitable for their survival in the short term, over the next 50 years there is likely to be a large decline in areas of suitable climatic conditions for widespread weeds such as *Cotoneaster glaucophyllus* and *Senecio jacobaea* (ragwort) *(Steel et al. 2008)*.

3.5.4 - Habitat Fragmentation & Genetic Diversity

Isolation in fragmented habitats is seen as a major threat to a species' ability to move to more suitable habitat under climate change. Yet *Eldridge et al.(2003)* demonstrated the tammar wallaby (*Macropus eugenii*), rufous hare-wallaby *(Lagorchestes hirsutus)* and black-footed rock-wallaby *(Petrogale lateralis)* in mainland isolated populations have greater genetic diversity than island populations.

Their ability to adapt to change, even though occurring in isolated populations, may be greater than previously thought.

4 - Gaps

Gaps outlined in the SCTSMP are all still relevant in 2014 to varying degrees *(Table 3)*. However the information outlined previously on recently gained knowledge and management outcomes illustrates some of these gaps have been progressed in the past 7 - 8 years.

Table 3: Current research and knowledge gaps identified for threatened species identified by the SCTSMP. **Note:** Focus is on threatened species but can be applied to all taxa.

Gap	Progress to Date
A comprehensive network of weather/climate stations across the South Coast region. Suggested areas for such stations include the major peaks and lowlands below the peaks, significant islands (such as Bald, Mondrain and Middle islands) and other sites containing significant threatened species occupying communities considered at high risk of climatic sensitivity - eg. western ground parrot habitat in sandplain systems of Cape Arid and Fitzgerald River national parks.	No progress.
Biological and ecological knowledge of threatened species to enable further assessment of the potential impacts of climate change on them - eg. fecundity, dispersal ability, generation time, habitat restrictions and population size.	Some progress (see section 3).
Vulnerability of threatened species to climate change based on threat matrix attributes. This assessment was based on expert knowledge of species and requires review and modelling for different climate change scenarios.	Some progress (noisy scrub-bird, refugial invertebrates and plants), SDM work.
Resilience needs to be defined for different scales - eg. landscape/single species.	No progress.
Ecological processes and interactions with climate change and other threatening processes need to be summarised for the South Coast region.	Some progress - eg. canker, fire - still little known (weeds, *Pc*).
Knowledge of basic physiological tolerances of threatened species. It is known species have climate preferences but their climate tolerances are unknown. Capacity to respond to natural climatic variation is poor and needs further research.	Some progress (eg. plant germination experiments, upper thermo-tolerance of freshwater fauna).
Identification and monitoring of threatened species as indicators of climate change would increase the capacity within the region to address the impacts of climate change on other threatened and near threatened species. Suitable climate change indicator species would have the following characteristics: • Display measurable responses to changes in the environment. • Strongly suspected to be sensitive to climate in terms of distribution, physiology or life cycle, • Less affected by other changes in the environment (eg. predator control etc). • Has baseline historical data available. • Mobile. • Easily recognisable from other species (taxonomic certainty). • Advantage if representative of a whole functional group so that results can be readily generalized to other species. • Cost effective to monitor on a repeatable basis.	No progress. Suggest alternative to passive long-term monitoring sites, rather target monitoring to evaluate responses to management actions in the short and long term.
The South Coast has several examples of threatened species that could be considered as indicators, including the noisy scrub-bird and Australasian bittern.	

5 - A Resilience Approach to Mitigating the Impacts of Climate Change on South Coast Species, Communities & Ecosystems

All the biodiversity principles outlined in *Southern Prospects 2011-2016* are applicable to the mitigation of climate change impacts on taxa/ communities. These are:

1. Maintain or restore healthy, resilient ecosystems by reducing threatening processes.
2. Identification and protection of key biodiversity assets.
3. Minimise incremental loss of native vegetation with goals of "no net loss".
4. Plan and manage natural ecosystems, species, communities, habitats and landforms at a landscape scale.
5. Facilitate delivery of strategic information to support actions.

All the principles are applicable to the mitigation of climate change impacts on species, communities and ecosystems.

Only *principle 3* should be modified to facilitate adaptation to climate change, eg. the goal should be to increase habitat, through maintenance of existing remnant vegetation and revegetation and restoration activities.

Of these principals the overarching principal for mitigating the impacts of climate change on biodiversity is the maintenance or restoration of resilient ecosystems.

There are four critical aspects of resilience:

1. *Latitude.* The maximum amount a system can be changed before losing its ability to recover (before crossing a threshold which, if breached, makes recovery difficult or impossible).
2. *Resistance.* The ease or difficulty of changing the system; how "resistant" it is to being changed.
3. *Precariousness.* How close the current state of the system is to a limit or "threshold.".
4. *Panarchy.* The degree to which a certain hierarchical level of an ecosystem is influenced by other levels. For example, organisms living in communities in isolation from one another may be organised differently from the same type of organism living in a large continuous population. Thus the community-level structure is influenced by population-level interactions.

Closely linked to resilience is adaptive capacity, which is the property of an ecosystem describing change in stability of landscapes and resilience. Adaptive capacity in socio-ecological systems refers to the ability of humans to deal with change in their environment by observation, learning and altering their interactions.

5.1 - Components

5.1.1 - Strategic Habitat Management & Restoration

The cornerstone of creating resilient ecosystems within fragmented landscapes is strategic habitat management and restoration.

Its goals are protecting and buffering large remnants and increasing connectivity. Increasing connectivity has emerged as the most favoured option for conservation in the face of climate change *(Hodgson et al. 2009)*.

There are strong arguments that allowing range expansion through increasing connectivity is just as important for conserving evolutionary processes as maintaining genetic diversity for reducing climate change impacts *(eg. Driscol 2007)*.

Connectivity can be coincidentally improved by targeting more concrete metrics: habitat area and habitat quality *(Hodgson et al. 2009, Kool et al. 2012)*.

Therefore, in light of the lack of knowledge on the connectivity requirements of many South Coast species and populations at multiple scales, increasing habitat area and habitat quality should be considered as equally as important as increasing connectivity per se.

By managing existing native vegetation to maintain ecological integrity and following best practice principles and guidelines for landscape restoration to increase resilience ensuring the majority of restoration work has a biodiversity/increased resilience outcome, will have a major positive influence on mitigating impacts of climate change on biodiversity.

5.1.2 - Identifying & Managing Climate Change Vulnerable Species & Communities

Strategic habitat management and restoration should ultimately lead to the protection of vulnerable species and communities.

The immediacy of the threat of climate change, makes it imperative those most vulnerable, directly or through exacerbation of other threatening processes, to target actions to species and communities identified and protected as a priority.

The *SCTSMP* lists species and communities predicted to be most vulnerable to climate change:

- Montane - species occurring more than 400m above sea-level.
- Climate refugial and relictual species.
- Species dependent on freshwater wetlands (especially seasonal wetlands and damplands).
- Short-range endemics (eg. geographically localised species).
- Migratory species.
- Species occurring in highly-fragmented remnants or highly-patchy habitat.
- Species occurring in small populations genetically impoverished.

The *SCTSMP* outlined certain biological attributes of species, identifying them as determining a species or community's resilience to climate change or its ability to adapt to changes. These attributes include:

- Dispersal ability (poor).
- Habit preferences (eg. habit of burrowing or aestivation reduces exposure to drying and temperature, so could potentially tolerate higher temperatures).
- Reproductive capability/fecundity (low).
- Susceptibility to *Pc* (eg. its spread may widen with an increase in summer rainfall).
- Susceptibility to seasonal variability (eg. requirement for winter rain).
- Dependence on fire for regeneration strategy (eg. opportunities for regeneration are likely to be limited by the fire interval).
- Dependence on late stage ecosystems (eg. long periods since fire or long juvenile period).

Biological/ecological attributes outlined above were used in a threat matrix to assess the susceptibility of South Coast threatened species to climate change *(SCTSMP App 6)*. Almost 80 per cent of the region's threatened fauna and 95 per cent of threatened flora were categorised as *extremely* or *highly vulnerable* to climate change. More sophisticated and broadly applicable vulnerability indices have recently been developed.

Maggini et al. (2014) developed a vulnerability index that integrates estimations of projected range change and different proxies of species resilience in a quantitative way, allowing the ranking of species so as to prioritise conservation actions.

Watson et al. (2013) incorporated an assessment of a global ecoregion's adaptive capacity, based on spatial analysis of its natural integrity - the proportion of intact natural vegetation, to present a measure of global ecosystem vulnerability. Southern Australia was categorised among the most vulnerable according to this measure.

5.1.3 - Managing Other Key Threatening Processes

Natural systems in the 21st century start from an already massively 'shifted baseline' with an eroded ecological resilience. Most habitats are already degraded and their populations depleted, to a lesser or greater extent, by past human activities.

Thus, the scope for sufficient ecological and evolutionary adaptation to anthropogenic climate change, is already severely constrained by this shifted ecological baseline.

There is increasing acknowledgement direct threatening processes are usually interacting and mutually reinforcing and synergistic feedbacks between threatening processes are driving ecosystem change (*Brook 2008*). Climate change will impact species, communities and ecosystems through their interaction with other threatening processes.

How climate change is predicted to interact with other threatening processes are listed in the *Table 4* below.

Table 4: The potential impacts of climate change on the primary threatening processes in the South Coast region. From *SCTSMP*.

Fire Regimes	Increased frequency, intensity and extended fire season.
	Increased risk especially in integrated land systems.
	Decreased recovery of species following fire due to lower rainfall impacting on physiological processes.
Phytophthora cinnamomi	Change in climatically suitable area for *P. cinnamomi*.
	Increased flood events may increase *P. cinnamomi* spread.
	Climatically stressed plants may be more vulnerable to *P. cinnamomi*.
	Increase in summer rainfall will create optimal conditions for the pathogen to reproduce and spread.
	Change in climatically suitable area for *P. cinnamomi*.
Predation	Increased risk of invasion by feral and invasive species due to their ability to rapidly disperse and invade "new" climatically suitable areas.
Altered Hydrology	Fewer recharge events, decrease in salinity and waterlogging.
	Reduced water availability for aquatic species.
Fragmentation	Fragmentation of habitat will substantially reduce the ability of species to move to areas of suitable climate.
	Increased edge effects.
	Low genetic variability.
Small population size	Decreased genetic variability of small populations will reduce the ability of species to adapt to changing climatic conditions.
Weeds	Increased risk of invasion by feral and invasive species/diseases due to their ability to rapidly disperse and invade "new" climatically suitable areas.

5.1.4 - Identifying & Managing Climate Refugia

The recent work on identifying refugia in the South Coast Region *(Schut et al. 2014)* provides valuable information for developing an integrated approach to identifying, defining and conserving refugia.

Keppel and Wardell-Johnson (2011) have recently developed a framework for the identification and description of refugia in any environment. This framework could be applied to the South Coast region to facilitate better understanding of refugia and its capacity to act as safe havens under climate change.

It is important to note many fauna species/groups have survived without migration over long periods under large climate fluctuations (eg. *Crinia sp.* (frogs) and that animal and plant evolution is ongoing within the south-west. Therefore recent as well as ancient (including Gondwanan) diversity is an important conservation goal *(Dale Roberts UWA Albany lecture, 19/06/14)*

5.1.5 - Monitoring Management Actions Within an Adaptive Management Framework

Long-term research and monitoring is imperative in understanding the dynamics of communities and ecosystem and what drivers influence environmental change *(Burns and Lindenmayer 2014).*

Recently, the setting up of long-term ecological monitoring sites or areas has been promoted for providing information on long-term changes in species distribution and community composition. For example:

- Climate Watch, a national program developed by Earthwatch Australia, Bureau of Meteorology and the University of Melbourne aims to better understand how climate change is affecting wildlife by monitoring changes in phenology on a continental scale. Observations by citizen scientists are used to assist the country's scientific response to climate change.
- The South Coast Macro Corridor Project *(Wilkins et al. 2006)* proposed the setting-up of a system of long-term sites to monitor change and review existing ones in the South Coast region. This provides a good starting point for developing a system of long-term ecological monitoring sites.

Non-management or non-research-based long-term monitoring sites which have no experimental component, do not provide information on what is driving change.

It is therefore preferable in determining responses to climate change, to carry-out long-term research and management that has a monitoring component and ensure this research and management has continual implementation, monitoring and adaptation over a long timeframe (20 + years).

Terrestrial Ecosystem Research Network (TERN, www.tern.org.au) provides a framework for long-term ecological research.

TERN is fostering national networks of scientists, environmental managers and stakeholders to improve understanding and management of Australia's ecosystems.

They will achieve this through long-term studies documenting changes, identifying the drivers of change and providing the evidence and knowledge needed to inform improved natural resource management in Australia.

6 - Aspirations & Goals

A workshop conducted with the South Coast NRM Biodiversity Reference Group and one-on-one consultations with experts, provided guidance in the development of the new, or revised, aspirations and goals relevant to climate change and biodiversity that could be added to the existing program logic summary of *Southern Prospects 2011 - 2016.*

These amended aspirations and goals are outlined in the updated program logic summary of the *Climate Adaptation Addendum.*

Southern Prospects 2011 -2 016 lists the following aspiration directly addressing climate change:

"Improved understanding of potential impacts of climate change on biodiversity and appropriate management responses."

This aspiration is appropriate to mitigating the impacts of climate change on biodiversity. In addition, all other biodiversity aspirations listed in *Southern Propects 2011 - 2106* are also appropriate to some degree.

7 - Strategic Decision Framework

It is increasingly being recognised that broad conceptual frameworks are needed to facilitate a systematic approach to identification and evaluation of the multitude of on-ground management responses to climate change impacts put forward *(Heller and Zavaleta 2009, Prober et al. 2011, Shoo et al. (2013).*

These frameworks enable the prioritisation of actions that provide best value for money - risk versus threat versus cost.

Heller and Zavaleta (2009) emphasise such frameworks, in combination with well-documented case studies, are needed to organise the current 'sea of adaptation ideas' into a structure to guide adaptation planning.

They synthesise recommendations with respect to three likely conservation pathways: regional planning; site-scale management and modification of existing conservation plans. Climate change challenges conservation practice with the need to respond to both rapid directional change and tremendous uncertainty.

Climate adaptation measures are classified along a risk continuum. Under each risk category are examples of general approaches, followed by examples of specific adaptation measures. A complete strategy should span a risk continuum.

Prober et al. (2012) developed a 'change-resilience' framework that can guide identification of climate change impacts and adaptive management options in a given region or biome.

The framework focuses on potential points of early climate change impactand provides and evaluations of attributes of resistance and resilience to prioritise actions. They apply the framework to the Great Western Woodlands as a case study and developed priority actions based on systematic identification of processes likely to drive change and response.

Shoo et al. (2013) provided a decision framework in which conservation actions are linked to species' genetic adaptability and potential to adjust their ranges in response to climate change.

These actions range from ongoing conservation in existing refugia through various forms of mobility enhancement to ex-situ conservation outside the natural environment.

They explicitly recognise allocation of conservation resources toward particular actions may be governed by factors such as the likelihood of success, cost and likely co-benefits to non-target species in addition to perceived vulnerability of individual species.

As such, they recommend the use of expert judgment of probable trade-offs in resource allocation to inform the sequential evaluation of proposed management interventions.

A decision framework, based on one or a combination of the above frameworks, or following a *conservation action planning* approach could be applied within the South Coast region to prioritise actions presented in *Table 2.*

Due to the vast differences in ecosystems across the region, these frameworks should be applied at an ecozone level, not a regional level. *Conservation action plan*s were commenced for all the ecozones in the region approximately 10 years ago. These may be able to be revisited as a potential approach to the development of these frameworks.

The *Coffey (2009) Workshop* provides a preliminary expert opinion based prioritisation of actions and this could also be used a starting point for developing such a framework.

8 - References

Barrett, S., Comer, S., McQuoid, N., Porter, M., Tiller, C., & Utber, D. (2009). *Identification and Conservation of Fire Sensitive Ecosystems and Species of the South Coast Natural Resource Management Region.* Department of Environment and Conservation, South Coast Region, Western Australia.

Brook , B.W. (2008). Synergies between climate change, extinctions and invasive vertebrates. *Wildlife Research* 35 (3): 249–252.

Burns, E. and Lindenmayer, D. (2014) *Policy Handbook. Learning from Long-term Research to Better Manage Biodiversity in Australia.* CSIRO Collingwood.

Byrne, M. (2010). *Species response to climate change – can the past inform the future?* DEC Information Sheet 36/2010 WA Department of Environment and Conservation, (now WA Department of Parks and Wildlife) Science Division.

Byrne, M., Prober, S. McLean,E. Steane, D. Stock, W.D., Vaillancourt, R.E. & Potts, B.M. (2013). *Climate-resilient revegetation of multi-use landscapes: adaptation to climate in widespread eucalypt species.* Department of Environment and Conservation (now Department of Parks and Wildlife). Information Sheet 71/2013 Science Division.

Chambers, L.E., Altwegg, R., Barbraud, C., Barnard, P. and Beaumont, L.J. (2013) *Phenological Changes in the Southern Hemisphere.* PLoS ONE 8(10): e75514. doi:10.1371/journal.pone.0075514.

Cochrane, A. and Daws, M.(2008). How will warming affect recruitment of South Western Australian narrow range mountain endemics? *Australian Plant Conservation* 16 (4): 16-18.

Cochrane, A., Daws, M. and Hay, F.R. (2011). Seed-based approach for identifying flora at risk from climate warming. *Austral Ecology* 36, 923–935.

Coffey (2009). Climate Change: Whole of Landscape Analysis of the impacts and options for the South Coast Region. Prepared for South Coast Natural Resource Management by Coffey Environments Pty.Ltd.

Crane C.E., Shearer, B.L. , Dunne, C.P. (2012). Influence of climate on canker disease in the Proteaceae of the Southwest Australian Floristic Region. Abstract ASBS Conference 2012.

Comer, S., Tiller, C., Danks, A. and Burbidge, A. (2011). Translocations of the Endangered Noisy Scrub-bird as a mechanism for increasing resilience in changing climates. Western Australian Department of Environment and Conservation Ecological Society of Australia Conference Abstract, Hobart 2011.

DEC (2009). South Coast Region, WA, Threatened Species & Ecological Communities. Regional Strategic Management Plan. Western Australian Department of Environment and Conservation, South Coast Region.

DEC (2012). Fitzgerald Biosphere Recovery Plan: A Landscape Approach to Threatened Species and Ecological Communities Recovery and Biodiversity Conservation. Department of Environment and Conservation, Albany.

Driscol, D. (2007). The conservation challenge of sustaining spatially dependent evolution. *Pacific Conservation Biology.* 13:84-92.

Dunlop M., Hilbert D.W., Ferrier S., House A., Liedloff A., Prober S.M., Smyth A., Martin T.G., Harwood T., Williams K.J., Fletcher C., and Murphy H. (2012) *The Implications of Climate Change for Biodiversity Conservation and the National Reserve System: Final Synthesis.* A report prepared for the Department of Sustainability, Environment, Water, Population and Communities, and the Department of Climate Change and Energy Efficiency. CSIRO Climate Adaptation Flagship, Canberra.

Eldrige, M.D.B., Kinnear , J.E., Zenger K.R., McKenzie, L.M. & P.B.S. Spencer (2004). Genetic diversity in remnant mainland and ''pristine'' island populations of three endemic Australian macropodids (Marsupialia): *Macropus eugenii, Lagorchestes hirsutus and Petrogale lateralis. Conservation Genetics* 5: 325–338, 2004.

Fitzpatrick, M.C., Gove, A.D., Sanders, N.J. and Dunn, R.R. (2008) Climate change, plant migration and range collapse in a global biodiversity hotspot: the *Banksia (Proteaceae)* of WA. *Global Change Biology* 14: 1337–1352.

Ford, B., Cook, B., and Rogers, D. (2013). Climate change impacts and adaptation in the Southern & Southwestern Flatlands cluster: review of existing knowledge. Report No 133, Centre of Excellence in Natural Resource Management, University of Western Australia, Albany.

Framenau, V. W., Moir, M. and Harvey, M. (2008) Terrestrial Invertebrates of the South Coast NRM Region of Western Australia: Short Range Endemics in Gondwanan Relictual Habitats. Report prepared for South Coast NRM.

Gibson, L. and McNeill, A. and de Tores, P. and Wayne, A. and Yates, C. (2010). Will future climate change threaten a range restricted endemic species, the quokka *(Setonix brachyurus)*, in south west Australia? *Biological Conservation* 143. pp. 2453-2461.

Gilfillan, S. (2014).Monitoring Protocol for the Black-gloved Wallaby within the Gondwana Link Area. Produced for South Coast NRM, Restoring Gondwana Project.

Gollan, J.R., Ramp, D. and Ashcroft, M.B. (2013). Assessing the distribution and protection status of 2 types of cool environments to facilitate their conservation under climate change. *Conservation Biology* 28 (2): 456-466.

Gunby, C. (2014). Background Paper: *Climate Change and Water Resources in the South Coast Region*. Produced for South Coast NRM.

Harris, B. J. C., Fordham, D. A., Mooney, P. A., Pedler, L. P., Araujo, M. B., Paton, D. C., Stead, M. G., Watts, M. J., Resit Akcakaya, H. & Brook, B. W. (2012). Managing the long-term persistence of a rare cockatoo under climate change. Journal of Applied Ecology 49, 785-794.

Heller, N.E. and Zavaleta E.S. (2009) Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological Conservation* 142:14–32.

Heller, N.E., and Hobbs, R.J. (2014). Development of a Natural Practice to Adapt Conservation Goals to Global Change 28 (3): 696-704

Hodgson, J.A. , Thomas, C.D., Wintle, B. A. and Moilanen, A. (2009) Climate change, connectivity and conservation decision making: back to basics. *Journal of Applied Ecology* 46 (5): 964–969.

Keppel, Gunnar and Van Niel, Kimberly P. and Wardell-Johnson, Grant W. and Yates, Colin J. and Byrne, Margaret and Mucina, Ladislav and Schut, Antonius G. T. and Hopper, Stephen D. and Franklin, Steven E. (2012). Refugia: identifying and understanding safe havens for biodiversity under climate change. Global Ecology and Biogeography. 21 (4): 393-404.

Kool, J.T., Moilanen, A. and Treml, E.A. (2012). Population connectivity: recent advances and new perspectives. *Landscape Ecology*. Published on-line 04 December 2012

Lester, R., Close, P.G., Barton, J., & Pope, A. (2014). Predicting the likely response of data-poor ecosystems to climate change using space-for-time substitution across domains. *Global Change Biology* Volume 20, Issue 11. pp3471–3481

Lindenmayer D, Burns E, Thurgate N, Lowe A (Eds) (2014) 'Biodiversity and Environmental Change: Monitoring, Challenges and Direction'. (CSIRO Publishing: Melbourne.).

Maggini, R. Lehmann, A. Zbinden, N. Zimmermann, N.E., Bolliger, J. Schröder, B., Foppen, R. Schmid, H., Beniston, M. & Jenni, L. (2014). Assessing species vulnerability to climate and land use change: the case of the Swiss breeding birds. *Diversity and Distributions* 20 (6): 708-719.

Mantyka-Pringle, C.S., Martin, T.G., Moffatt, D.B., Linke, S. and Rhodes, J.R. (2014) Understanding and Predicting the Combined Effects of Climate Change and Land-Use Change on Freshwater Macroinvertebrates and Fish. *Journal of Applied Ecology* 51(3): 572–581.

Moir, M.L., Brennan, K.E.C. and Harvey, M.S. (2009). Diversity, endemism and species turnover of millipedes within the south-western Australian global biodiversity hotspot. *Journal of Biogeography* 36, 1958–1971.

Molloy, S., Davis, R. & Van Etten, E. (2014).Species distribution modelling using bioclimatic variables to determine the impacts of a changing climate on the western ringtail possum *(Pseudocheirus occidentals; Pseudocheiridae*).*Environmental Conservation* 41(2): 176-186.

Prober, S.M., Thiele, K.R., Rundel, P.W. , Yates,C.J., Berry, S.L., Byrne, M., Christidis, L. Gosper, C.R. Grierson, P.F. Lemson, K., Lyons, T., Macfarlane, C. , O'Connor, M.H., Scott, J.K., Standish, R.J. and Stock, W.D. (2012). Facilitating adaptation of biodiversity to climate change: a conceptual framework applied to the world's largest mediterranean-climate woodland. *Climatic Change* 110:227–248.

Schut, A.G.T., Wardell-Johnson, G.W., Yates, C.J., Keppel, G. and Baran I. (2014) Rapid Characterisation of Vegetation Structure to Predict Refugia and Climate Change Impacts across a Global Biodiversity Hotspot. PLoS ONE 9(1).

Scott JK, Murphy H, Kriticos DJ, Webber BL, Ota N and Loechel B (2014) Weeds and Climate Change: supporting weed management adaptation. CSIRO, Australia. ISBN 978-1-4863-0401-1.

Steffen W., Burbidge A. A., Hughes L., Kitching R., Lindenmayer D., Musgrave W., Stafford Smith M. & Werner P. A. (2009) *Australia's Biodiversity and Climate Change: A strategic assessment of the vulnerability of Australia's biodiversity to climate change*. CSIRO Publishing, Melbourne.

Stewart, B. Close, P.G., Cook, P.A. and Davies, P.M. (2013). Upper thermal tolerances of key taxonomic groups of stream invertebrates. *Hydrobiologia* 718 (1): 131-140.

Steel, J., Kohout, M. and Newell, G. (2008). Wither the weeds under climate change? Department of Primary Industries, Victoria.

Thompson, S.E., Levin, S. and Rodriguez-Iturbe, I. (2014).Rainfall and temperatures changes have confounding impacts on *Phytophthora cinnamomi* occurrence risk in the southwestern USA under climate change scenarios. *Global Change Biology*, 20 (4): 1299-1312.

Tulloch, A. (nd). When and how frequently should we burn a senescing landscape to safeguard against loss of species? Report for Bush Heritage Australia. National Environmental Research Program Environmental Decisions Hub University of Queensland, Brisbane QLD 4102.

Watson, J.E.M., Iwamura, T. And Butt, N. (2013). Mapping vulnerability and conservation adaptation strategies under climate change. *Nature Climate Change* 3, 989–994.

Williams, R.J., Bradstock, R.A., Cary, G.J., Enright, N.J., Gill, A.M., Lucas, C., Whelan, R.J, Anderson, A.N., Bowman, D.M.J.S, Clarke, P.J., Cook, G.D., Hennessey, K.J. and York, A. (2009) Interactions between Climate Change, Fire Regimes and Biodiversity in Australia: A Preliminary Assessment. Report to the Department of Climate Change and Department of Environment, Water, Heritage and the Arts, Canberra.

Wilkins, P., Gilfillan, S., Watson, J. and Sanders, A. (2006). The Western Australian South Coast Macro Corridor Network: a bioregional strategy for nature conservation. Department of Conservation and Land Management. South Coast Regional Initiative Planning Team.

Williams, S.E., Shoo, L.P., Isaac J.L., Hoffmann, A.A., Langham, G. (2008). Towards an integrated framework for assessing the vulnerability of species to climate change. PLoS Biol 6(12).

Yates, C. J., Elith, J., Latimer, A. M., Le Maitre, D., Midgley, G. F., Schurr, F. M. & West, A. G. (2010). Projecting climate change impacts on species distributions in megadiverse South African Cape and Southwest Australian Floristic Regions: opportunities and challenges. *Austral Ecology* 35: 374-391.

Appendix 1: Recovery Plans & Interim Recovery Plans Produced Since 2007

SPECIES	YEAR
FAUNA	
Western ringtail possum (*Pseudocheirus occidentalis*)	2014
Quokka (*Setonix brachyurus*)	2013
Chuditch (*Dasyurus geoffroii*)	2012
Western spiny-tailed skink (*Egernia stokesii*)	2012
Carnaby's cockatoo (*Calyptorhynchus latirostris*)	2012
Woylie (*Bettongia penicillata ogilbyi*)	2012
Western ground parrot (*Pezoporus wallicus flaviventris*) Western bristlebird (*Dasyornis longirostris*) Noisy scrub-bird (*Atrichornis clamosus*) Western whipbird (western heath) (*Psophodes nigrogularis nigrogularis*) Western whipbird (western mallee) (*Psophodes nigrogularis oberon*) Rufous bristlebird (western) (*Dasyornis broadbenti litoralis*)	2010 Commonwealth Approved 2014
Western trout minnow (*Galaxias truttaceus hesperius*)	2008
Baudin's cockatoo (*Calyptorhynchus baudinii*)	2008
Forest red-tailed black cockatoo (*Calyptorhynchus banksii naso*)	2008
Dibbler (*Parantechinus apicalis*)	2008
Muir's corella (*Cacatua pastinator pastinator*)	2008
FLORA	
Gastrolobium luteifolium	2009 - 2014
Daviesia ovata	2010 - 2014
Eremophila ciliata	2010 - 2014
Latrobea colophona	2010 - 2015
Marianthus aquilonaris	2010 - 2015
Scaevola macrophylla	2010 - 2015
Banksia pseudoplumosa	2011 - 2016
Hibbertia abyssa	2011 - 2016
Calochilus pruinosus	2013- 2018
Leucopogon gnaphalioides	2013- 2018
Caladenia bryceana subsp. *bryceana*	2008 - 2013
Caladenia harringtoniae	2008 - 2013
Drakaea micrantha	2008 - 2013
Verticordia fimbrilepis subsp. *australis*	2010 - 2015

water

land

coastal and marine

cultural heritage

biodiversity

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