DETAILED EDITORIAL REVIEW OF

"THE IMPLICATIONS OF CLIMATE CHANGE FOR LAND-BASED NATURE CONSERVATION STRATEGIES"

by

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INTRODUCTION

Climate change is a significant issue for biodiversity conservation, particularly where ecosystems already experience external pressures such as clearing, salinity, and introduced diseases, pests, and predators.

The study from which the Pouliquen-Young / Newman report was prepared *"was set up to research the degree of vulnerability of the distribution native species of WA to the changes in regional temperatures and rainfall patterns predicted under climate change. The study used modelling to assess the impact on species distribution using a number of climate change scenarios"* (pages 9-10).

A report (hereinafter The Report) was prepared in 1999 by Murdoch University for the Australian Greenhouse Office (AGO). The study had two objectives:

- *"develop a spatial analytical tool for studying the impacts of climate change on the distribution of species in Western Australia, integrating soil features and land uses;*
- *"develop recommendations and strategies for nature conservation under a climate change scenario addressing land based strategies for reserves and for areas outside reserves, particularly in highly fragmented landscapes such as the agricultural region of the south west of the State"* (page 16).

The Report applied BIOCLIM, a widely used bioclimatic model, to a range of taxa of Western Australian plants and animals, using then-current and apparently specifically generated CSIRO climate change scenarios for the south west of WA. The Report was in 1999 and probably remains now the most comprehensive biodiversity - climate change modelling initiative for Western Australian biota. However, it has not been released publicly and remains largely inaccessible to land managers, policy analysts and other research scientists.

The AGO has commissioned the WA Department of Environment and Conservation (DEC) to review The Report, with a view to assessing its utility and defining the boundaries of that utility. It was also intended that the review would enable both the AGO and DEC to learn more about the uses and limitations of bioclimatic modelling for biodiversity protection and land management purposes.

The agreed objectives of the DEC review were to

- **determine the extent to which The Report's findings can be used in regional, NRM or biodiversity planning and management;**
- **investigate the strengths and weaknesses of the approach used by Pouliquen-Young & Newman in light of subsequent scientific and technical developments; and**
- **develop an improved basis for further investigations of climate change biodiversity impacts in WA and Australia more broadly.**

The specific requirements of the DEC review are to provide advice to the AGO with respect to:

- the scientific basis of the data used;
- the methodologies and their application; and
- the extent to which The Report's findings and conclusions align with other research findings.

This review fulfils these requirements by providing advice on the following matters:

1. The approach and content of each chapter of The Report;
2. The text, figures and readability of The Report overall;
3. The extent to which The Report meets its study objectives;
4. Prospective scientific use of The Report, with particular attention to the data and methodology;
5. Policy and management use of The Report for NRM or biodiversity planning or management;
6. Comparison of The Report with other similar publications, previous, concurrent and subsequent.

This Review concludes with several prospective areas for further research.

APPROACH TO THE REVIEW

DEC's review addressed the following questions:

1. Does The Report meet the study objectives (as defined in The Report)?
2. Does The Report use appropriate models and data and does it use the models and data appropriately?
3. Does the analysis support the findings?
4. Do the findings support the conclusions?
5. How and with what caveats can The Report's findings be used for policy?
6. How do the findings in The Report compare with other research findings?
7. What key management and research directions emerge from The Report and the DEC review?

There are three main parts to the DEC review:

1. Review of each substantive chapter;
2. Relevance and potential use of The Report;
3. Recommendations for further research.

REVIEW OF CHAPTERS

Chapter 1: Background

Scientific basis of the study

The Report provides a brief summary of the scientific basis for climate change, responses by organisms to changes in climate, atmospheric composition and synergies between these factors and others such as competition, as evident from the literature available when The Report was prepared.

The Report highlights the difficulty of generating an understanding of how a complex ecosystem might respond, and the need for expert knowledge as well as good information. The response of individual species distribution to climate change is discussed, and the interplay between climate change responses and ongoing impact of human activities through land management is noted.

Several assumptions underlying climate change modelling are stated. A first set of assumptions appears in the section "Climate and range limits" in relation to the other scientific material reviewed in this chapter of The Report:

- present day range limits are in equilibrium with the present climate;
- there are no gaps in knowledge regarding the distribution data;
- impacts of CO_2 fertilization on physiological processes are not included;
- differential dispersal attributes are generally not integrated in the studies.

A second set of assumptions is presented in the following section "*Modelling distribution*":

- current distribution of a species is in equilibrium with climate;
- the range of the species over different climate zones is well known.

The Report states: *"These studies [ie bioclimatic modelling] are … extremely sensitive to the quality of the distribution data used in the analysis"* (page 24).

The Conclusion to Chapter One notes that bioclimatic studies are relatively recent, approaches are varied, and methodologies suffer from a lack of integration of methodologies and results. *"Results from studies on single species cannot be extrapolated to mixed stands; biogeographic studies usually disregard the potential for adaptation and rapid evolution; ecosystem modelling ignores dispersion attributes and species composition"* (page 25). Few studies include more than one or at most two factors.

However, The Report concludes that studies into the vulnerability of single species distribution to climate change is relatively well advanced with reasonably well defined assumptions. Distribution has both spatial and temporal dimensions, with integrating factors ranging from individual physiology and reproduction to long term population dynamics.

Discussion

The distribution of a species at any time is governed by many factors, including genetics, life-history characteristics (e.g. dispersal ability, reproductive strategy), physiological tolerances, interactions with other species (competitors, predators, pathogens, mutualisms) and stochastic influences (climate variability, disturbance regimes, externally generated events). Thus, current distribution results from physical factors (e.g. soil and climate), biological factors (e.g. physiology and ecology) and chance (e.g. lightning, European settlement and land clearing). Where for an extended period of time physical and biological factors have been stable and chance has not been active species distribution may also be stable within bounds. Where physical and biological factors have recently been changing or chance has recently been active species distribution may be evolving in response to these recent events. Where it is anticipated that the factors will change in the future, it can be expected that species distribution may also be affected. Bioclimatic modelling seeks to provide insight into how the distribution of a species might change as a result of a defined change in climate conditions.

This chapter gives a useful overview of the approaches and assumptions in modelling the species distribution effects of climate change, to the date The Report was prepared (1999). The limits of bioclimatic studies outlined in the chapter provide a basis for appropriate use of The Report's findings; the assumptions listed indicate the limits of this use.

Chapter 2. Methods

Chapter 2 briefly outlines the six-step approach used to model the impacts of climate change on the selected biota and the consequences for conservation of the biota in conservation reserves and refuges.

The application of the BIOCLIM model is explained and its strengths and weaknesses noted or referenced. The rationale for and method of including soil data at a 1:2.5 million scale is outlined.

The climate change scenarios and impacts used in the study are described including changes in mean annual temperatures, disaggregated to monthly mean temperature changes, and changes to monthly average rainfall. While the projected climate changes are applied in a very geographically broad manner, as shown on maps provided in the Appendix, they appear to be more responsive to regional circumstances than the 2001 CSIRO climate projections.

Discussion

The methods chapter provides a very terse summary of the approach taken for the study's bioclimatic and policy analysis. The description is inadequate to enable replication and testing of the research and its findings. However, it compares well with similar reports, such as Dexter *et al.* (1995), which generally have even more restricted explanations of the methodology used.

Some aspects of the methodology description raise immediate questions. For instance, what was the basis for choosing the particular 18 climatic variables applied in the modelling? What is "the cookie cutter method" of applying soil data?

Developing a capacity to generate credible projections of climate change impacts on species and ecosystems remains a major challenge globally. To facilitate effective collective professional learning and development in bioclimatic modelling options, future reports of this type should provide a more detailed description of methods including references where specialized terms are used.

Assumptions

The assumptions underlying a methodology define how the results can be used. The methods chapter does not explicitly list the assumptions which affect the methodology, but several assumptions are listed in the introduction:

> *"The main assumptions are that the distribution of species is in equilibrium with climate and that the range of the species over different climatic zones is well known, otherwise the relation between distribution and climate does not hold. These studies are therefore extremely sensitive to the quality of distribution data"* (page 24).

The Methods chapter does note several limits inherent in the methods used:

- *"BIOCLIM is sensitive to the quality of the distribution data, but less so to the geographic bias which often accompanies surveys and specimen collecting"* (page 31).
- *"While the reason behind the use of BIOCLIM is to reflect habitat suitability based on climate, the percentile limits are somewhat arbitrarily chosen"* (page 31).
- *"Most other limitations of BIOCLIM are expanded in Nix (1986) and Bennett et al. (1991) and will not be repeated here"* (page 31).
- *"The present study does not include the potential effect of atmospheric* CO_2 *fertilisation"* (page 34).

The implications of these methodological limits are not discussed in the chapter.

Several other assumptions can be discerned in the methods chapter. There is an implicit assumption in the use of four categories of climatic suitability that climatic values at the boundaries of the climatic envelope are in some way less favourable than those near the middle. This is clearly not the case, as the authors acknowledge in the instance of the quokka: *"Its stronghold remains Rottnest Island where the population survives in an atypical dry and open habitat"* (page 52). This assumption should be explicit and requires at least some discussion regarding its rationale, applicability, limitations and implications.

A fundamental assumption of all bioclimatic studies is that some aspects of temperature and rainfall are principal factors determining the occurrence of a species. This assumption requires considerable investigation in the Australian context as it underlies all past, current and prospective bioclimate studies.

BIOCLIM Model

Modelling is a process of building simple, abstract representations of complex systems to understand how they work, how they might behave in the future, and how a system might be managed. Provided the limits of the models are acknowledged and understood by those who are using them, the explicit manner in which data are used and functional relationships are defined in models enables them to play a useful role in decision making, and in identifying critical information gaps.

Underlying BIOCLIM are 16 climatic surfaces interpolated from meteorological stations within the State. Each surface is actually made up of a number of distinct patches. The disjunct boundaries between the patches produce noticeable artefacts in some of the surfaces and derived products. From these 16 surfaces, up to 35 other surfaces are derived as seasonal or other variants. Thus a number of the surfaces are correlated.

The scale of the model (125 km resolution) is similar to the distribution of many restricted taxa, and the geographic scale of climatic variation is much greater than this. This could result in the analysis indicating a greater impact than would be the case if the scale was at a more meaningful biological scale. This suggests that for areas such as south west Western Australia, relatively smaller geographic scales may be appropriate for assessing the implications of climate change for many taxa.

Data used

The value of the projections from any analysis will depend significantly on the quality of the data used to support the analysis. The Report uses BIOCLIM and relies on species distribution data and soil data available at the time of the study.

It is not always clear which climate change parameters were chosen for the analysis. Eight temperature and nine rainfall variables were listed in Table 0.1 (page 31) as climate variables used by BIOCLIM, but the description of the climate prediction scenarios on pages 33-34 appears to be concerned only with applying global average temperature changes on a regional basis and applying projected rainfall changes on a monthly basis, an interpretation of the text which is supported by the maps used to visually describe the climate changes applied in the analysis (Maps 1, 2 and 3). Future reports would benefit from a more explicit treatment of this matter.

Defining a species' climatic envelope on the basis of the distribution of that species at a particular time will normally result in a smaller envelope than would result from an analysis based on its distribution over an extended period of time. Removing species distribution data points where these data are not known to be incorrect will exacerbate a situation where distribution is only partially represented. Geographical disjunctions in the distributions of rare and common plant taxa are well documented in south-west Western Australia, often extending the geographical range of a taxon by hundreds of kilometres. Moreover, the environmental weeds literature and common garden experiments show that species can grow on soils and in climates where they are not normally found because they have been released from competition, predators and other limiting factors.

The Report does not discuss how accurately historical records reflect past actual distribution, and there appears to be no recognition that the distribution inferred from historical records is different to the original distribution. The difference is this: using an assumption that the actual pre-European settlement distribution is fixed, the historical records are simply an observational process applied to the actual distribution. The historical records are a subset of the actual distribution, and are neither comprehensive (because the observations are necessarily incomplete) nor representative (because of regional or locational biases in the location of observers). A logical consequence is that the recorded historical distribution must be smaller than the actual (realized) distribution. Therefore, any analysis that predicts changes in distribution due to changes in climate would likely underestimate increases in range and overestimate decreases in range. This highlights the importance of developing good distribution records for future bioclimatic modelling studies and further exploring the implications of using distributional records generated by differing levels of biological surveying.

Soil maps

Recent biological survey modelling in the Western Australian wheatbelt supports the proposition that climate and soils are major factors, among others, affecting the distribution of plant species and assemblages in the region. Acknowledging that there are a number of other factors influencing the distribution and abundance of species, there is merit in the approach of the study as outlined in the modelling methodology in Fig. 0.3.

The study improves on previous bioclimatic studies by including soil data. However while this important predictive factor operates on a relatively localized scale in south-west WA it is applied at a scale of 1: 2.5 million in the study, which is likely to be too coarse in these circumstances. In addition, the specific interaction between soils and species is idiosyncratic and complex (e.g. deep-rooted plants may interact with a different part of the soil profile to shallow rooting ones) and therefore not easily modelled. There would be value in future bioclimatic studies exploring these matters in greater depth. In addition, the Report demonstrates the importance of aligning the geographic scale of the analysis with the scale of key parameters or data sets. In this instance, it is clear that to appropriately include soil as a factor in bioclimatic studies of SW WA will require a more detailed geographic analysis to be undertaken.

Summary

The Methods chapter is not sufficiently detailed to enable an independent replication of the study, but it compares well with precedent study reports such as Dexter *et al.* (1995). Some of the assumptions underlying the methods, choice and use of data and use of the findings are discussed, but the chapter would have been strengthened by a comprehensive, clear and objective treatment of the assumptions which govern The Report’s validity and application. Such a treatment might also have reduced the tendency elsewhere in The Report to extrapolate from the legitimate findings to what appear to be unsupported conclusions.

Several important insights for current and future bioclimatic studies arise from the Methods chapter:

- Because bioclimatic analysis methods are still being developed and assessed, future bioclimatic study reports should provide a detailed description of methods, including references where specialized terms are used, to enable effective determination of the applicability of assessment options.
- Underlying assumptions should be explicitly stated, and their implications fully discussed.
- The assumption that species distributions were in equilibrium with the climate at the time of European settlement of Western Australia should be explored.
- The fundamental assumption underlying all bioclimatic studies that some aspects of temperature and rainfall are principal factors determining the occurrence of a species needs to be investigated in the Australian context.

- The geographic scale of bioclimatic studies needs to take account of key factors such as the apparent range of the taxa of interest and soil type distribution. In that case of south west Western Australia this would suggest a relatively small geographic scale may be appropriate for assessing the implications of climate change for many taxa in comparison with recently glaciated areas such as northern North America.
- Because bioclimatic analyses are directly dependant on the availability of distribution data, it is important that key sets of good distribution records are developed for indicator taxa for future bioclimatic modelling studies.

Chapter 3: Fauna

21 taxa of vertebrates (3 frogs and 18 mammals) were chosen for analysis on several criteria:

- each taxon is on the WA or Commonwealth protected species list; and
- each is endemic to WA, or the only known wild populations are now endemic to WA, or WA populations of an Australia-wide taxon are important for its survival, or the WA populations are differentiated genetically or morphologically from related taxa elsewhere in Australia.

Species vulnerability was estimated from:

- change (i.e. increase or decrease) in the size of its bioclimatic envelope;
- change in the location of its bioclimatic envelope; and
- change in the connectivity of its bioclimatic envelope.

The species chosen were described, the number of data points identified and the source and treatment of the data described.

Frog distribution data were sourced from a UWA zoologist; mammal data were sourced from the WA Museum. The chapter notes *"… the distribution drawn from [Museum] collected specimens is unlikely to represent the true distribution of the species, especially for the historical records"* (page 39). Taxonomical misidentification may be a problem due to uncertainties with older records or due to recent taxonomical changes. Nevertheless, Museum records were used because they are *"often the only large-scale source of distribution records available, and usually cover a longer time period than other organisations' databases,"* and *"Their use in distribution analysis is therefore valid."* (page 39) Supplementary mammal records were added and the Museum data were corrected.

Where distribution data correlated with distribution shown in an Australian Museum publication, those data were used. Where modern records indicated a more restricted distribution, only modern records were available or historical records were not comprehensive enough to define a valid historical climatic envelope, only post-1960 records were used.

Islands are important refuges for endangered mammals, so although *"BIOCLIM does not produce climatic parameters for offshore islands … it was assumed that the climatic data from the nearest continental locations would give a fair estimate of the islands' climates … [and moreover the climate projection] regional grid is sufficiently coarse-grained to include offshore islands" (*page 40).

Results

The 3 frog species have very small ranges in the higher rainfall area of the extreme south west, *"… the three frog species are predicted to disappear completely at [a] global temperature increase of 0.5^{o}C"* (page 11).

The Report outlines habitat requirements, historical and modern distributions, threatening processes, treatment of WA Museum and other records and the results of BIOCLIM analysis for each species of mammal. Most mammal species were found to experience significant effects from climate change, some losing all current distribution, some losing all current habitat at only 0.5^{o}C increase, but a few experiencing an increased distribution.

The implications of geographic choice of data were discussed in the context of the Western barred bandicoot (*Perameles bougainville*) whose *"distribution once extended over most of the south of WA (except the extreme south west) and east to NSW and Victoria and the Gibson Desert"* (page 47). It is now limited to Bernier and Dorre islands with a reintroduction to Heirisson Prong. The Report states that using only WA records from the Shark Bay area and the Gibson Desert generated a bioclimatic envelope comprising those areas, which changed in size and quality with climate change. With climate change, fragmentation is accentuated and high quality habitat disappears. The Report notes that Dexter *et al.* (1995) found that the species would not suffer drastically on the basis of an analysis that included all Australian historical records. The Report posits that using the more restricted set of records is a better predictor because the species is currently very limited in occurrence.

A similar outcome is found for the Boodie or Burrowing bettong *(Bettongia lesueur)*, which was once widespread over most of WA and the arid and semi-arid zones of SA, Victoria, NSW and the NT, with few apparent soil limitations, but which is now restricted to Barrow, Dorre and Bernier islands with a reintroduction to Heirisson Prong. While Dexter *et al.* (1995) found that the species would increase its range under climate change, the Report states that its indication of reduced habitat was preferred in the absence of a commitment to aid migration or undertake translocation and fox control.

The implications of temporal choice of data were discussed in the context of the Bilby (*Macrotis lagotis*), which was once found over most of Australia except the high rainfall areas. It is now extinct over much of its range due to changed fire regimes, grazing, competition and predation following European settlement. While post-1960 WA Museum records are all from the north of WA, the Museum holds records for the species' entire original distribution. Using all records habitat declines by 50% to about 800 000 km^2; using only post-1960 records habitat declines by 74% to 270 000 km^2.

The changing nature of impacts potentially arising from increasing climate change was indicated in the analysis of the Numbat *(Myrmecobius fasciatus)* for which a small temperature increase (+0.5^{o}C) indicated a greater habitat (+171%) but a larger increase (+2.0^{o}C) indicated reduced habitat (-50%).

In the chapter's *Discussion*, The Report describes two precedent bioclimate studies (Bennett *et al.* 1991 and Dexter *et al.* 1995), and suggests that the newer climate projections more than likely explain the differences in the species projections between the studies. However The Report also notes that several other differences also exist between this study and Dexter *et al.* (1995): *"… source and comprehensiveness of distribution data, identity of the BIOCLIM climatic variables, definitions of habitat suitability categories and in some cases even the population taxonomy" (page 55).* A table is provided which compares the findings of Dexter *et al.* with this study. The findings of Bennett *et al.* (1991) are also briefly summarized.

Four conclusions are drawn from the findings of Dexter et al. (1995) and Bennett *et al.* (1991):

- *"most species' distributions are vulnerable to climate change;*
- *species will react to climate change on an individual basis;*
- *usually, but not always, a large distribution is less vulnerable to climate change than a small distribution;*
- *the degree of vulnerability of species to climate change is a function of the degree of change in temperature and rainfall." (page 56)*

The findings of this discussion are summarized: while the response to climate change varies between species, there is a clear trend for most species to decrease in distribution as global temperature increases. Two related variables are stated to influence the degree of vulnerability found in the study:

- Effect of the original distribution area: Species having a very restricted modern distribution were found to entirely lose their distribution area under very low increases in temperature. In many cases these are species now found only on virtual or actual islands.
- Choice of distribution data used in the analysis: Most species' current distribution is much smaller than their historical or pre-European distributions. Using smaller current distributions yields an indication of greater vulnerability than does using historical distribution data. The utility of each option is discussed:
    - Using the historical distribution for species currently only found on islands would enable an analysis of potential translocation sites under climate change;
    - Using modern (current) distribution data would enable an analysis of the likely fate of current refuges under specified levels of climate change, taking account of [the rapid genetic, physiological and / or morphological divergence that often rapidly happens for island populations].

In a discussion about fauna conservation under climate change, The Report notes that the study focused on mammals which *"belong to a group that is exceptionally vulnerable to introduced predators"* (page 59), currently found only in refuges from these predators, in particular on islands. The study finds that these island refuges are extremely vulnerable to climate change, placing in jeopardy the long term protection of the species found on them. The islands and refuges are individually described:

- Shark Bay islands: Several species have survived under a highly variable climate; if climate change increases the variability of seasonal rainfall one or more of the species may not continue to survive.
- Barrow Island: The CSIRO climate projection used for this study indicated a marked increase in summer rainfall over the Pilbara coast, which would benefit some mammal species currently found there.
- Southern refuges: The three species of frogs should be able to survive in the micro-climates they require, which are abundant in the dissected landscape of the higher rainfall region, but would be vulnerable to large scale land use changes. Rock wallabies are currently constrained by habitat requirements and predator pressure rather than climate *per se*, the isolated populations are sensitive to local extinctions and climate change might limit carrying capacity following predator control.

The range of threatening processes affecting vertebrate species is discussed, and potential impacts on these processes from climate change are considered, especially fire regimes, dieback and introduced species distribution.

Recommendations made in the chapter:

- Develop strategies to reduce vulnerability of vertebrate species to climate change, especially those species currently only found in tiny refuges;
- Incorporate potential climate change impacts into recovery plans;
- Reintroduce formerly widespread species which are now restricted to islands and refuges;
- Monitor the survival of species introduced to islands;
- Investigate the potential implications of not segregating genetically distinct populations;
- Encourage wildlife corridors on private land in southern regions to enable southerly migration;
- Include in research programs studies of climate change impacts on population dynamics and distribution of introduced and indigenous vertebrates.

Further directions for research are suggested:

- Threshold studies on eco-physiological and population dynamics;
- Effect of climate change on introduced vertebrates;
- Effect of climate change on diseases and vectors affecting introduced and indigenous vertebrates;

- Effect of climate change on aquatic species and habitats, including introduced species.

Discussion

This chapter is reviewed first from a scientific perspective and thereafter from a policy perspective.

Scientific Review

The analysis of climate change impacts on mammal distribution is based on WA data only, and was sourced from the database of the WA Museum, generating 2 important considerations.

- The first consideration relates to potential geographic bias: when modelling the distribution of a species, locality records from the entire geographical range, not just from a part of the range (in this case within WA), should be used.
- The second consideration relates to potential temporal bias: reliance on vouchered specimens held in a single museum will be limited to the extent to which that institution has been able to develop a complete collection of specimens. Because the WA Museum was not established until 1892, earlier collections are lodged in other museums. Early collectors were hampered in their activities by poor infrastructure and transport (few roads, reliance on horses or camels) and even more recently there is a heavy bias towards incidental collections or observations near roads. Early collectors were also working in an era that did not appreciate biological variation, resulting in deliberate collection of very few specimens, sometimes limited by the transport and storage available.

To ensure scientific veracity for a distribution modelling activity, all possible sources of information about the occurrence of the mammal species should be examined and where appropriate used. In the case of Western Australian mammals these would include explorers' journals, collections in the Australian Museum (Sydney), Macleay Museum (Sydney), Museum of Victoria (Melbourne), South Australian Museum (Adelaide), Queensland Museum (Brisbane), and collections held outside Australia (e.g. Natural History Museum, London; American Museum of Natural History, New York; and many smaller museums in Europe and North America). It is essential that modelling studies are based on as near a complete set of geocoded records as it is possible to collate.

According to the maps presented in Strahan (1995), 8 of the mammal species studied occurred in historical time in the deserts. This highlights the importance of using bioclimatic modelling as only one element of an assessment of climate change vulnerability. Based on the assessment of mammal species' current highly restricted range, The Report suggests that species that occur (or occurred before the fox colonized) in deserts could not cope with projected temperature increases and rainfall decreases. The species referred to are *Bettongia lesueur, Dasyurus geoffroii, Lagorchestes hirsutus, Macrotis lagotis, Myrmecobius fasciatus, Phascogale calura, Pseudomys fieldi,* and *Petrogale lateralis*. This 'result' overlooks physiological and behavioural adaptations possessed by Australian mammals, such as conservative use of water, nocturnal activity and reliance on daytime shelters such as burrows, rock cavities and dense bushes. While geographically isolated populations might develop limited genetic variability and associated limited capacity to successfully meet the rigours of changed climate conditions, these limitations are not investigated or proven in the analysis.

The study also overlooks the many vicissitudes in climate experienced over millions of years by frogs and marsupials, experiences that would suggest these taxa might show some resilience to changes in climate on the scale used in the study.

Of the 18 animal species studied, the results for only 4 pose real questions based on known ecological requirements: *Geocrinia alba, G. vitellina, Spicospina flammocaerulea,* and *Setonix brachyurus* are linked to and appear to require moist sites. For these species, it is reasonable to expect that reduction in rainfall may decrease the extent of suitable habitat, and this question deserves attention. Similarly, altered fire regimes resulting from changed climate conditions could modify habitat type or quality. However, the geographic scale of analysis and the scale of 'refuges' (minimum 50 ha) does not allow these matters to be addressed.

Policy Review

Chapter 3 summarizes an analysis of the impacts of specified climate changes on the distributions of 21 vertebrate species found in WA. Both current and historical distribution were separately used and the separate results and their applications are discussed. The climate change analysis is compared with precedent analyses of a similar nature (Bennett *et al.* 1991) and of the same species (Dexter *et al.* 1995). The chapter also includes a discussion of other factors that threaten the species studied, including predation, clearing, fire regimes, competition, disease and pests, livestock and hydrology. There is a consideration of the implications of climate change for the effectiveness of existing conservation reserves. With the addition of these latter factors, the study is possibly the most comprehensive attempt to place climate change within the context of all processes which threaten some of WA's vertebrates.

The chapter therefore provides a basis for developing a means of determining the potential utility of bioclimatic modelling for including climate change in species recovery plans and for developing a climate change vulnerability assessment framework that would include modelling and other analytical options.

There are several difficulties with the discussion, most of them appearing to arise from the very broad range of elements included in the analysis. The most striking of these relate to apparent internal contradictions. For instance the statement *"It was assumed that the climatic data from the nearest continental locations would give a fair estimate of the islands' climate …"* (page 40) appears to conflict directly with *"There does not appear to be any mainland area whose climate approximates that of the Shark Bay islands."* (page 41).

In addition, several assertions are neither intuitively obvious nor are they supported with references or argued discussion. The most problematic of these assertions relates to the acceptance that a small current distribution and a derivative small range in climate variables for that location will result in the loss of a species currently limited to that distribution, even where the species was once widespread. The discussion of the Rufous hare wallaby illustrates this matter. This species *"… was once widespread over most of Australia's arid zone, down to the south west of WA"*, but is *"now restricted to the Shark Bay area which represents a very marginal location for [it]"* (page 41). It is now found only on Bernier and Dorre islands. The current climate envelope for the species is stated to be less than 100 km^2, and *"accordingly, the range of the climatic variables is also extremely reduced"* (p41). With such a reduced distribution, which is very marginal *ab initio*, the modelling exercise projects that the species has no distribution with only a $0.5^{o}C$ temperature increase. This projection is to some extent mitigated by a later statement: *"Whether the populations of these refuges (i.e. Bernier and Dorre islands) will be able to survive or not depends on their physiological and demographic adaptability …[which] may already be constrained by a lack of genetic heterogeneity due to low population numbers, bottleneck effect and high interbreeding (Spencer 1998; Spencer and Eldridge 1998)"* (pp. 59-60).

While section 1.2.3 states that *"…studies on the impacts of climate change on distribution … [are] … extremely sensitive to the quality of the distribution data used in the analysis"* (page 24), the source of fauna distribution data is largely restricted to records from the WA Museum (section 3.3.2). This fauna data is then used as if they were a comprehensive and representative sample of the pre-European settlement distribution. The results of this analysis are contrasted with the findings of a previous study which used more comprehensive and representative data (Dexter *et al.* 1995).

An example of the difficulty in adopting this approach is exemplified by the climate change impact analysis for the Western barred bandicoot (section 3.3.5.2), which in pre-European times was distributed over most of southern Australia. Using only the records of the WA Museum, this study projects *"a severe contraction in range"* in this species' distribution under all climate scenarios applied. By contrast, Dexter *et al.* (1995), which added historical records from Victoria, NSW and SA to the WA records, *"found that the species would not suffer drastically under varied climate change scenarios. The difference between the two studies is due to very different sizes of the climatic envelope which result from taking into account the whole, against just a subset, of the historical records of the species"* (page 48). While both analyses are probably correct within their analytical boundaries, Dexter *et al.*'s analysis is more likely to be more useful for policy and planning purposes because it has used a more comprehensive and representative data set to define the climatic envelope. By comparing the relatively larger Dexter data set against the more restricted data set used for this study, the discussion in the Report elucidates the importance of the data set used for the analysis.

A similar result arises where records are excluded. In climate impact analysis for the Banded hare wallaby, it is noted that this species was once widespread over most of the Australian arid zone, but only recent WAM records from the Shark Bay area are used. Two WAM records of the Banded hare wallaby outside the Shark Bay area were *"…dropped from the analysis because of lack of comprehensiveness when compared* *with its much larger past distribution"* (page 41). The climate change impact analysis based only on WAM records at Shark Bay projected local extinction of this species. However, including representative, if not comprehensive, records from other areas might have generated a broader climatic envelope and different analytical outcome.

The discussion in this chapter regarding the relative utility of differing data sets, the implications for restricted *vs* widespread species and the relative threats from climate change and other factors such as predation and clearing is useful for subsequent similar exercises.

Conclusion

This chapter provides a set of useful and timely analyses, discussions and commentaries. While the policy and management utility of the products of the modelling exercise *per se* is limited by the approach taken (to investigate several species using relatively limited data rather than a lower number of species using relatively more comprehensive data, and use of restricted sets of distribution data), the wide range of additional matters it includes, such as other threats to biodiversity conservation, enhances the potential use of the chapter for methodological purposes.

The findings in the chapter contribute to scientific understanding and policy analysis subject to a clear understanding of:

- the limits of any modelling exercise to predict future outcomes where complex matters such as climate and biodiversity are concerned;
- the limitations imposed by the assumptions on which this specific analysis was based; and
- the nature of the analytical exercise: that is, that the chapter sought to illustrate the relative utility of alternative approaches to data use and to illustrate the potential utility of bioclimatic modelling in an assessment of species vulnerability to climate change, rather than seeking to generate bioclimatic predictions *per se*.

Chapter 4: *Dryandra*

Chapter 4 assesses the potential impact of climate change on all species of the plant genus *Dryandra*. The Chapter initially outlines the rationale for choosing *Dryandra* for a regional climate impact study: the genus is entirely endemic to the study region, it is an important element of the region's biodiversity, it is found in a number of vegetation communities, there is a range of vegetation types, and the distribution range varies from very restricted to widely distributed.

The database was outlined, and while it was unpublished and unreferenced, the scientists providing the data were specifically identified. Outliers were either corrected or eliminated.

Distributional data were superimposed on soil maps to identify species' favoured soil types. The conservation protection of species under climate change was determined by comparing distribution under climate change. Reserves 50 ha and smaller were excluded.

Statistical analyses were outlined

The climatic characteristics of the region were described, statistically analysed for correlations, and compared to the variables used in BIOCLIM. Redundant climate variables were excluded from the subsequent analysis.

The distribution of *Dryandra* spp. was described, two centres of diversity were identified and compared and bioclimatic envelopes were identified, in the absence of soil data. The potential distribution of *Dryandra* was found to be greater than that currently observed. A 25 km^2 grid cell was used.

A cluster analysis of all 92 species identified 7 groups, distinguished on climate grounds. A lack of geographical differentiation between the groups was explained as arising from distributions of most *Dryandra* species being "*not currently limited by strict climatic parameters but by soil relationships, landscape features and historical processes*." (page 75) This explanation "*does not however infer that climate factors might not be an important factor in the distribution of Dryandras under climate change*." The use of climate parameter means is posited as an alternate explanation of limited distinction between groups, implicitly highlighting the importance of identifying which climate parameter might be most significant in determining species distribution. (page 75)

Modelled changes to distribution

The impacts of climate change on *Dryandra* distribution were found most frequently to be a southern and south-western shift, a decline in range, and extinction *in situ* with temperature increases. Soil requirements limited the capacity of species to move from their current ranges to new ranges.

The northern sandplain centre of diversity loses species at an increasing rate as temperature increases, with the range of most species contracting *in situ* but some contracting to a new centre of diversity which emerges south-east of Perth. The southern centre of diversity remains more or less in place but its area and species diversity decline.

All species' distribution area is reduced progressively with increasing temperature, but while species retain any bioclimatic envelope there is a high degree of overlap between the current and new climate envelopes for most species.

The hypothesis that there is a direct relationship between low annual temperature or rainfall ranges evident in a species' current distribution and (a) high likelihood of complete disjunction of current distribution and distribution under climate change and (b) high vulnerability to climate change was tested using a single climate change scenario on a range of species and declared to be 'correct'. Some limitations of this finding are discussed.

Smaller species distribution areas, which were positively correlated with smaller variability in mean annual temperature and rainfall, were found to decline with climate change more quickly than larger areas.

The number of *Dryandra* species surviving in the south west declines from 92 currently to 66 with 0.5^{o}C temperature increase, 49 with a 1.0^{o}C increase, and 31 with a 2^{o}C increase. However, the conservation coverage of surviving *Dryandra* species was found to be relatively unchanged on a proportion of surviving species basis. The Report states that *Dryandra*'s strong edaphic constraints, and the relatively low topographic heterogeneity and intensive land uses over much of the south west mean *Dryandra* "*will be severely impacted by climate change*", (page 83) a conclusion that could *"in all probability be applied to most other plant taxa with a high degree of endemicity and a similar distribution in the south west of WA"* (page 83) "…*the results of the present study point to an almost total collapse of native flora of the region under climate change*" (page 84). The climate scenarios used in this study suggested that an area east of Perth appears to be a refuge for northern species, and an area between Fitzgerald River National Park and the Stirling Range might become a climatic refuge for southern species, though these findings could be altered as a result of more recent climate change impact data.

The Report notes the intuitive attractiveness of positing a positive relationship between the size of a species' climate range, its genetic variability and the likelihood of it being adversely affected by an extreme event. While the Report notes that even restricted plant species *"can grow well outside the climatic confines of their original distribution and can display a high genetic diversity"* (page 85) there are few studies of this type. Therefore, The Report advises a version of the precautionary principle: "i*t would be wise to consider all rare and restricted species at great risk under climate change*" (page 85).

Potential climate impacts on plant processes and indirect impacts are discussed. An assumption is stated: *"… the distribution of a species integrates the range of climatic characteristics which are necessary to meet the species' regeneration requirements, from germination to seed production. However, it is clear that some stages of a plant life cycle are more sensitive than others to environmental conditions"* (page 85). Rapidly increasing minimum temperatures, changes to the seasonality and frequency of fire and changes to pathogen incidence are discussed.

The Report states that conservation strategies need to be strengthened to improve the representation of *Dryandra* in conservation reserves because large scale species movement will be limited and few species are well-represented in conservation reserves or private remnants. Corridors of native vegetation will also be necessary to enable species movement.

This chapter of the Report concludes with seven recommendations for nature conservation:

- monitor and manage corridors to enable species movement;
- study adaptation potential for rare and restricted species at greatest risk from climate change;
- use the results for *Dryandra* as a blue print for other taxa having a similar distribution range; use the greater knowledge of *Banksia* phenology for risk assessment purposes and distribution modelling;
- undertake distribution modelling for canopy forest trees; investigate regeneration of forest trees under climate change conditions;
- investigate the implications for *Phytophthora cinnamomi* under climate change;
- expand conservation coverage in the wheatbelt;
- use northern sandplains species as part of a monitoring system of climate change impacts on the demography and phenology of south west species.

Discussion

Scientific Review

Assessment of the species data used

Dryandra is a moderately large genus of Proteaceae confined to southern Western Australia, with many localized to naturally rare species and taxa.

The study includes all 92 species of *Dryandra* described in WA Herbarium records in 1998. This comprehensive inclusion of all taxa is a strength of this component of The Report and overcomes certain limitations or issues identified in the review of *Chapter 5: Acacias*.

The database used for this study is described as being “exceptional”, presumably because allows analysis of a full genus. Because it was stated to have been obtained from unpublished surveys the study would have been strengthened by some confirmation of records in, for example Herbarium databases, published literature or reports. A description about how subspecies were treated would enable an understanding the extent to which the considerable habitat differentiation of subspecies were protected or lost.

Taxonomic coverage

The taxonomy applied in the study does not recognize the existence of subspecies, possibly resulting in the use of flawed or inadequate distribution data. For instance, *Dryandra sessilis* has three subspecies, one subspecies of which, *cordata*, is common along (and restricted to) the coast between Cape Naturaliste and Albany. However, the environmental envelope for this species does not show this distinction and the core habitat suitability does not reflect this distribution.

Dryandra's current distribution

The current distribution of *Dryandra* species is thought to be derived from climate (especially seasonality and amount of rainfall, and temperature in the driest quarter), soil characteristics, stochastic events and competition for nutrients and space. By comparison with many other WA taxa, the distribution of *Dryandra* is well known, but inevitably this knowledge is partial and limited to current occurrence resulting from the interplay of the factors listed above. The methods used to superimpose geographical records onto soil maps for determining the distribution area of a species needs to be clearly described given that soil properties appear to be important in defining a species distribution.

Analysis

The model applies the current distribution of each taxon of *Dryandra* to known climate and soil parameters in order to define a bioclimatic envelope which is then used to project the likely distribution of that taxon under changed climate conditions. This approach would be expected to yield realistic scenarios of the known effects of climate change into the future, where the distribution of *Dryandra* and their soil requirements are well known and no other factors had acted in the past or would act in the future to affect distribution.

There are four basic problems with the study which limit the direct use of its findings and conclusions. These relate to the climate data used, the treatment of outlier populations and distribution data, the representativeness of Dryandra species of south west WA flora and the scale used in the model:

- the climate parameters used in the analysis do not appear to be those which are currently understood to be most critical for the establishment and survival of *Dryandra* species. These are seasonality and amount of rainfall and temperature in the driest quarter of the year. The climate parameters applied to *Dryandra* taxa in the study were total annual rainfall and average annual temperature, disaggregated to monthly means.

- the study *"either corrected or eliminated"* outlier populations. Removing outlier populations of a taxon from the analysis almost necessarily reduces the climate range BIOCLIM defines for it. While records that are clearly incorrect should be removed, removing records that are correct but complicate an otherwise simpler distribution can misdirect modelling outcomes. For instance, *Dryandra formosa* occurs in the Whicher Range, some 200 km NW of the mapped occurrences used in the study. The Whicher Range has a very different climatic zone from the area occupied by the mapped occurrences and would presumably extend the climatic envelope for this taxon. A similar issue arises with respect to *D. foliolata*. Removing outlier populations would have particularly serious implications for analysing the impacts of climate change for taxa defined as having limited distribution.
- The representativeness of *Dryandra* of vascular plants found in the south west of WA is highly debatable. Many species of *Dryandra* are relatively short lived obligate seeders with a relatively high shoot-root ratio (implying high water use) compared with deep-rooted resprouters which have a lower shoot-root ratio.
- the scale of the model. The scale of the model at 125 km^2 resolution is about equal to the distribution of many restricted taxa. The impacts of climatic variation operate on a much greater scale than this and refuges can function at a much smaller scale. This makes it very difficult to extrapolate findings of one type to broader generalizations or could generate much greater impacts than if the scale were at a more meaningful biological scale.

In addition, in section 4.3.2 no rationale is given for selecting certain climatic variables from a larger subset. There is, for instance, no reference to principal component analysis. In the description of the discriminant analysis (section 4.4.4) there is no evidence that the assumptions underlying this technique have been tested or satisfied.

Modelled findings compared with other matters and information

The model outcomes indicate a unidirectional nature for the temperature effect on all species. While this outcome is reasonable within the bounds of the Report's assumptions, it runs counter to direct field experience which includes the effects of predation, competition and other factors. For example, *Dryandra montana*, a species restricted to the eastern peaks of the Stirling Range above 800 m, is projected by the study to become extinct by an increase in average annual temperature of 0.5-1 ^{O}C. However, seed orchards of this taxa established near the Stirling Range at 200 m, are thriving, flowering and seeding. This area probably has an average annual temperature at least 3-5^{0} C warmer than the peaks suggesting that competitive effects may be considerable in determining geographic ranges for this species at least.

Similarly, reduced rainfall is projected to have significant impacts on *Dryandra* distribution and survival. Palaeoclimate studies indicate that dry periods have occurred in the past in the south west of Western Australia, through which *Dryandra* persisted. While the distribution of *Dryandra* during these periods may have been more restricted than current patterns, this evidence would argue against impacts as significant as those projected by the modelling.

Summary

The basic premise of the analysis and findings of this chapter are logical and supported by other evidence: If climate change generates a warmer and drier south west of WA, taxa restricted to cold or wet sites in the medium to lower rainfall areas are at risk or those species with outlying populations in such sites are greatly at risk.

However, this study does not appear to provide more than theoretical support for this general proposition because of the way the data are used, the scale at which the analysis is undertaken and at which the various factors are applied and the wide range of other factors that affect the distribution of *Dryandra*.

The lack of perfect distribution data, soil data, and life history attributes inevitably constrains the capacity of even the most comprehensive analysis to derive an ‘optimal environmental’ envelope for each species that reflects the optimum habitat and climate for each species across the south west of WA. An analysis of this type can probably only generate a “best fit guesstimate” similar to the types used by weed researchers to model the potential for weeds to spread within broad climatic parameters.

To suggest that changes slightly outside this envelop will cause the dramatic range reductions predicted is beyond the limits of the data used.

The study highlights the importance of analysing the impact of climate change on specialized habitats such as riparian zones, mountains, high rainfall areas, and wetlands, and a detailed consideration of other climate-related threatening factors, such as inappropriate fire regimes, competition and disease spread.

The study’s outcomes relating to *Dryandra* are reasonable within the bounds of the study’s stated assumptions and the technical limits it faced. However, these assumptions and limits are too significant to support the study’s broader conclusions relating to the survival of *Dryandra* under climate change conditions. A more considered approach is required for matters such as the treatment of “outlier” populations, the inclusion of information relating to transplanted individuals in areas outside the determined “bioclimatic envelope”, and the implications of palaeoclimate experience in the region.

In addition greater emphasis needs to be focused on assessing species’ life-histories with respect to their resilience to climate change. For example, species that sprout may be more resilient to drying and might therefore decline at a slower rate than species that have shorter life-spans and rely on seeds to replace themselves. Similarly, where soil data is included in an analysis, characteristics such as depth of soil and likelihood and period of waterlogging need to be considered as well as pH, texture and other factors.

Policy Review

The analysis underlying The Report focuses on a set of key biodiversity conservation issues. The products of the modelling exercise provide clear indications of a possible fate of Dryandra species under specified types of climate change. These model outputs would be useful additions to information derived from assessments of climate change vulnerability derived from biological, ecological and other analyses.

The main benefit of a modelling analysis is that it can generate a relatively simple response to a complex question; the main danger is that the response might be taken to be an answer to the question.

In this instance, the responses are interesting and instructive, but where they have been used as the basis for broader conclusions The Report becomes highly problematic. For instance, the chapter's third recommendation suggests that *"the results derived from the study on Dryandra can be considered as a blueprint of the fate under climate change of other taxa with a similar distribution range"* (page 86) with no supporting data or reference for this assertion, which in itself contradicts statements elsewhere in The Report, such as *"… conclusions drawn from studies of a small number of species over a large area of the continent or those from a large number of species over a small area cannot be extrapolated to near-by regions or to other species"* (page 98).

The argument that the size of a species' distribution is likely to be associated with its degree of vulnerability to climate change is not convincing. Although there appears to be some support from the data presented there are many examples where climatic modelling and field experience has shown that a localized species can potentially exist well outside its current known range (weed species for example). This aspect of the chapter highlights the need for a critical approach to extrapolating from modelling results to broader projections.

There are a number of well documented exceptions to the suggestion that species having a smaller area of distribution have a more restricted genetic variability than those which have a larger area of distribution. Population size rather than area of distribution is often the key factor, where a restricted species with very large populations may have high levels of genetic variation regardless of its current geographical distribution.

Looking past these difficulties, the chapter has many useful findings and suggestions to orientate further research. Some of these are explicitly listed in the recommendations on pages 86-87, and others are evident in the text, such as:

- It is important to understand the potential importance of climate *per se* as a generator of even present day distribution of species. Species analysis revealed outcomes that required factors other than climate to be considered: *"The lack of geographical differentiation between the groups could be explained by a lack of concordance between distribution of Dryandra species and climate parameters at the scale of the south-west. In other words, within the Mediterranean climate of the* *south-west of Western Australia, the distributions of most Dryandra species are not currently limited by strict climatic parameters but by soil relationships, landscape features and historical processes"* (page 75).

- It is important to identify and use the climate parameters that have the greatest influence in determining the distribution of a species, rather than those parameters that are most easily accessible, such as changes to temperature or rainfall means.

Degree of protection on public and private land

The *Dryandra* species distribution maps were intersected with maps of public protected areas and private remnant vegetation areas, in order to estimate the proportion of the species distribution under protection. Only reserves or vegetation remnants greater than 50 ha in area were retained for analysis. This approach is useful because it acknowledges that large parts of the southwest have been cleared for agriculture which limits the capacity of many species to persist, move into refuges or disperse across the climatic gradient. However there is no clear rationale as to why reserves and remnants less than 50 ha were excluded. Future analyses should provide explicit rationales based on ecological principles for such decisions, especially where they have the effect of excluding a large number of remnants, as in the wheatbelt.

The importance of life histories

As noted earlier all *Dryandra* taxa are treated as though they would respond in similar ways to climate change, but there are a number of different life-histories within the genus which may affect their resilience to climate change.

Other potential processes sensitive to climate change

Analytical tools for projecting the impact of climate change on the distribution and activity of *Phytophthora cinnamomi* (dieback) remain currently poorly developed in 2006. It is probably correct to suggest that at least in some parts of the south-west warmer winter and spring seasons due to climate change could extend the activity of the pathogen. However changes to seasonal rainfall could countervail this effect or exacerbate it: predicted lower annual rainfall is likely to significantly reduce the area where *Phytophthora* will be able to survive while predicted increased summer rainfall for other areas may result in a dramatic increase in *Phytophthora* activity.

Summary

Bioclimatic modelling potentially has an important role as one of several risk assessment and impact projection tools in a decision tree or environmental tool-box for projecting the impacts of climate change on single species or ecological systems. Other tools in this set might include "expert" opinion and life history information. Better soil data, a smaller spatial scale, more relevant climate data and plant disease data would also enhance both modelling and overall impact analysis and projection. Any of these tools applied independently can only provide a narrow insight into how a species might respond to climate change; even all of them applied in an integrated manner would not provide more than a projection subject to significant caveats.

Chapter 4 provides a useful analysis of potential climate change impacts on a species of plant that is entirely endemic to the south west of WA, and an important component of the region's biodiversity. The analysis is necessarily limited by the knowledge and modelling capacity available when it was conducted. The analysis is enhanced, by comparison with other similar studies, by the inclusion of soil data, a consideration of a range of other factors, and an assessment of the conservation coverage of the species following climate change impacts.

The greatest weaknesses of the chapter are the extrapolation of the modelling products to broader conclusions that they do not appear to explicitly support and the presumption that *Dryandra* as a genus is representative of vascular plants found in the south west of WA.

The greatest strengths of the chapter are its exploration of the limits of bioclimatic modelling and the importance of data quality, and the discussion of the importance of functional relationships and other factors which affect species distribution in WA.

Chapter 5: *Acacia*

Summary of the chapter

Chapter 5 commences with a description of the biophysical and socio-economic characteristics of the Goldfields, a study area chosen for assessing the vulnerability of selected *Acacia* species to climate change. The study area contains a range of climate types and conditions and a significant number of *Acacia* taxa, some of which are locally dominant.

The *Acacia* database was accessed from the WA Herbarium records and validated by scientists from the WA Herbarium and DEC. No *Acacia* species were found to be endemic to the study area and also widely distributed within it. Species were chosen for analysis on the basis of having greater than or equal to the median number of data locations within the study area (compared with all *Acacias* collected within the study area). Twenty seven species with a total of 1093 individual records were selected for analysis.

The methodology used for soil types, conservation coverage and statistics conforms with that described for Chapter 4. Only public reserves (national parks and nature reserves) were included in the analysis of conservation coverage because *"land clearing or agriculture and townships is not widespread in the region"* (page 94).

A climate analysis of the study area indicates that it has "a transitional location between the strict Mediterranean climate of the south west and the more arid and variable desert region to the north", with a "lack of climatic homogeneity."

The 27 species of *Acacia* used for the analysis were placed into three groups:

- those found exclusively in the cooler wetter south west corner of the study area (6 species);
- those found throughout the southern part of the study area (15 species);
- those found throughout the region (6 species).

Bioclimatic analysis indicated that the sizes of the bioclimatic envelope within the study area of most species (i.e. 82%) declined with only 0.5^{o}C temperature increase, with an overlap between the current and projected envelope at this level of temperature change. All species lost their entire bioclimatic envelope in the study area at 2^{o}C temperature increase. A strong correlation was found between the size of the current bioclimatic envelope in the study area and the rate of loss of the envelope with increasing temperatures.

On the basis of a comparison of the analytical results for *Acacia* with those for *Dryandra* species The Report cautions against extrapolating from specific findings to general principles: *"conclusions drawn from studies of a small number of species over a large* *areas of the continent or those from a large number of species over a small area cannot be extrapolated to near-by regions or to other species"* (page 98).

The Report discusses factors important to *Acacia* biogeography - winter temperature and rainfall reliability and amount. *"The movements of Acacia in the semi-arid zone will …depend on the balance between winter temperature increases, which should entice Acacias to move north, and rainfall decreases which should lead to Acacias moving south-west. … The influence of soil types has also to be taken into account"* (page 98).

The Report states that the fate of the *Acacia* species studied needs to be considered over their entire current and prospective ranges: *"… their fate within the Goldfields is not an indication of their fate over their whole distribution"* (page 98) with the distribution of some species potentially shifting outside the region's boundaries.

The Report suggests that research on the impact of climate change on regeneration processes *in situ* would be useful, given the high overlap between current and predicted distributions. The Report also states that the potential impacts of climate change on the pastoral industry, introduced species, fire and indigenous use and management of local ecosystems need to be integrated with direct climate parameters such as rainfall seasonal patterns and amount when attempting to define the impacts of climate change in this zone.

The Report does not make specific recommendations regarding the conservation of *Acacia* species in the Eastern Goldfields, pending better understanding of the biogeography of arid and semi-arid zones. The Report states that species distribution modelling *"… is probably not the best methodology to use for the region."* (page 99) Further research directions are proposed to provide better insights into the potential impacts of climate change on arid ecosystems:

- socio-economic and ecological studies on climate change impacts on land uses;
- investigate key species or ecological processes such as the mulga line or woody species invasion;
- risk assessment studies using climatic thresholds to learn about species persistence in a region rather than distribution modelling based on restricted biological surveys;
- potential for introduced vertebrates, weeds and diseases to expand their distribution and climate impacts on control strategies.

Discussion

Scientific Review

Assessment of the species data used

Total species coverage

Current WA Herbarium specimen records contain about 270 described taxa of *Acacia* within the study area, of which The Report detailed distributions of 27 taxa or about 10% of the total. The Report does not provides a specific rationale for choosing these particular 27 taxa, but notes that all *Acacia* species non-endemic to the region were eliminated and that it was not possible to find *Acacia* species which were endemic to and widespread within the region, and that those *Acacia* species with more than the median number of data locations were retained for analysis. Most of these species are in fact both widespread and endemic to the study area (page 94). Therefore, they represent a reasonably adequate representation of the *Acacia* flora for the region (see below). There is no reason to indicate that choosing other species would have added significantly to the information derived from the analysis.

Taxonomic coverage

The 27 taxa of *Acacia* used in the analysis cover most of the major taxonomic groups within the study area.

However, because The Report does not indicate infraspecific names for taxa, it is not clear in some cases to which taxon it is referring. Possibly the infraspecific names were not available to the authors when they constructed the datasets, as they were created for the eight relevant taxa in 1995. However, the datasets do appear to distinguish some taxa on this ground. For instance, *A. coolgardiensis* currently comprises three subspecies of which the distribution map in The Report appears to refer only to subspecies *effuse.* Had pre-1995 point source data been used to create the *A. coolgardiensis* distribution map then it would have shown a much wider geographic range for this species. This point is again discussed under *Taxon distributions* (below).

Geographic coverage

The Report notes that it was not possible to find *Acacia* species that were both endemic and widespread within the study area (nevertheless, the 27 species studied were largely confined to the area where they showed narrow or moderately wide distributions). As a result of this approach, species with wide distributions that extend outside the study area (e.g. *A. acuminata*) are not included, and consequently Arid Zone taxa that predominate in the north of the study area (i.e. the Austin Botanical Region) are somewhat under-represented.

Geographic data source references

Better information about the derivation of the data sources, including references, is required. For instance, the derivation of their geographic data is described as a data set that was begun 1978 and which was subsequently published in the Records of the WA Museum, but no reference to that publication is given. The data points were stated as having been validated by Hopkins and Griffin, but no details are provided as to how this was done or what this means insofar as the accuracy of the names is concerned. It is therefore not possible at the time of this review to independently assess how current the geographic data are and whether or not it is based on specimens lodged at the WA Herbarium, although a statement in the Executive Summary (but not in this chapter) would tend to support assumptions to this effect. For full scientific credibility, each data point should be verified by either a herbarium voucher specimen, or each specimen's identity should be verified by a taxonomic specialist (in this case by DEC *Acacia* specialist, B Maslin). While data points may have been verified in this manner, it is not evident from The Report.

However, this approach is common to other studies of this type. For instance, Dexter *et al.* note that *'For the purposes of this project, where most of the species have been studied extensively, and because the majority of the data came from the Australian museums, the taxonomy was assumed to be correct.'"* (page 9) This Report therefore would appear to have undertaken greater care with the quality of the data used than other reports of a similar nature.

Taxon distributions

Assessing the accuracy and significance of the mapped distributions of the 27 taxa is difficult because:

- the maps do not show any reference points at all, there are no latitude or longitude markings or indications, no towns and so on,
- the study area boundary is not shown, and
- in some cases infraspecific names for the taxa are not used.

Irrespective of these problems many of the distributions appear to correspond reasonably well with distributions based on current data for the taxa. However, there are some notable exceptions, namely, *A. assimilis, A. chrysella, A. lasiocalyx, A. resinimarginea, A. sulcata, A. coolgardiensis* and *A. hemiteles*. In all these cases the mapped distributions are somewhat narrower than current records indicate (in most cases the current distributions show the taxa as extending further into the northern wheatbelt than do the maps in The Report). These differences may possibly reflect the fact that an "old" (pre 1995) data set was used for mapping *Acacia* distributions in The Report. However, because the discrepancies between the mapped and current distributions are not all that great these differences may not have unduly affected the results.

Acacia's current distribution: species clusters identified in Table 0.8

A cluster analysis identified three main groups of *Acacia* (Table 0.8). There appears to be nothing particularly significant about the taxonomic composition of these groups because each contains species from all major taxonomic groups represented in the study area. Therefore, the changes discussed for these Groups in The Report under different climate regimes are not likely to impact disproportionally on any particular group of *Acacia*.

Effect of climate change on Acacia distributions

The authors cited Hnatiuk *et al.* (1982) when discussing climatic variables in relation to *Acacia* distributions. While this is not an inappropriate document to have used, a more comprehensive and current paper was published on this same subject titled, 'Phytogeography of Acacia in Australia in relation to climate and species-richness' (Hnatiuk & Maslin 1988, Australian Journal of Botany 36: 361–383).

Summary

The 27 *Acacia* taxa used appear to be appropriate and adequate for a study of this type and represent a fair subset of the major taxonomic groups of *Acacia* that occur within the region.

While the methodology, particularly insofar as explaining the taxon selection, naming taxa and specimen vouchering appears to conform with or be better than general practice for reports of this type, better information would enable a more comprehensive review and would thereby project better confidence in The Report's scientific findings. Of particular concern is the lack of information concerning how the point source data used to generate the distribution maps were derived. As these data are crucial to the climatic change interpretations such interpretations would necessarily be restricted. Future reports should provide a more explicit description of the origin and treatment of the data sources used to develop the climate change impact projections.

Policy Review

The latter part of Chapter 5 (Discussion, pages 97 – 100) provides several interesting perspectives for managing *Acacia* species in the eastern Goldfields, drawing on the analysis in the first part of the chapter. These perspectives include:

- The potential importance of rainfall amount and reliability for *Acacia* species distribution in this region, as opposed to temperature;
- The relative vulnerability of Eastern Goldfields' *Acacia* species to temperature increases as opposed to *Dryandra*;
- The possibility that *Acacia* species that lose distribution in the Eastern Goldfields under climate change could migrate to adjacent regions;
- The need to integrate a wide range of physiological factors (e.g. dispersal and regeneration processes) and external factors (e.g. climate change impacts on the pastoral industry, fire, introduced species and indigenous land use and management) with an assessment of the potential impacts on *Acacia*.

The Report makes two striking suggestions:

- *"An important consequence is that conclusions drawn from studies of a small number of species over a large area of the continent or those from a large number of species over a small area cannot be extrapolated to near-by regions or to other species."* (page 98)
- *".. the modelling of species distribution in the arid or semi-arid zone is probably not the best methodology to use for the region [given the lack of knowledge on the distribution of most species in these regions]."* (page 100)

However, these statements are not expanded, beyond the four research directions outlined in the summary above. They provide a tantalizing introduction to the important process of determining an effective analytical approach and decision framework for biodiversity – climate change interactions for policy and planning purposes. However, the modelled findings for Goldfields *Acacia* taxa appear to be accepted as revealed, and used in the Conclusions chapter (see below) and the Executive Summary (see above) as though they had little or no restriction.

Conclusion

Chapter Five provides a combination of well-conducted bioclimatic modelling and well-argued discussion about the key issues concerned with bioclimatic analysis. Unfortunately, some confusion arises from unresolved contradictions between the two elements of the chapter. This highlights the need to include both quantitative and qualitative analyses in bioclimatic assessments, and also resolve any contradictions between differing analytical approaches.

Conclusions

Summary of the chapter

By 2025, the distribution of 61 species of the 137 species studied is predicted to decline by more than 75%, and by 2060 104 species will have declined by this proportion of their current distribution. This finding is extrapolated: *"In 2100, 88% of species currently living in W A south of the Kimberley may be listed as either extinct or threatened, if … the species analysed in the study are characteristic of the fauna and flora assemblage in which they currently exist" (page 102).*

Local extinctions indicated in The Report suggest that centres of biodiversity may lose species rapidly despite protection through reservation for conservation purposes, and that identifying and conserving potential climate refuges will be difficult.

If rainfall reductions continue in the south west, species dispersal will be limited and Gondwanan relicts may suffer because of their restricted habitats, reliance on high rainfall and low dispersal rate. New communities would emerge that may not be stable in the longer term, may be vulnerable to weed invasion and may contribute to changes in the frequency and intensity of fire.

A small number of generalist shrub species should survive even significant increases in temperature and may come to dominate the landscape with declining woodlands.

"It is difficult to predict what the impacts of this potentially high level of extinction of species will have on ecosystem structure and function" (page 102), pollinators may be affected leading to further impacts, soil structure and water movement may also be affected.

The Report notes that the assumptions on which the analysis is based limit a determination of the likelihood of the scenario outlined in The Report:

- The assumption that a species distribution is in equilibrium with the present climate is unlikely to hold true;
- Adverse land uses can mask the 'true' distribution of a species;
- Edaphic constraints on species movement may not operate as projected if species distribution turns out not to be as tightly coupled to soil type as currently thought;
- The impacts of increased CO_2 on species physiology and land use changes resulting from climate change have not been included in the analysis.

Climate change may not be the sole agent of species extinction, with competing land uses, resource degradation and introduced species and diseases playing the most important role in biodiversity decline in WA for the foreseeable future. However, climate change could exacerbate the detrimental effects of the other factors.

The Report states that there is an urgent need to promote research on climate change impacts and adopt adaptation strategies. *"The results of this study indicate that biodiversity in this region is highly vulnerable to climate change and there is a risk of a high rate of extinction – perhaps unprecedented since European settlement"* (page 104).

Discussion

Generally the conclusion section of a technical document should provide a succinct statement of the major findings of the study and their implications, and demonstrate how the study has met the requirements of its rationale and objectives. The conclusion section of The Report contains both a discussion of the nature and limitations of the project's findings, and also some impact projections derived from them through extrapolating model outputs. Much of what is presented in The Report's conclusions section would be better suited to a general discussion, a construction that would allow a full consideration of the findings, their limitations and their relevance.

However, there is no clear underpinning for some of the conclusions made; they are not supported by the analysis or by references and in some cases they appear to conflict with the content of The Report itself. There is little indication as to whether some conclusions are a best or worst case scenario; a single vision of the future is generated and delivered. This tends to detract from the value of the important well-supported and useful conclusions that could be drawn from and which would relate explicitly to the methodology used to analyse potential impacts on the species and the summary of other publications which forms the main body of The Report.

For instance, the catastrophic loss of biodiversity predicted for Western Australia south of the Kimberley is followed by a statement which virtually eliminates all strength from the prediction: "*It is extremely difficult to decide whether the scenario highlighted above is likely to happen or not, to which degree some of the concerns may eventuate, given the assumptions which accompany the methodology we have been using"* (page 103). Moreover, predictions *per se* do not easily arise from models nor are they derived from models with any confidence, where the system being modelled is complex, non-linear and only partially known and understood.

The Conclusion also leans towards unwarranted extrapolation and uses alarmist terms ('dramatic', 'drastic', 'disastrous'), ignoring even its own cautions about applying its findings in this manner: *"conclusions drawn from studies of a small number of species over a large areas of the continent or those from a large number of species over a small area cannot be extrapolated to near-by regions or to other species" (page 98).*

In summary, the Conclusion as written derogates from the useful analysis and findings in the body of The Report, and does not relate well to the stated objectives of the study (see page 7 of this review).

RELEVANCE AND USE OF THE REPORT

1. Text, figures, and readability

This review necessarily concentrates on how The Report could be improved, and so does not comment on the many aspects of it that are appropriate.

Consistency

There are several instances where terms appear to be used inconsistently or differing terms appear to be used for the same matter. For instance, the term 'modern distribution' is stated to be *"…only post-1960s records"*, which could in turn mean records from 1960 onwards, from 1961 onwards, or from 1970 onwards. In addition, in latter parts of The Report the term "post-1960" is used, which either clarifies of further complicates interpretation, depending upon whether this is the same or a different term. Subsequently, the term 'current distribution' is also used, but not defined. However, in parts of The Report 'modern distribution' and 'current distribution' are apparently used interchangeably.

Similarly, in the analysis of faunal distributions, the term 'original distribution' is introduced (section 3.3.3), and is said to be used in The Report *"… to refer to the distribution used to determine the climatic envelope of a species."* However, this term is then used, apparently interchangeably, with 'historical distribution'.

Future reports of this type should include a glossary, in which any potentially problematic terms are defined, and ensure that terms are used consistently.

Navigation

The Report was provided without page numbers and a number of diagrams were incorrectly referenced. Detailed chapter heading pages provided page numbers, so it appears that pagination is intended but not completed. Most figures were difficult to read, because they were monotone and small. There were few if any identifying points on the maps and no latitude / longitude identifiers.

Style

The text used varied from a clear, objective scientific style to the use of terms such as 'dramatic', 'drastic', 'disastrous' in relation to the findings. The former style is appropriate to a scientific analysis with a statement of some policy implications, whereas the latter is relevant to a call to arms to avoid an impending disaster. It is difficult to bring these differing types of documents into a single report. Future reports of this nature should consider separating the findings and conclusions in line with the IPCC practices into a scientific report and a "policy makers' summary".

2. Meeting the study objectives

The study *"was set up to research the degree of vulnerability of the distribution native species of Western Australia to the changes in regional temperatures and rainfall patterns predicted under climate change"* (pages 9-10) and had two objectives:

- *"develop a spatial analytical tool for studying the impacts of climate change on the distribution of species in Western Australia, integrating soil features and land uses;*
- *"develop recommendations and strategies for nature conservation under a climate change scenario addressing land based strategies for reserves and for areas outside reserves, particularly in highly fragmented landscapes such as the agricultural region of the south west of the State"* (page 16).

This review finds:

- The study appears to have undertaken the work described in the first excerpt (above from pages 9-10 of The Report).
- The first objective, to develop a spatial analytical tool (above), has not been met by the study, or in any event has not been described in The Report. The study applied a widely available bioclimatic modelling package, BIOCLIM, and integrated soil features and land uses in its analysis. The Report provides a useful description and analysis of the climate variables used in the project. The study also considered the implications of a range of other factors, such as fire and disease. All of these aspects of The Report are helpful to a subsequent investigator. However, there is no discussion in any chapter or in the Executive Summary of a spatial analytical tool developed as part of the study. However,developing a spatial analytical tool is a major endeavour, and as an alternative to developing such a tool, a great deal of useful advice is apparent in The Report, that once collated and ordered would contribute to future bioclimatic analyses in Australia. This might not amount to a spatial analytical tool *per se*, but it would be more like such a tool than is currently available. Future bioclimatic assessments initiatives should find much of the discussion in The Report helpful, whatever tool is used in the assessment.
- The second objective, to develop recommendations and strategies for nature conservation (above), is largely met. Five recommendations contained in the "Executive Summary and Recommendations" focus on research related to nature conservation under climate change (pages 12-13). Eight conservation management recommendations and four conservation research recommendations are provided for Fauna (pages 62-63). Seven recommendations are provided for *Dryandra* (pages 84-85), some of which are concerned with conservation management and some with conservation research. Four "further research directions" but no conservation recommendations are provided for Acacia (pages 99-100). The Conclusion contains no recommendations, *per se*, though some of the text explicitly or implicitly advises research directions. Statements that could be read as recommendations occur throughout The Report, but are not presented as such. In many cases these are very useful findings or advice for later researchers or conservation managers. The review has found it very useful to consider the findings in The Report, and recommends them to other interested parties.

3. Scientific use

This section addresses the question: *How and to what extent does The Report contribute to or extend our understanding of the science associated with the implications of climate change on biodiversity and its protection through the conservation reserve system through its application of useful data to appropriate methodologies?*

Six years after its completion, The Report remains the most ambitious bioclimatic modelling initiative for Western Australian biota to date. It applies a highly regarded and easily available bioclimatic model developed for Australian conditions, uses species distribution information from Government or other credible sources, introduces soil maps, and considers a range of complicating factors, including diseases and fire. The discussion considers the implications of using alternate distribution data (historical *vs* current), and investigates relationships between modelled resilience to climate change and the size of current distribution and other factors.

At its best, The Report demonstrates a good checklist of factors that should be included in a thorough investigation and assessment of the potential implications of climate change for biodiversity. The Report would be of great value and use if this information were extracted and elaborated to orientate further investigations into these potential implications, such as might arise from the National Biodiversity Climate Change Action Plan.

However, The Report does not sufficiently subject the findings of the modelling and other analysis to objective assessments of their usefulness and does not adequately seize the opportunities generated by the considerable work that is evident, such as identifying the type of data required to make the models more realistic and the findings more useful.

Moreover, where The Report seeks to apply to policy and management the findings from the research it describes, that science is sometimes insufficient for the task. In fairness, it is well understood that modelling of any type, including climatic modelling, can only be used to test hypotheses in a general sense, to explore levels of knowledge or ignorance and to seek better definition of critical uncertainties. For most interesting questions, including the potential impacts of climate change for biodiversity, the underlying systems are complex and only partially understood, the interactions are too complex to model in more than a general manner and there are multiple physical scales. Modelling can therefore be only one tool from a large number, adding to the capacities of expert knowledge, and so on, with the outcomes applied with humility. This may be more broadly understood in 2005 than it was in 1999 as a result of ongoing efforts to apply bioclimatic and other models to complex ecological problems.

Some problems with the approach to the science base of The Report have been noted in chapter reviews. This section will not list each problem, but will highlight four:

- **Choice of data sets** is critical and any exclusions will affect the climate envelope, vulnerability, resilience and distribution under climate change conditions. These matters are discussed in The Report, but are so important that they require a specific discussion and explicit rationale for the choices made. The study and The Report would have benefited from more careful attention to generating data sets that were as complete as possible and ensuring the implications of inevitably incomplete data sets were incorporated in any findings and conclusions.

- **Assumptions need to be clearly enunciated and their implications discussed.** Every modelling exercise is based on a set of assumptions which govern the extent to which the results can be used for decision-making and management purposes. While the nature of the assumptions is a policy consideration, the clear statement of them and the rationale for using them is a scientific consideration. The Report needs a much better statement of assumptions with their rationale.
- **A clear statement and exposition is required of the hypothesis to be tested**. In some cases it is not clear what scientific activity and finding The Report is seeking to communicate. For example: a hypothesis is stated: *"Species with a small distribution range also display a small range of climatic parameters"* (page 84) and is to be tested. But what does the sentence mean? It probably should state: *"Species with a small distribution range also display a small range* ***in*** *climatic parameters",* indicating that the range of a species climatic envelope is smaller if its geographic range is smaller, and vice versa. But this may be a trite statement, as BIOCLIM defines a climatic envelope on the basis of the geographic range (where and how big) that is provided to the model for the species in question. This is followed by the statement: *"It is clear from the present study that those species with a very small distribution are extremely vulnerable to climate change, even though they may originate from different climate zones with in the region"* (page 84). It is hard to find the analysis that would support such an absolute statement as opposed to a general indication or possible inference, but the statement is followed by a further statement that softens its impact or even contradicts it: *"… [even restricted plant species] can grow well outside the narrow climatic confines of their original distribution …"* (page 85). This discussion is concluded with: *"… it would be wise to consider all rare and restricted species at great risk under climate change"* (page 85). The discussion therefore traverses a hypothesis of uncertain meaning, an unsupported absolute statement of analytical outcome and a retraction from this outcome, to conclude with a call for wisdom and care in biodiversity management. This is an issue that requires attention, but The Report seems to lose its analytical focus in its desire to cover the vast number of complex scientific concepts relevant to this matter. The large amount of work evident in The Report and its treatment of a comprehensive set of issues tends to be overlooked when the scientific objective is unclear.
- **Some discussions are not concluded**. A second hypothesis was stated in the same section discussed above: *"A small variability* (sic) *in climatic parameters tends to predispose the species to early extinction or displacement under climate change"* (page 84). This hypothesis appears to be an outcome of the models generated by the study, but it is not further discussed.

As an overall assessment: there is a sound scientific foundation to The Report, but it is sometimes hidden by either material extraneous to the core scientific objective or unsupported extrapolations of findings. The Report would benefit from a tighter focus on what the analysis aims to deliver, such as an assessment of methodologies and a discussion and analysis of the wide range of factors relevant to bioclimatic / climate change impact research.

4. Policy and management use

The Report is laudibly ambitious: it seeks both to apply the science underlying biodiversity – climate change interactions and also to apply the scientific findings to decisions and planning about biodiversity protection matters, principally conservation reserve adequacy and enhancement.

The difficulty inherent in modelling complex systems (e.g. climate or ecological communities), and even more so modelling several linked complex and dynamic systems (e.g. climate change and biodiversity), is noted in preceding sections. In short, the use of the findings of any modelling exercise cannot be pushed beyond the limits of knowledge, the assumptions and the complexity of the model. Similarly, the findings of other types of analysis can only be used within the boundaries of the assumptions on which the analysis is applied.

Given this limitation, much of the policy interpretation in The Report is a very useful status point and is clearly drawn from the analysis, such as:

- A projected shift of *Dryandra* species towards newly defined centres of biodiversity; and
- The potential sensitivity of taxa currently confined to small areas to changes in climate conditions, if their confinement has reduced their genetic diversity.

The policy or management use of such findings is, of course, one or two steps removed from the precise projections or predictions provided in The Report, due to assumptions and uncertainties and other factors. But despite the limitations inherent in the findings, they do nevertheless provide a good set of analyses.

However, the strength and text of many policy interpretations appear to go beyond the findings in The Report and at times also appear to conflict with other interpretations in The Report. Some of these have been noted in reviews of chapters and the conclusion. Most significantly, the suggestion that "*the results of the present study points to an almost total collapse of the native flora of the region under climate change*" is not only not supported by the analysis, but it conflicts with some of the findings.

There is a risk that such statements will both lead to unsupportable applications of The Report's findings and also conversely lead to all findings in The Report being disregarded. Either outcome would be detrimental to WA biodiversity policy and management. There is already evidence of apparently uncritical mention of the findings of the modelling and even of the conclusions. A search of the internet for references to The Report has identified up to 40 such references, including several in which the modelling findings have been mentioned in normally highly regarded publications, such as the 2001 report of Working Group II of the IPCC (section 12.4.2), the web page of the National Biodiversity Climate Change Action Plan 2004 – 2007) (http://www.deh.gov.au/biodiversity/publications/nbccap/background.html), and the summary of the "Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1-2 October 2002" (http://www.deh.gov.au/biodiversity/publications/greenhouse/chapter5.html).

5. Comparison with other similar publications

This section addresses the question: *How does The Report compare with other reports concerning its treatment of data, its methodology, its findings and its conclusions?*

The Report has been compared with three similar reports:

- a precedent publication frequently referred to in The Report, Dexter *et al.* (1995),
- a broadly contemporaneous publication, Hughes (2003) and
- a recent publication concerned with climate change impacts on conservation values in South Africa, Hannah *et al.* (2005).

Dexter et al. (1995)

Summary: This report is concerned with the potential impact of global climate change on threatened vertebrates in Australia. BIOCLIM was used with four future climate scenarios supplied by the CSIRO Division of Atmospheric Research. Specific data sources were identified but the data provided by each source was not. A short section relating to "assumptions, limitations and caveats" was included. The status of and modelled results for each taxon are separately described, with associated maps accompanying the text. The results of the analyses were described as "alarming" in the Executive Summary (page iv). The two main outcomes of the project were the individual species response to each climate scenario and the differences in the impact of the scenarios. The foreword by Dr Bridgewater noted the wide range of other factors affecting the distribution of biota, including predators, competitors, pathogens and prey. Dr Bridgewater invited "successors to the study to evaluate what [its] authors have done, to progressively improve on each step, thus gradually reducing the uncertainties in the consequent predictions" (page iii).

Comparison with The Report: Both analyses applied the best climate scenarios available at the time they were performed. Dexter *et al.* investigated a larger geographic area but only vertebrates, while The Report analysed only WA but both vertebrates and flora. Neither report provided sufficient information to allow independent replication of the analyses, but The Report provided more detailed descriptions of the sources and treatment of the data used. While the inclusion in Dexter *et al.* of a section on "assumptions" was welcome, the explicit and implicit treatment of assumptions in The Report was more complete, if somewhat uncollated. Both reports noted the alarming nature of the findings, but The Report extrapolated its findings to biota not specifically studied with a conclusion that the broader ecosystems of WA south of the Kimberley could be disastrously affected by climate change. In overall terms, The Report represents a significant advance on the methodology applied in Dexter *et al.*, but suffers from unsupported conclusions based on extrapolations of model outputs.

Hughes (2003)

Summary: This report summarized recent (to 2003) research on predicted impacts from modelling studies on Australian ecosystems and species. It noted that while most authors acknowledged the importance of elevated CO_2, few included it in the research undertaken. The Report is discussed as one of several species-specific applications of bioclimatic modelling. The inclusion in The Report of soil and vegetation distributions with bioclimatic estimates is described as "important steps forward in improving the utility of predictions (page 430), and the findings of The Report were outlined with those of similar reports. Research directions were suggested:

- greater investment in impacts research generally, to complement the research into emission mitigation;
- greater emphasis on the basic question: "what determines the distribution and abundance of Australian biota?"
- the interaction of CO_2, temperature, nutrients and water for Australian plants in Australian conditions;
- vegetation changes at ecotones;
- more integration and collaboration between monitoring, modelling, physiology and ecology.

Comparison with The Report: Hughes' (2003) review of The Report presented the findings of the modelling, but not the extrapolations or conclusions. Modelling outcomes were described as such, following a discussion of the important role of models and their significant limitations (page 430). In overall terms, Hughes apparently found the model outputs well based and valuable, but ignored or avoided the extrapolations and conclusions. The same approach was taken by Peterson *et al.* (2005).

Hannah et al. (2005)

Summary: This study used multispecies modelling to illustrate how local biology, climate and patterns of change combine to affect extinction risk and protected-area effectiveness. The study focused on the Cape Floristic Region of South Africa, which has many similarities to south-west WA. The study investigated whether climate change would increase or decrease the number of species in protected areas, how these changes would unfold over time and what species and areas would be most affected. The impacts of climate change were studied for more than 300 species in the Proteaceae family endemic to the Cape, using detailed information about current distribution available from the Protea Atlas Project at a geographic scale of about 1.6 km by 1.6 km, a scale that was stated to be coarse relative to the area of occupancy of many species. A species specific approach was adopted as palaeo-ecology indicates that species have responded to past climate change independently. Modelled findings were discussed in the context of other factors which also affect the distribution and survival of species, principally habitat loss, increased CO_2, invasive weeds, fire regimes. Dispersal characteristics were included. The role of protected areas was considered, with the implications of the modelling findings stated as strongly conditional on the underlying assumptions. The question of minimum protected area requirements, and the relative impacts of climate change on lowland *vs* upland species were discussed.

Comparison with The Report: Hannah *et al.* (2005) provides a more sophisticated treatment of climate change as one of several actual and potential threats to biodiversity and species representation in protected areas. The methodology in Hannah *et al.* (2005) uses a more geographically detailed model and an apparently more highly developed database of species distribution. Hannah *et al.'s* (2005) findings are stated in terms that honour the model output but also place it in a context that clearly illustrates its inherent limitations. However, The Report is equally comprehensive in its survey of the implications of climate and other factors for species distribution and its analysis of the potential impacts of climate change on the existing protected area systems. The Report predates Hannah *et al.* by about 6 years, and the development of the science in this area during this period is evident in Hannah *et al*. However, it is also evident that the conclusions of Hannah *et al.* relate to methodological matters more than predictions of impacts on species while The Report's conclusions build on questionable extrapolations of the model output. Hannah *et al.* indicate the potential utility of The Report for methodological purposes, particularly if this aspect of The Report's content had been emphasized and further developed.

6 Summary

The Report provides evidence that the study on which it was based met most of the study rationale and objectives as stated in The Report. While much of this evidence is inferential in nature The Report provides a great deal of useful information about biodiversity – climate change interactions and a well developed description of methodological approaches and issues. Even six years after its completion as a draft, it can contribute to Australia's understanding of how this issue can be investigated.

However, the Report's current physical form is more like a draft than a final report, and would have benefited from the following changes:

- a thorough edit to correct numerous grammatical and typographic errors, with each chapter having a broadly similar structure;
- a discussion focusing on those matters The Report could realistically address and conclusions about those matters the analysis could support or on methodological matters, about which there is considerable interest;
- more information in the introduction on the role that past climate variability and change has played in the evolution and biogeography of the southwest biota;
- a more explicit and consolidated description of methods used in the study;
- clearly enunciated assumptions with their implications discussed;
- a comprehensive treatment of the substantive findings and advice relating to each study objective;
- very limited introduction of findings that go beyond the boundaries of the analysis defined by the assumptions;
- greater emphasis on conclusions related to methodology in preference to projected specific impacts on species or broad generalizations about WA biota.

Appendix A: RECOMMENDATIONS FOR FURTHER RESEARCH

This section describes priority research initiatives which have been identified as a result of reviewing The Report. These sections may be useful for the National Biodiversity Climate Change Action Plan or other initiatives in WA or elsewhere in Australia.

Species distribution

Bioclimatic modelling depends on sound information about the historical distribution of species to define climatic envelopes and thereby to determine vulnerability to projected climate change. Collating high quality distribution maps, using all available data, for select species would facilitate modelling of those species for specified changes to climate conditions. Selecting species and collating the data would be a useful national initiative for those species which have (or had) distributions over more than one jurisdiction.

Ecophysiological thresholds

Determining eco-physiological factors / thresholds that are critical for the survival and persistence of a species in relation to temperature, water availability and ambient CO_2 concentrations would facilitate the inclusion of these matters in models. Gathering such data (including reviewing current literature) for a number of key species representing various life-histories in plants and animals and using these data to determine climatic envelopes for climate change predictions would provide an alternative approach to using current species geographical distribution data. This would also enable these analytical approaches to be assessed and compared.

Competitive advantage

Competition is a key factor in species distribution and ecosystem structure. While the climate and soil conditions in an area may be suitable for many species, competition will largely determine which species are actually able to occupy the area and benefit from its resources. Assessments of climate influences on competitive advantage might follow determination of ecophysiological thresholds.

Ecosystem responses to climate change

Species-based modelling ignores the interactions between members of ecosystems. Approaches to modelling ecosystem – climate change interactions should be investigated. South African biodiversity researchers have developed a model for a high biodiversity ecosystems which Californian researchers are testing for use with that state’s high biodiversity Mediterranean ecosystems – these initiatives may provide an insight into how Australia could address this matter. Greater collaboration between leading Australian and other international researchers could help Australian scientists accelerate their uptake on these issues.

Climate conditions and disease impact and spread

Possible climate change impacts on the spread and activity of *Phytophthora cinnamomi* will be critical to the future survival of much of south west WA's biota. Warmer and wetter summers on the south coast, as indicated by some climate change scenarios, are likely to have very serious consequences for *Phytophthora* impact on biodiversity in that area, while drier winters may restrict *Pytophthora* spread and might even reduce the spread of salinity. A thorough review of the potential implications of climate change projections for disease impact and spread would be of direct use to land managers.

Increased atmospheric CO_2 concentrations

Few *in situ* experiments have been performed on the effects of increased concentrations of atmospheric CO_2 on the growth and phenology of Australian plants, and none have addressed possible impacts on invertebrates and micro-organisms. The highly diverse heathlands of south west WA offer an excellent opportunity to generate data about these matters.

Location, distribution and climate envelopes

An assumption underlying the study that is so basic that it is not stated is that there is a clear relationship between the climate a species is currently experiencing and its preferred or acceptable climate parameters. Climate variability is a feature of the WA environment. However, in the south west of WA many relictual species have become extinct throughout much of their range but have persisted in geographically restricted and fragmented or disjunct population remnants. The chance persistence of a species in a certain area may thus reflect past climatic effects rather than indicate a specific adaptation to or migration to a current climate regime (or in some cases soils) in the area. In other words the current distribution of a species, particularly if it is geographically localized, may not at all reflect its ability to tolerate changes in key climatic variables. A better understanding of these dynamics is required to support interpretation of model results and other analysis.

Climate and biodiversity: equilibrium or continuing evolution

A key assumption underlying the study and The Report is that that *"the present day range limits (of species) are in equilibrium with the present climate"* (page 24). This assumption ignores our current understanding of the evolution and origins of the Western Australian flora particularly in the south-west. Reliable circumstantial evidence suggests that climate change has played a key role in origin and distribution of species in this region and that widespread climatic instability has been experienced in this region since the late Tertiary leading to cyclic expansion and contraction of the mesic and arid zones. There is also increasing palaeo-botanical evidence that a relatively high proportion of the flora is more ancient. All of these species have been responding in various ways to changes in climate for a very long time, continuing to the present. Therefore it is unwarranted to assume that the distribution of species is in equilibrium with the climate (a) at the present, (b) when WA Herbarium or WA Museum records commenced, or (c) when earliest European records were taken. Palaeoclimate research, particularly research which matches past climate change with ecosystem responses, would be invaluable to increasing knowledge about past climate change and past biodiversity responses to the climate change. Such research may provide an excellent basis for projecting future biodiversity responses to climate change.

Climate change and speciation

Climate change is a feature of the WA environment. Hopper (1979) proposed a hypothesis that the great speciation of many plant taxa resulted from past fluctuations in rainfall, which may have resulted in periodic isolation and genetic divergence of populations. When rainfall increased, these populations came into contact again, and were able to test the degree of genetic divergence achieved during the previous drier period. Understanding how this process might have operated in the past and what implications it might play in the future would contribute to understanding potential biodiversity - climate change projections and contribute to effective land management practices.

Resilience and the role of refuges

The Report noted that refuges smaller than 50 ha were excluded from the analysis of the vulnerability of *Dryandra* species to climate change (page 69). Converseley, The Report notes that (re frogs) …. Refuges are likely to play a significant role in harbouring plant and animal species under climate change conditions. Investigating the potential role of refuges of differing sizes and the implications of refuge sizes for differing taxa could provide a valuable input to conservation investment strategies and help ensure that investment in conservation initiatives is effective and efficient.

Fire regimes

Projected temperature increases and rainfall decreases may act in contrary ways and lead to change in fire regimes in the south west of WA. Decreased rainfall would be expected to reduce the LAI (leaf area index) of vegetation, ultimately decreasing the fall of litter to the ground and the amount added each year. This litter is a key ingredient of fire regimes and should reduce the extent, intensity and frequency of fire. Increased temperature will extend the duration of the fire season and may increase the frequency, extent and intensity of fires. The forests of south west WA have well-developed models relating the elements of fire regimes to environmental features. These data provide an unrivalled opportunity in Australia to model changes in fire regimes based on projected climatic shifts and assess impact on biodiversity. It would also be useful to investigate the impact of drying climate on annual grasses, fire severity and understorey structure.

Climate change and pests

Projected climate changes are expected to differentially impact on introduced and indigenous pests and predators, such as the cat, rabbit, rat, donkey, camel, and the various plants that affect ecological systems. A better understanding of the conditions that could result in rapid increases or decreases in pest populations or movement would enable biodiversity managers to be better manage their impacts.

The impacts of past climate changes

Parts of the south west of WA have already experienced significant climate change, the ecological impacts of which are only now being investigated. There is a suite of experimental opportunities in using the south west as a living laboratory for *in situ* research:

- Understanding changes in location, particularly at the margins of changing rainfall zones and in heaths and wet forests.
- Determining *post-hoc* the most relevant and useful key indicator species for monitoring and study.
- Determining the utility of strategic remotely-sensed data to monitor shifts in species, assemblage or community presence in response to climate change.

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