Climate Impacts on Australia's Natural Resources: Current and Future Challenges

Conference Workbook

Crowne Plaza Surfers Paradise
25th to 27th November 2003

Sponsored by:
The Standing Committee on Natural Resource Management
Managing Climate Variability Program

Queensland Government Natural Resources and Mines
Murray-Darling Basin Commission
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General Information

Registration Desk

The registration desk for the conference will be in the Conference Foyer, located on Ground Level, in the Eldorado Tower, at Crowne Plaza Surfers Paradise. The desk will be attended at the following times:

Tuesday 25th November:	8.00 am – 6.00 pm
Wednesday 26th November:	8.00 am – 6.00 pm
Thursday 27th November:	8.00 am – 3.30 pm

Name Badges

Name badges are to be worn at all times for access into the conference sessions.

Crowne Plaza Surfers Paradise

The conference will be held at Crowne Plaza Surfers Paradise. Contact details for the conference are:

2807 Gold Coast Highway
Surfers Paradise Qld 4217
Hotel
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Conference Secretariat
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Messages On-Site

Messages for delegates can be left at the registration desk, where it will be written on paper and pinned to the message board. Please check the message board regularly as sessions will not be interrupted for individual messages. Please mark all faxes clearly with the intended recipients name and "Climate Impacts on Australia's Natural Resources" and send to 07 5592 1519.

Conference Dinner

The conference dinner will be held at the Crowne Plaza Surfers Paradise on Tuesday, 25th November 2003. The dinner will commence in the conference foyer at 7.00pm and conclude at 11.00pm. A 3 course meal, standard drinks and entertainment will be included. If you have not advised the secretariat you are attending the dinner, or if you can no longer attend the dinner, please advise the registration desk immediately.

Special Diets

If you have notified the conference secretariat of special dietary requirements, via the registration form, this information has been passed on to the hotel. When food is being served you will need to notify the hotel waiters of your name and requirement and they will bring you a specially prepared meal.

Delegates who have special dietary needs, who have not previously advised the conference secretariat, should advise staff at the registration desk immediately so arrangements can be made.

Dress Code

The standard of dress for the conference is Smart Casual for all conference sessions and social functions.

Taxi Service

The taxi services at the Gold Coast are:

Regent Taxis	131 008
Yellow Cabs	131 924

Mobile Phones

Out of courtesy to the presenter and fellow delegates, mobile phones must be turned off while sessions are in progress.

Cancellations / Refunds

Please note that no refunds will be issued at the conference by the secretariat. All refunds will be issued post conference.

Liability

In the event of circumstances beyond the control of the Climate Impacts on Australia's Natural Resources: Current and Future Challenges Conference and/or the conference organisers, no responsibility will be accepted for any losses incurred.

Disclaimer

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Challenge: Ecosystem Resiliency Under Global Change

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1. Introduction

At the global level, human activities have caused and will continue to cause a loss in biodiversity and changes in ecosystems. Changes in climate exert an additional pressure and have already begun to affect biodiversity. We thus face a challenge to maintain the resiliency of our ecosystems under multiple pressures or global change. I will present a framework that links biodiversity (at genetic, species and ecosystem level) to the goods and services humans depend on and the multiple pressures, including climate change, that affect biodiversity and thus ecosystem goods and services. Many of the presentations in this workshop concentrate on climate change, given the theme of the workshop, however, we need to consider the multiple pressures that affect the ecosystems and thus for ecosystems to be resilient and for us to achieve sustainable development, we have to develop adequate responses that address the ensemble of these pressures.

2. Biodiversity And Ecosystem Services

Why should we care about biodiversity and ecosystem resiliency? Biodiversity underlies the goods and services provided by ecosystems that are crucial for human survival and well-being. In its recent report, the Millennium Ecosystem Assessment (MA) has classified the goods and services into provisioning, supporting, regulating and cultural services (MA CF, 2003). Provisioning services include providing food, fuelwood, fibre, biochemicals, natural medicines, pharmaceuticals, genetic resources, and fresh water; supporting services maintain the conditions for life on Earth including, soil formation and retention, nutrient cycling, primary production; regulating services include regulation of air quality, climate, floods, soil erosion, water purification, waste treatment, pollination, and biological control of pests and diseases; and cultural services provide non-material benefits including cultural diversity and identity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, cultural heritage and recreation (MA CF, 2003).

3. Global Change

What are the effects of global change or multiple pressures on ecosystems? In many parts of the world, they include: land use and land cover, species introductions or removals, technology adaptation and use, external inputs into landscapes (e.g. chemical use, pest control, irrigation), harvest and resource consumption and climate change (MA CF, 2003). The underlying causes for these changes are demographic, economic (e.g., globalization, trade, market, & policy framework), socio-political (e.g., governance, institutional, & legal framework), science and technology, cultural and religious (e.g., choices about what and how much to consume) (MA CF, 2003; IPCC, 2001). There are also natural physical and biological drivers.

4. Climate Change, Climate Variability And Impacts On Biodiversity

Given the emphasis on climate change in this workshop, what are some of the major conclusions from the Intergovernmental Panel on Climate Change? The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001a) concluded that the atmospheric concentrations of greenhouse gases have increased since the pre-industrial era due to human activities, primarily the combustion of fossil fuels and land-use and land-cover change. These and natural forces have contributed to changes in the Earth's climate over the 20th century; land and ocean surface temperatures have warmed, the spatial and temporal patterns of precipitation have changed, sea level has risen, and the frequency and intensity of El Niño events have increased.

These changes, particularly the warmer regional temperatures, have affected the timing of reproduction of animals and plants and/or migration of animals, the length of the growing season, species distributions and population sizes, and the frequency of pest and disease outbreaks. Some coastal, high latitude and altitude ecosystems have also been affected by changes in regional climatic factors. (IPCC, 2001b; IPCC, 2002).

For the wide range of IPCC emission scenarios, the Earth's mean surface temperature is projected to warm 1.4 to 5.8°C by the end of the 21st century, with land areas warming more than the oceans, and the high latitudes warming more than the tropics. The associated sea-level rise is projected to be 0.09 to 0.88m. In general, precipitation is projected to increase in high latitude and equatorial areas and decrease in the subtropics, with an increase in heavy precipitation events. Extreme weather events are projected to increase. The projections include: higher maximum temperatures; more hot days and heat waves over nearly all land areas (very likely), higher minimum temperatures; fewer cold days frost days and cold spells over nearly all land areas (very likely), more intense precipitation events over many areas (very likely), increased summer drying over most mid-latitude continental interiors and associated risk of drought (likely) and iincrease in tropical cyclone peak wind intensity, mean and peak precipitation intensities (likely) (IPCC, 2001a; 2001c).

The projected impacts due to changes in mean climate, extreme climatic events and climate variability are likely to affect individual organisms, populations, species distributions, and ecosystem composition and function both directly (e.g., through increases in temperature and changes in precipitation and in the case of marine and coastal ecosystems also changes in sea level and storm surges) and indirectly (e.g., through climate changing the intensity and frequency of disturbances such as wildfires). Processes such as habitat loss, modification and fragmentation, and the introduction and spread of non-native species will affect the impacts of climate change. Changes in the frequency, intensity, extent, and locations of disturbances will affect whether, how and at which rate the existing ecosystems will be replaced by new plant and animal assemblages. Projected changes in climate during the 21st century will occur faster than in at least the past 10,000 years and combined with land use change and exotic/alien species spread, are likely to limit both the capability of species to migrate and the ability of species to persist in fragmented habitats (IPCC, 2001c; IPCC, 2002). The risk of extinction will increase for many species that are already vulnerable. Species with limited climatic ranges and/or restricted habitat requirements and/or small populations are typically the most vulnerable to extinction, such as endemic mountain species and biota restricted to islands (e.g., birds), peninsulas (e.g., Cape Floral Kingdom), or coastal areas (e.g., mangroves, coastal wetlands, and coral reefs). In contrast, species with extensive, non-patchy ranges, long-range dispersal mechanisms, and large populations are at less risk of extinction. While there is little evidence to suggest that climate change will slow species losses, there is evidence it may increase species losses. In some regions there may be an increase in local biodiversity—usually as a result of species introductions, the long-term consequences of which are hard to foresee

Globally by 2080, about 20% of coastal wetlands could be lost due to sea-level rise. The impact of sea-level rise on coastal ecosystems (e.g., mangrove/coastal wetlands, seagrasses) will vary regionally and will depend on erosion processes from the sea and depositional processes from land. Some mangroves in low-island coastal regions where sedimentation loads are high and erosion processes are low may not be particularly vulnerable to sea-level rise (IPCC, 2002).

Changes in biodiversity at ecosystem and landscape scale, in response to climate change and other pressures (e.g., deforestation and changes in forest fires), would further affect global and regional climate through changes in the uptake and release of greenhouse gases and changes in albedo and evapotranspiration. Similarly, structural changes in biological communities in the upper ocean could alter the uptake of carbon dioxide by the ocean or the release of precursors (dimethyle sulphates) for cloud condensation nuclei causing either positive or negative feedbacks on climate change (IPCC, 2002).

5. Adaptation

Since there are observed impacts of climate change on ecosystems and human societies, adaptation activities have to be designed and implemented. Adaptation should not be seen to be just for climate change, but to multiple pressures facing the ecosystems and human societies. Much of the work to date has concentrated on adaptation to climate change, but a few strategies and activities are now starting to address multiple pressures including some in Australia (see e.g. Done this volume). Globally, there are very few adaptation activities implemented on the ground but we have some good examples in Australia, some being discussed at this workshop.

IPCC concluded that climate change adaptation activities have the potential to reduce adverse effects of climate change and can often produce immediate benefits, but cannot prevent all damages to ecosystems and human societies from the impact of climate change. In addition, ggreater and more rapid climate change would pose greater challenges for adaptation (IPCC, 2001b). Climate change adaptation activities can enhance ecosystem resiliency and reduce the impact of changes in climate and climatic extremes on biodiversity. Adaptation activities can include the establishment of a mosaic of interconnected terrestrial, freshwater and marine multiple-use reserve protected areas designed to take into account projected changes in climate, and integrated land- and water-management activities that reduce non-climate pressures on the biodiversity and hence make the system less vulnerable to changes in climate. Some of these adaptation activities can also make people less vulnerable to climatic extremes (IPCC, 2002).

There are potential environmental and social synergies and tradeoffs between climate adaptation and mitigation activities and other aspects of sustainable development. These synergies and tradeoffs can be evaluated and can be compared against a set of criteria and indicators using a range of decision-making frameworks. For this, current methodologies, criteria, and indicators will have to be adapted and further developed as they are lacking at present (IPCC 2002). "Adaptive management", which allows for the re-evaluation of results through time and alterations in management strategies and regulations to achieve goals may be a helpful tool but has to applied and tested (Watson and Berghall 2003).

6. Some Challenges

We face a few challenges when it comes to looking at responses for multiple pressures or even just climate change:

1. Globally and to some extent in Australia, we are not able to cope with the present climate variability and thus ecosystems are not resilient enough mostly due to their degradation.

2. Many ecosystems are characterised by inertia. Inertia means delay, slowness, or resistance in the response. It also implies continuation of change in the system after the cause of that change has been removed. In terms of our activities, it means that the impacts may not be observed for decades to centuries.

3. Due to inertia and our metric used for observation, unless we look at the early stages in a life cycle of an organism (e.g. regeneration and establishment), we may not be able to observe changes.

4. There are many information gaps, e.g. development of appropriate resolution transient climate change and ecosystem models especially for quantification of the impacts of climate change on biodiversity at all scales, taking into account feedbacks and improved understanding of the local to regional scale impacts of climate change adaptation options on biodiversity (IPCC, 2002).

I have presented a global view, but the presentations in the workshop provide details of climate change and the impacts of climate change in Australia. The presentations include the impacts of climate change on biodiversity in general and for many specific systems including: mangroves, coral reefs, freshwater systems, wet tropical mountainous ecosystems, (and important addition to a system with little work globally). Given the link of our intensively and non-intensively managed ecosystems in the provisioning services, the workshop also covers agricultural areas and water resources. There are also some presentations dealing with change in fire frequency and intensity and weeds related to projected climate change. They are thus on themes that are important globally, e.g., water resources, the potential changes in disturbances due to climate change (e.g. fires and invasive species), the multiple pressures that face some systems, e.g. some coastal systems including the Great Barrier Reef). The representative areas program in the Great Barrier Reef and Peterson and Chia's paper deal with potential responses including policy, legal and regulatory frameworks. In many ways, we are leading the world in adaptation to climate change and ecosystem resiliency and putting it in the context of landscape management (e.g. Turner *et al's* this volume). I hope the workshop goes further to consider the ensemble of pressures and develop ideas for strategies and interventions to deal with them for many of our ecosystems.

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IPCC 2001a. Summary for Policy Makers. In: *Climate Change 2001, The Science of Climate Change, Contribution of Working Group I to the Third Assessment Report of the International Panel on Climate Change,* Houghton, J. T., et al

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IPCC, 2001c: *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.

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What Climate Variability Tells Us About Climate Change: Some Views On Policy Evolution

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1. Climate Variability And Climate Change

Governments have a public policy interest in ensuring that economic and social activities carried on by their citizens are compatible with the climatic regime. In an unvarying climate the annual cycle of temperature, precipitation and other variables would be repeated unendingly. Weather systems, integrated over time produce climate. Weather systems are chaotic with every day, month and year unlike any other, either before it or yet to come. Given that there is a chaotic component to climate, governments are faced with deciding which of two fundamental models apply. Is the chaotic climate system:

- Operating within stable limits (a variable climate); or,
- Underpinned by a non-stationary mean, in which case the envelope of the climatic variables will be changing, possibly in a non-linear fashion (changing climate)?

Historically governments have assumed that situation (1) applies, that is, climate maybe variable but it is stable within definite limits. More recently however, driven by the analysis of climate data (eg. Figure 1), the conventional wisdom is that we are faced with a changing climate (IPCC a, b and c) – that is, situation (2) applies.

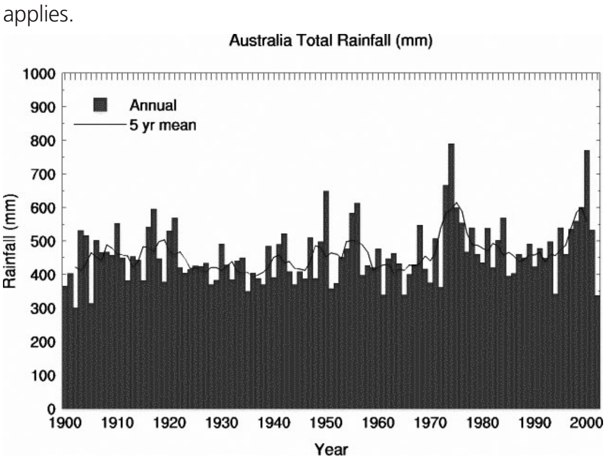

Figure 1. *Australian annual, and five-year average (running mean) total rainfall for the period 1900 to 2000 (mm).*

Policy formulation in a non-stationary climate is far more complex than for the stationary case discussed above. In the first instance the government would wish to determine the rate of underlying change. It would then be reasonable to seek to understand what was driving the change to determine such things as:

- Whether the changes in climate were accelerating, and if so, at what rates;
- Whether there were natural limits to the change, and if so, when these would be reached; and,
- Whether, if deemed necessary, there were actions available to mitigate the change, and if it was sensible (cost effective, environmentally effective) to engage in these actions.

2. The Global Climate Change Policy Environment

Faced with the possibility of sustained global climate change governments have largely acted in a rational way. To better assess the causes and likely consequences that have commissioned national research activities, sought to assess this research in an intergovernmental process using the Intergovernmental Panel on Climate Change (IPCC) and sought to respond in a globally coordinated way using the United Nations Framework Convention on Climate Change (UNFCCC).

There is a wide range of timescales associated with the warming processes linked with the changing concentrations of Green House Gases (GHGs) (Figure 2) that introduces a significant time dimension to the policy formulation issues.

A number of policy relevant messages have emerged from the science, technology and socio-economic assessments of the climate change issue, they include:

- The Earth's climate is warming and human activities are primarily responsible. Furthermore climate change is inevitable without actions to reduce greenhouse gas emissions; Most socio-economic sectors, ecological systems and human health will be adversely affected by climate change, with developing countries being the most vulnerable; and,
- Technologies are available to reduce greenhouse gas emissions but policies and measures are needed to realise the technological potential

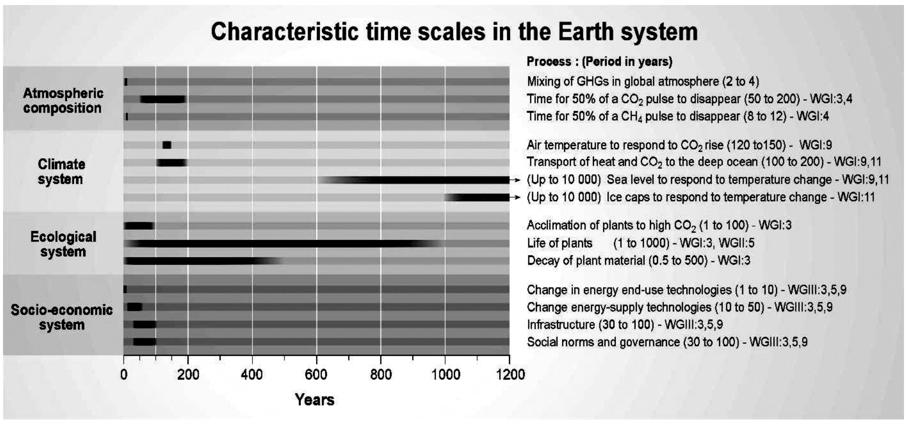

Figure 2. *Estimates of the time scales of various processes that are involved in the climate change associated with the changing concentration of atmospheric carbon. (From the IPCC d, Figure 5.1).*

3. Policy Responses

The Kyoto Protocol, designed to place a cap on the emissions of the developed nations, assist the developing world to move to cleaner technologies (including through use of the Clean development Mechanism (CDM)) and put in place accounting arrangements for the emissions of all signatory countries, has been the globally coordinated, multi-lateral response. There is some evidence that it is a protocol that, when fully ratified, would favour the European Union (EU) over the remainder of the developed world. Features that favoured the EU included choice of the base year for emissions accounting and the ability to trade within the EU 'bubble'.

At the current time it is clear that Russia's must sign the Protocol to reach the threshold of ratification by countries responsible for 55% of global emissions. Some observers still expect a Russian signature, possibly as late as 2005. Until ratification of the Protocol by countries accounting for 55% of global emissions there will be ongoing uncertainty globally, but particularly in Australia, as to which policy directions to pursue. While Australian scientists and negotiators are well respected in the climate change arena Australia is a very small player, and will essentially be a 'price taker' in any internationally negotiated agreements.

The role of the developing world is important. The largest emitters are the US, EU, China, Russia and India. With the growth of the Chinese economy it is becoming increasingly clear that China will need to be a part of any effective emission management strategy if stabilisation of atmospheric concentrations of carbon dioxide is to be achieved by 2100. China is increasingly being seen as the leader of the developing world and is unlikely to agree to any cap arrangements in the foreseeable future. The G77 will follow China's lead, and will most likely seek financial recompense, and capacity building support, from the developed world (Kyoto Protocol Annex 1 countries) for any mitigation activities its members undertake.

The US strategy, being offered as an alternative to the Kyoto Annex 1 cap approach, appears to have four facets:

- Reduction of uncertainties through the collection of more observational data and the support of climate change science research;
- Domestic adoption of 'no regrets' (zero economic cost adaptation and mitigation) actions to limit emissions;
- Investment in research and the pilot implementation of new technologies to facilitate mitigation, if necessary at some future time (the hydrogen economy, carbon sequestration, high efficiency coal fired power plants, etc); and,
- Pursuit, internationally of a range of bi-lateral agreements consistent with the approach outlined in the three bullet points above, while still remaining an active player (but not supporter) of the multi-lateral (UN) approach.

At this stage it is not clear how the US approach would actually lead to stabilisation of the global atmospheric concentration of carbon dioxide at some future time without a range of new, as yet unforeseen, technological breakthroughs.

4. Some Views On The Future

Clearly it is not possible to predict how international, or domestic policy formulation in response to global warming will play out. Policy formulation is a continuous activity, and generally policies are developed in response to public opinion. Public opinion will shift in response to observed and perceived climate changes and also in response to the ensuing public debate concerning causes and optimum responses.

In Europe, the US and Australia there is acceptance that the climate is warming. There is less agreement on, or understanding of, the causes and impacts of this warming and so consensus on the appropriate policies to respond to climate change has not been achieved.

Over time the impacts of climate change will differ substantially across the regions of the globe. The higher latitudes are expected to warm more, and rainfall patterns will be significantly disrupted with globally a more active hydrologic cycle but in some regions diminished rainfall. The climatology of extreme events will change in ways that are not yet predicted. There will be surprises but the underlying physics of climate change will not change – there will be global warming while the atmospheric concentrations of greenhouse gases increases. The necessity to adapt regionally will make it difficult to implement a global mitigation strategy. Furthermore, a system of voluntary measures at a national level, that are not coordinated multi-laterally, is not a system that has been used successfully in dealing with any global environmental problem.

From a national perspective, Australia, as a major energy exporter (coal, natural gas and processed materials such as aluminium and steel) is substantially exposed. Emission trading regimes, which place a cost on carbon emissions represent another exposure if our near neighbours, and economic competitors do not adopt a similar regime. If Australia is not a contributor to, and an early adopter of, new technologies that improve the greenhouse efficiency and/or decrease the carbon intensity of the Australian economy then it will be very expensive for Australia to participate in a cost effective way in a global economy that places an emphasis on reducing greenhouse gas emissions.

Finally, from an international perspective, a word on Australia's position. Australia is rarely thought of by the major players on the international scene, but when it is, it is perceived to be small, rich and a major emitter (on a per capita basis) of greenhouse gases. I believe that the international community expects Australia to reduce its per capita emissions and decrease the carbon intensity of its economy. It will have to conduct effective research programs into relevant new technologies, and be an active partner in broader international programs. It will have to assist in building the capacity of its near neighbours including improving their capacity to contribute to the observations of climate change. Australia cannot afford to be seen as a bad international citizen in the climate change issue or will have to deal with the consequences of losing the support of its neighbours in international for a on other matters.

5. References

IPCC a (2001). *Climate Change 2001: The Scientific Basis. Cambridge University Press,* pp 881.

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Recent Australian Climate Change

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1. How Has Australia's Climate Changed?

Time series of Australian average annual rainfall and mean maximum and mean minimum temperature anomalies, since 1910 (temperature data prior to this are difficult to compare with recent data, because of changes in exposure of instruments) are shown in Figure 1. Rainfall, averaged across the country and year, has increased over the last century. Both minimum and maximum temperatures have increased more markedly than rainfall, especially since the middle of the 20th century.

Figures 2-4 show maps of the linear trends of annual rainfall and annual mean maximum and mean minimum temperatures from 1910 to 2002. Figures 5-7 show heavily smoothed time series of rainfall and mean maximum and minimum temperatures averaged over five degree latitude-longitude boxes (note that Figures 5-7 use standardised anomalies, so the relative magnitudes of the variations cannot be compared between locations – the figures simply indicate the direction of any long term changes).

The main features in Figures 2-7 are:

- Rainfall greater in second half of 20th century, except for southwest (which shows a strong decline) and parts of east coast.
- Maximum temperature increasing everywhere since mid-20th century; cooling in some eastern and central parts prior to this (Della-Marta et al., 2003).
- Minimum temperatures warming everywhere since at least mid-20th century.

One consequence of these changes is that droughts, as measured by rainfall alone, have not intensified but they are now accompanied by warmer temperatures than in the past (Nicholls, 2003a, b).

2. What Has Caused These Changes?

2.1 Continental-Scale Warming

Stott (2003) compared the warming simulated in a coupled climate model forced with anthropogenic influences with that observed globally and continent-by-continent. The model reproduces the Australian warming observed in the second half of the 20th century, but simulates more warming than was observed in the first half of the century. Stott concludes that "The warming effects of increasing greenhouse gas concentrations have been detected in all the regions examined", although the discrepancy in the early 20th century leaves some doubt about this conclusion for Australia.

2.2 Rainfall Decrease In Southwest Western Australia

IOCI (2002) concluded that "Most likely, both natural variability and the enhanced greenhouse effect have contributed to the rainfall decrease" in southwest Western Australia. This conclusion was reached because many climate models forced with enhanced greenhouse gas concentrations simulate a decrease in southwest rainfall, and the large-scale changes in atmospheric pressure associated with the observed decrease in rainfall are similar (although not identical) to those simulated in the models. The model simulated decrease, however, is substantially smaller than that observed, suggesting that natural variability may have contributed to the decrease (unless the model response is too weak).

2.3 Mid-20th Century Cooling In New South Wales

Mean annual maximum temperatures increased across nearly all of Australia during the 20th century (Figures 3, 6). The major exception was in parts of central and eastern New South Wales where mean maximum temperatures decreased somewhat. Variations in mean maximum temperatures in New South Wales are strongly (negatively) associated with rainfall variations.

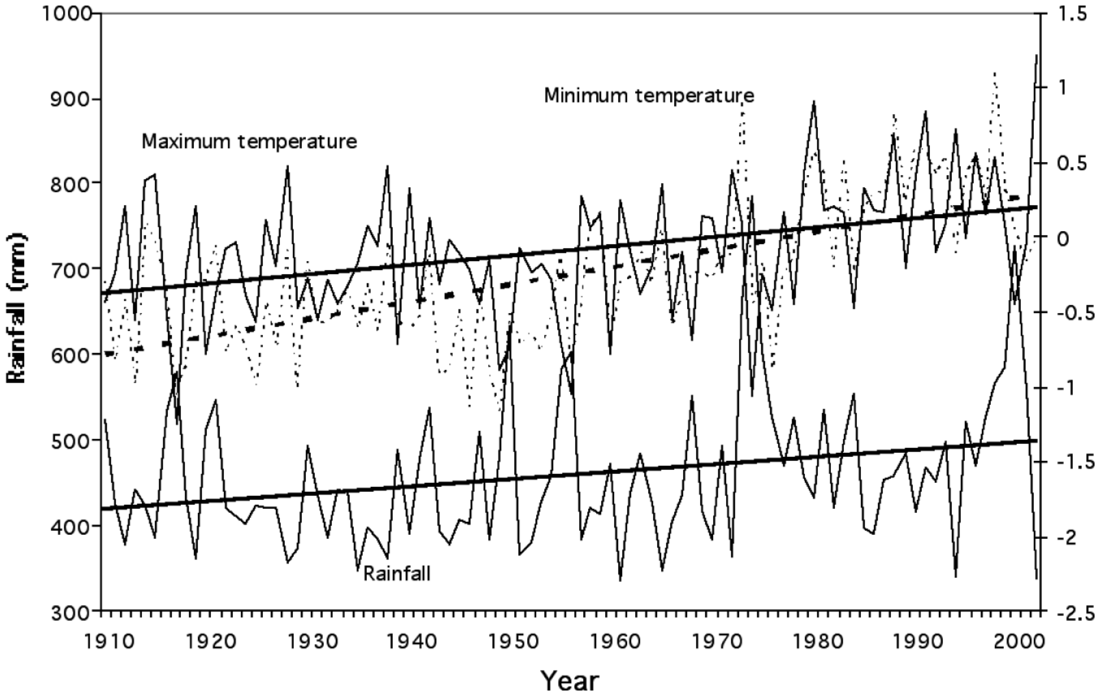

Figure 1. *Time series of Australian average annual rainfall (lower lines) and mean maximum (solid lines) and mean minimum (broken lines) temperature anomalies (from 1961-90 means). Linear trends shown as thick lines.*

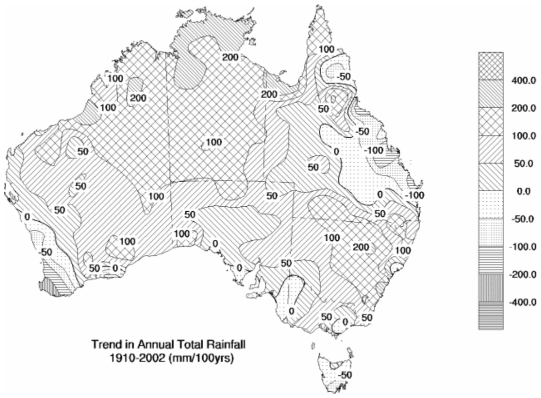

Figure 2. *Trend in annual total rainfall 1910-2002*

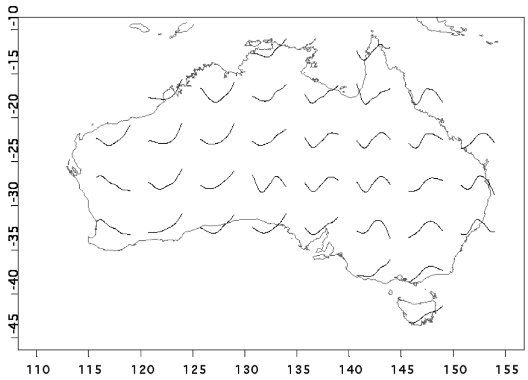

Figure 5. *Smoothed rainfall1910-2002*

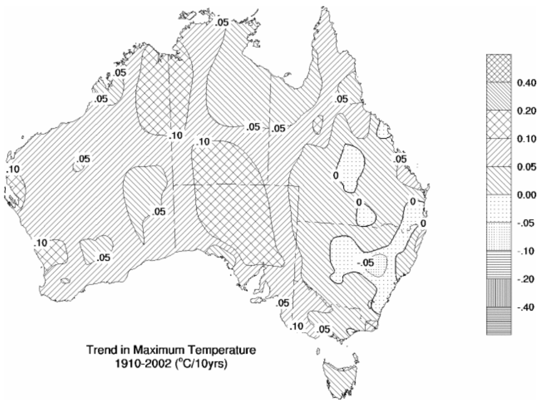

Figure 3. *Trend in maximum temperature 1910-2002*

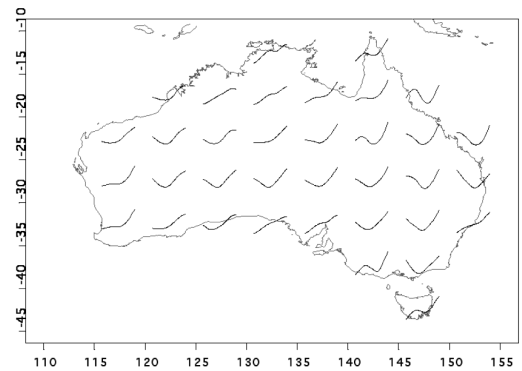

Figure 6. *Smoothed maximum temperature 1910-2002*

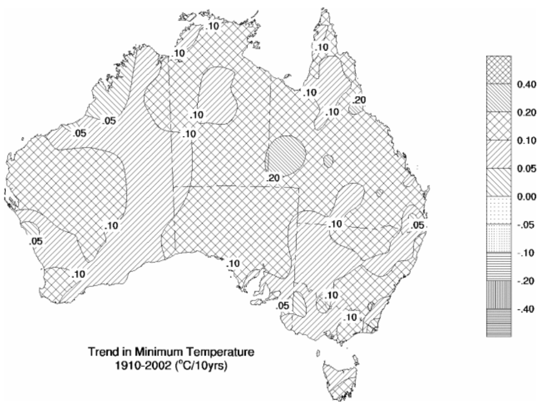

Figure 4. *Trend in minimum temperature 1910-2002*

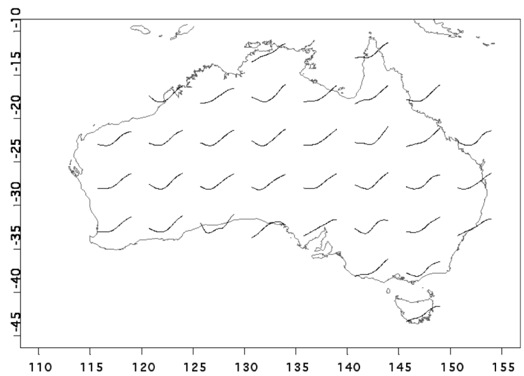

Figure 7. *Smoothed minimum temperature 1910-2002*

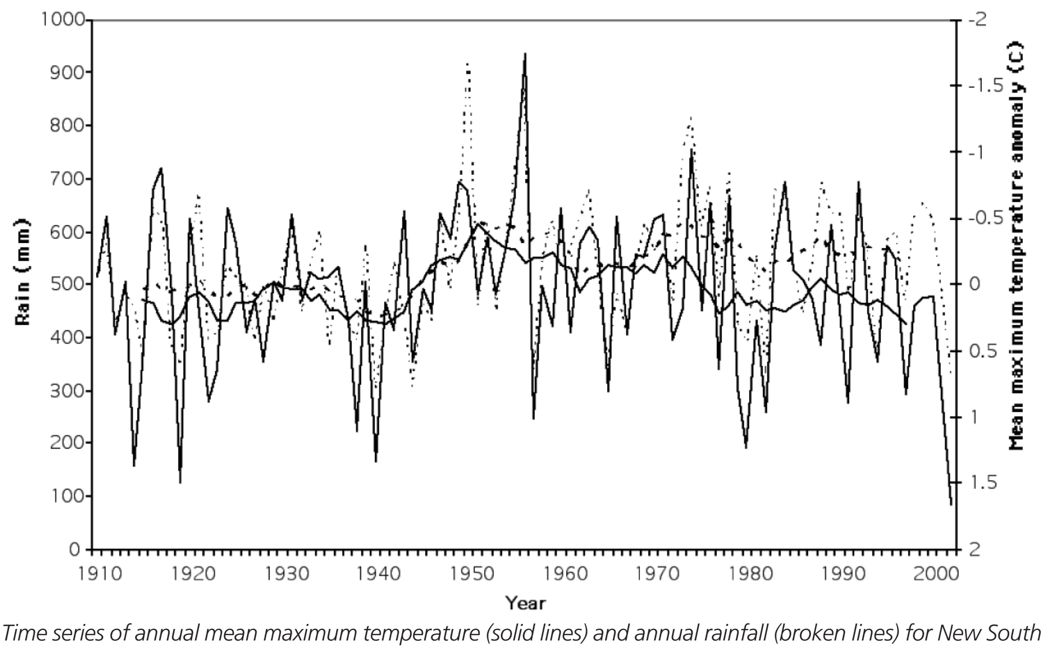

Figure 8. *Time series of annual mean maximum temperature (solid lines) and annual rainfall (broken lines) for New South Wales, 1910-2002. Eleven-year running means (centred) are shown as thick lines. Note that the temperature scale (right hand side) is inverted.*

Temperatures in New South Wales decreased very rapidly in the space of a few years in mid-century, and this decrease was associated with a similarly rapid rainfall increase (Figure 8). Since the middle of the century, mean maximum temperatures have increased, largely independent of any rainfall change. In the early 1970s mean maximum temperatures increased sharply, unaccompanied by any sharp decrease in rainfall. The simultaneity of the rainfall increase and temperature decrease in mid-century suggests that this was a “natural” fluctuation. The absence of a substantial decrease in rainfall accompanying the warming of the last few decades suggests that another process is affecting the temperature. The most obvious candidate for this would be the enhanced greenhouse effect (Nicholls *et al.*, 2004).

3. Are These Changes Having An Impact?

3.1 Impact Of Rainfall Decrease In Southwest Western Australia

During the mid-1980s water resource managers in Perth became concerned about the reduced rainfall and consequent inflows into Perth reservoirs. In the mid-1990s, as these reduced flows persisted, the design basis for future water resources was adjusted downwards, by taking account of only observations from the recent (relatively dry) 25 years, rather than the entire record of rainfall and inflow. This adjustment led to an accelerated development of new water sources, having a current cost of some $500 million, as well as sharpening initiatives to reduce demand through water use efficiency measures (IOCI, 2002).

3.2 Spring Snow Depth In Snowy Mountains

The depth of snow in mid-spring (as measured in the first observation in October each year) at Spencers Creek near Mt Kosciusko has decreased about 40% since 1962 (Figure 9). October snow depth is closely correlated ($r = -0.73$, $n = 41$) with June-August mean maximum temperature at Cabramurra (35˚36’S, 148˚23’E). Mean maximum temperature at Cabramurra has increased since 1962 and this can account for all the decrease in snow depth in spring. The trend of the snow depth estimated with linear regression from the temperature variations almost exactly matches the observed snow depth trend (Figure 9). The obvious conclusion is that the warming has caused the decline in spring snow depth.

3.3 The 2002/03 Drought And The Bush Fire Season

The mean daily maximum temperature averaged across the Murray Darling Basin in May-October 2002 was 0.7˚C warmer than the previous record (Nicholls, 2003b). This substantial increase in the record maximum temperatures, which was a continuation of the warming observed since the middle of the 20th century, was associated with very high evaporation levels. The very warm temperatures probably contributed to the severity of the 2002/03 bush fire season, by accelerating the “curing” of fuel by “shifting” the warm season forward about a month (Figure 10).

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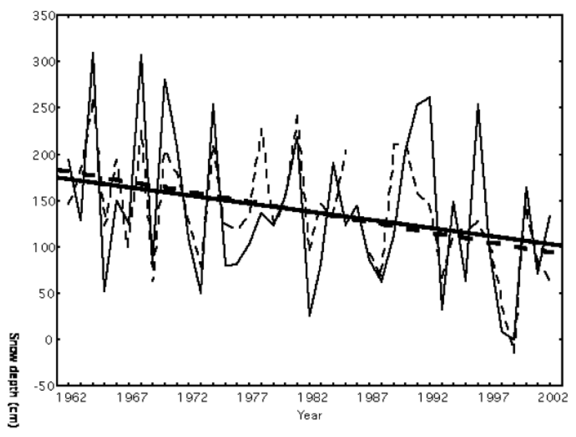

Figure 9. *Observed snow depth at Spencers Creek, first observation in October (solid lines), and depth estimated from Cabramurra mean winter maximum temperature (broken lines). Thick lines are linear trends.*

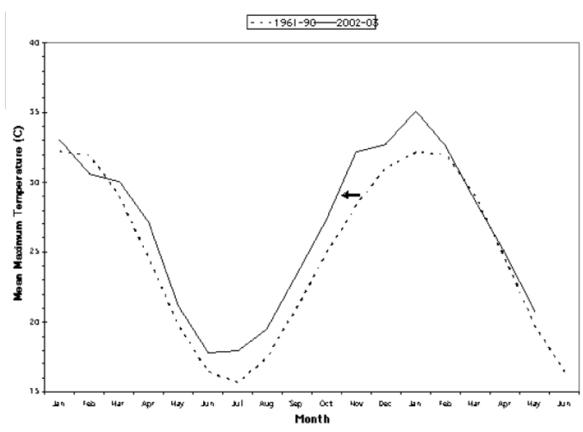

Figure 10. *Murray Darling Basin mean monthly temperatures in 2002/03 (solid line) and climatological temperatures (1961-90, broken line).*

Projected future climate change for Australia

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1. Introduction

The Intergovernmental Panel on Climate Change (2001) concluded that the global climate is changing and that human activities such as the burning of fossil fuel, agriculture and land clearing are contributing to this change. Despite effort to reduce greenhouse gas emissions, further climate change is inevitable. In the Australian region, changes to climatic averages and extremes are likely to induce significant impacts on the Australian environment including water resources, agriculture, and biodiversity. Increasing temperature and temperature extremes, possible increases in extreme rainfall and flooding, increases in drought, changes to characteristics of tropical cyclones and other extreme wind events all have the potential to affect natural and managed systems. This presentation gives an overview of changes to Australia's climate that may be expected in the future. This paper also considers a range of recent enhanced greenhouse results for the Australian region obtained from global and regional climate models with a focus on their relevance to natural resources.

2. Changes To Average Conditions

All global climate models simulate an increase in surface temperature over the Australian continent, although warmings among the models vary slightly. CSIRO (2001) presented projected changes in temperature over Australia, taking account uncertainties in future global warming (varying emission scenarios, uncertainty in global climate sensitivity), and the varying regional results of nine global climate model experiments. By 2030, annual average temperature increases between 0.4 and 2.0°C over most of Australia, with greater warming over inland regions and slightly less warming in some coastal areas and Tasmania. By 2070, annual average temperature increases between 1.0 and 6.0°C, but the spatial pattern remains unchanged. The corresponding projected changes in rainfall show both increases and decreases under enhanced greenhouse conditions. Projected annual average rainfall ranges tend towards decrease in the south-west (–20% to +5% by 2030 and –60% to +10% by 2070). In parts of south-east Australia and Queensland annual rainfall changes range from –10% to +5% by 2030 and from –35% to +10% by 2070. In other inland areas, projected ranges are –10% to +10% by 2030 and –35% to +35% by 2070. The ranges for tropical north are from –5% to +5% by 2030 and from –10% to +10% by 2070. Seasonal results showed that rainfall tended to decrease in southern and eastern Australia in winter and spring, increase inland in autumn and increase along the east coast in summer.

Since the publication of CSIRO (2001) projected rainfall and temperature changes have been prepared under contract for Queensland, Victoria and South Australia. In each case additional climate model experiments available since CSIRO (2001) were considered. Regional validation assessments were also undertaken, and some experiments were excluded due to poor representation of current regional climate. As an example, Figure 1 illustrates seasonal rainfall projections over Queensland, prepared using a set of models that included three simulations that had become available since those published by CSIRO (2001). In this case most of the models indicate reduced rainfall annually and in winter and spring. Summer rainfall shows a slight increase, particularly in the north of the State.

The simulated changes in rainfall are likely be related to some consistent features in the simulated changes in atmospheric circulation. Most models simulate a hemispheric-wide pattern of increased pressure around 40-50 degrees south and then a band of decreased pressure to the south of this. This represents a shift toward one extreme of a well recognized mode of climate variability in the southern hemisphere know variously as the 'Southern Annular Mode' or the 'Antarctic Oscillation' (Cai *et al.*, 2003). This change in circulation represents a southward shift of the band of westerly winds and associated fronts, and is likely to be associated with the decrease in winter half year rainfall in southern Australia simulated in most models. For enhanced greenhouse conditions, IPCC (2001) noted that whereas models did not show consistent changes in El Niño-Southern Oscillation (ENSO)-related year-to-year variability, there was a tendency for most models to show a pattern of change in the average sea-surface temperature in the Pacific that was 'El Niño-like', i.e. a pattern that shows higher sea-surface temperature anomalies over central and eastern Pacific. Such changes in ENSO behaviour may be related to the simulated decrease in rainfall in eastern Australia present in many models.

2. Changes To Extremes

Increases in average temperature can lead to large changes in the occurrence of extremely hot or cold days. This may be assessed by applying the changes in average temperature as discussed above to the observed daily temperature record at some selected sites and then calculating the resulting change in the frequency of extremes. Changes in the frequency of extremes can be marked. For example, the average number of days over 35°C each summer in Melbourne would increase from 8 at present to 9–12 by 2030 and 10–20 by 2070. In Perth, such hot days would rise from 15 at present to 16–22 by 2030 and 18–39 by 2070.

Where GCMs simulate a decrease in average rainfall it may be expected that there would be an increase in the frequency of dry extremes (droughts). Whetton and Suppiah (2003) examined simulated monthly frequencies of serious rainfall deficiency spatially for the case of Victoria, which showed strong average rainfall decrease in most simulations. There was a marked increase in the frequency of rainfall deficiencies in most simulations, with doubling of frequency in some cases by 2050. This tendency for the models that declining average rainfall is associated with increases in the frequency of serious rainfall deficiency would be expected to apply in other parts of Australia. Drought occurrence and intensity will be also be affected by changes in potential evaporation and temperature. 'Potential evaporation' represents the maximum evaporation possible from a particular surface under given environmental conditions. Simulated increase in surface temperature leads to increased potential evaporation throughout Australia. The combined effect of regional changes in rainfall and evaporation represents a change in the regional atmospheric moisture balance, i.e. the net amount of moisture available from the atmosphere. Annually averaged from 1961-1990, most of Australia has an atmospheric moisture deficit, i.e. more evaporation than rainfall. Under enhanced greenhouse conditions, almost all models simulate greater water balance deficit over most of the continent. This tendency for decreased moisture is much more robust than any simulated decrease in rainfall itself. Although these results are for average conditions, they strongly suggest the potential for extreme dry events to become more intense when viewed in terms of the availability of atmospheric moisture.

A range of CSIRO and other modelling studies in recent years have identified a tendency for daily rainfall extremes to increase under enhanced greenhouse conditions (e.g. Hennessy et al., 1997; IPCC, 2001, Whetton et al., 2002). This tendency commonly applies even when average rainfall is simulated to decrease, thus raising the prospect of increased drought in combination with increases in heavy rainfall events. Although, in some cases, substantial decreases in rainfall return periods have been simulated concern that the rainfall data represents large areas (model grid squares of 60km by 60km or larger) means that further work is required to represent the changes at the spatial scale that extreme rainfall is experienced in the real world. Recent work at CSIRO Atmospheric Research has addressed this issue through using a very high resolution model (7km by 7km) to dynamically downscale current and enhanced greenhouse sets of extreme rainfall occurrence in northern NSW and southern Queensland as simulated by the CSIRO GCM. The downscaled extreme events for a range of return periods compared well with observations and the enhanced greenhouse results for 2040 showed increased of around 30% in magnitude and changes in return period such as the 1-40 year event becoming the 1-15 year event.

CSIRO modeling has also been used to investigate possible future changes in mean and extreme winds. Simulated mean wind changes in both 2030 and 2070 reveal that they are generally less than ±2% across much of the region in all seasons. In particular there is a general pattern of decreases in the mid-latitude westerlies between 30-40°S consistent with the changes in circulation described above. Changes in extreme winds show increases of up to 10% across much of the northern half of Australia and the adjacent oceans during summer in 2030. In the mid-latitudes, decreases in extreme winds of less than about 5% occur immediately to the south of the continent. Off the east coast of Australia and in the southern Tasman between Tasmania and New Zealand, increases in extreme winds of up to 4% are evident in 2030 and 2070. In some regions, the changes in mean and extreme winds are of opposite sign indicating that even though mean winds may decrease, extreme winds due to severe storm events may increase. Extreme wind conditions in tropical coastal areas may increase due to more intense tropical cyclones, but uncertain changes in the frequency and location of cyclones.

3. Adaptation And Mitigation

Changes in climate such as described above have potential implications for natural and managed systems. For example changes to rainfall, temperature and potential evaporation are likely to reduce water resources available for natural ecosystems, agricultures and human settlements. Increasing temperature will also have direct effects on natural and managed ecosystems. Drier conditions and an increase in the frequency of hot days are likely to increase the frequency of bushfires and their associated damages. Higher storm tides associated with stronger extreme winds may lead to more coastal inundation. Many of these potential impacts will be considered in more detail in other presentations.

Impacts of climate change on natural resources can be ameliorated in two ways (i) reducing greenhouse gas emissions and (ii) adaptation. Measures to reduce greenhouse gas emissions globally will also slow the rate of change and may eventually limit future change if greenhouse gas concentrations are stabilised. However very large emission reductions are required if stabilisation is to be achieved within the next century or so. This is because carbon dioxide and other greenhouse gases have atmospheric lifetimes of decades to centuries. Stabilising the carbon dioxide concentration at 550 ppm by 2150 would require a prompt reduction in emissions, continuing to 50% below 1990 levels by the year 2150. To stabilise at 750 ppm by the year 2250 can allow for continued increases in emissions up to the year 2050, followed by reductions reaching 50% below 1990 levels by 2150. The extent of warming associated with a given stabilisation scenario cannot be precisely specified because of the uncertainty associated with the sensitivity of the global climate system. However, there are emerging techniques that enable us to estimate the probability of keeping global temperature increase below a given target (and of therefore not exceeding an equivalent level of regional impact) for a given stabilisation scenario. Adaptation to some degree of inevitable climate change will thus be essential.

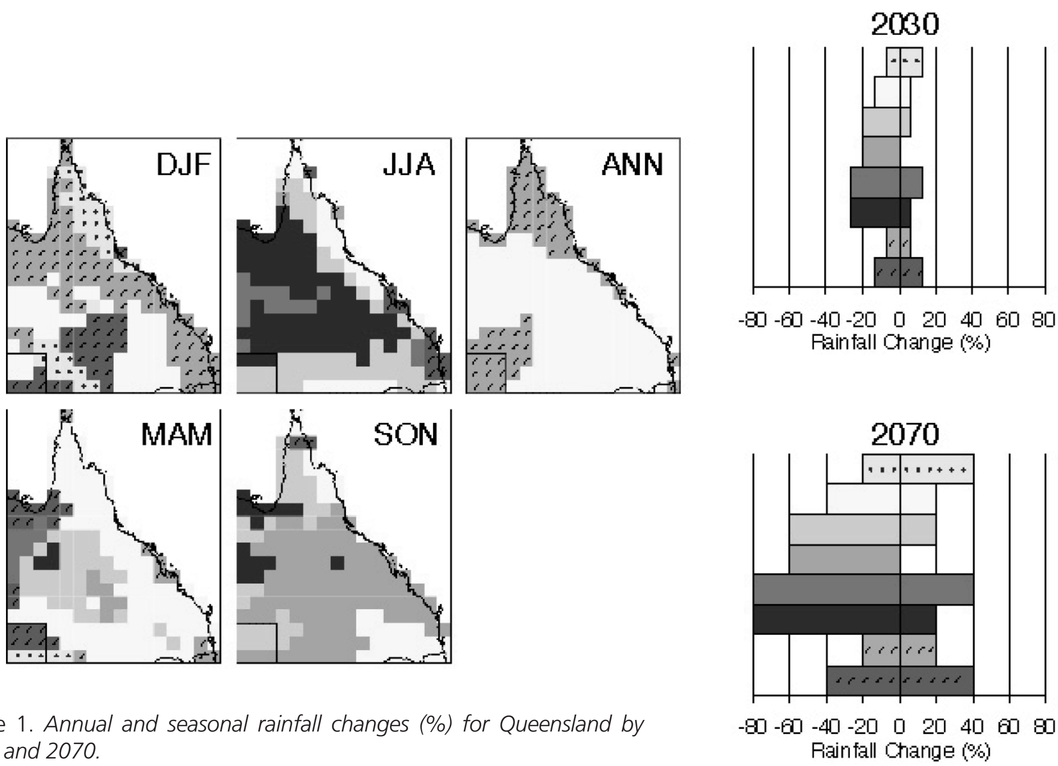

Figure 1. *Annual and seasonal rainfall changes (%) for Queensland by 2030 and 2070.*

4. Acknowledgments

The results presented here represent the work of a range of colleagues at CSIRO Atmospheric Research. In particular I wish to thank Kevin Hennessy, Kathy McInnes, Debbie Abbs and Roger Jones for their contributions.

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Climate Change and the Coast

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1. Introduction

Climate change has a number of implications for coastal Australia. Previous reviews have detailed many of these, but the recent introduction in several states of statutory coastal plans has changed the planning environment at the local level. In addition, the possible future introduction of a National Coastal Policy will further influence the legislative framework of coastal management.

While sea level rise is the prediction of climate change science that is most obviously applicable to the coast, there are also other possible impacts, including effects on coastal ecosystems.

2. Issues

Sea level rise is one aspect of climate change caused by global warming. Predicted sea level change in the 21st century will be slow and thus difficult to measure. Most damage to coastal infrastructure, however, is caused by extreme events. It is possible that in some locations a small rise in sea level could cause a large increase in extreme flood events, if a critical threshold is exceeded. For instance, if sea level rise caused a dune field to be overtopped in a particularly extreme weather event, this dune field may not survive (Nott and Hubbert, 2003). This may have some implications for coastal development planning.

Sea level rise has the potential to cause erosion, thus affecting vulnerable coastal infrastructure. Yet erosion is a natural process, occurring all the time. Historically, assessments of landward erosion due to a rising sea have often been assessed using Bruun's rule (Bruun,1962), but this is a highly simplified representation of complex coastal processes. Extreme erosion events in Australia are associated with tropical cyclones, east coast lows and intense mid-latitude low pressure systems. Flooding caused by high rainfall is also an issue. In coastal regions that are already vulnerable to riverine flooding, the addition of sea level rise can cause increases in flooding incidence upstream from the river mouth.

Coastal ecosystems may be vulnerable to climate change. These include mangroves, saltmarshes, wetlands and coral reefs. In particular, coral reefs, although not strictly a "coastal" ecosystem, are particularly vulnerable to increased ocean temperatures, another prediction of climate change research (Done *et al*., 2003).

Economic considerations are numerous, ranging from the obvious, such as damage to infrastructure from erosion, to the less obvious, such as disputes over who will pay the cost for an adaptation to climate change. Quite apart from its economic importance, the Australian coast has significant cultural value for most Australians. Thus communities will demand action on issues that affect their access to cultural amenities: climate change may be one of these issues in the future.

3. Trends

Overall, sea level is rising in Australia, as it is in many parts of the world (Church *et al*., 2001). Estimates of this change are around 1-1.5 mm per year during the 20th century (Pugh *et al*., 2002). However, local land movements can be large, with some locations undergoing substantial subsidence.

The wind and wave climate at a location is crucial to the amount of erosion taking place there. For wave climate, in general the record is too short to assess any trends. Queensland and New South Wales have a baseline wave climate monitoring program based on waverider buoy information, but this data has only been available for about 30 years. Wind data has been available for rather longer, but it is trends in extreme wind events that are relevant to erosion. For Queensland, extreme wind events are largely associated with tropical cyclones; in the south-east of the State, there is also a contribution from severe thunderstorms and east coast lows. There has been a downward trend in tropical cyclone numbers off the east coast of Queensland since the period of reliable records began (in the late 1960s – Nicholls *et al*., 1998), while the number of east coast lows has shown an upward trend over the past 40 years (Hopkins and Holland,1997).

For erosion trends, there appears to be little material in the open literature. Given the 20th century sea level rise, however, most regions of the coast should be eroding landward. The rate of erosion would vary tremendously from location to location, however.

An overarching consideration is the demographic trend in Australia that shows a sharp rise in coastal population. This will act to exacerbate any issues of coastal stability that are related to climate change, as an increased population means increased infrastructure in some locations that may be at risk.

4. Science

Global average sea level rise is likely to continue in the 21st century and is predicted to accelerate. Global mean sea level is expected to rise by 3-30 cm by 2040 and 9-88 cm by 2100 (Church *et al*., 2001). The range of projections is large as there remain continued uncertainties regarding the projections of climate models and the future concentrations of greenhouse gases in the atmosphere. Nevertheless, there will always be some uncertainty in climate change projections. One of the challenges for users of this information is to decide what level of uncertainty is low enough for the projections to be used in planning, and whether the range of plausible projections exceeds critical planning thresholds that would require action to be taken.

Future trends in tropical cyclones suggest modest to moderate increases in cyclone intensities (Walsh *et al.*, 2004). It is not clear yet whether cyclones would necessarily travel further south in a warmer world. One significant uncertainty is that tropical cyclone numbers in the Queensland region are substantially affected by the phase of the El Niño/Southern Oscillation, with considerably more cyclones affecting the Queensland coast during La Niña conditions. Unfortunately, it is not yet clear how climate change will affect ENSO.

All other things being equal, an accelerating future sea level rise will lead to increased landward erosion. For beaches in particular, though, their maintenance depends not only upon the level of the sea but also upon the supply of sediment. This is a difficult prediction to make, particularly since these factors are so specific to a location.

Coastal ecosystems may well be more affected by the increase in coastal population than by global warming. Nevertheless, the ecosystems of estuaries may be affected by warmer sea surface temperatures. For example, the growth rate of phytoplankton is highly sensitive to sea temperatures, which in turn could affect algal growth rates. Predictions call for a likely decrease in runoff rates in southern Australia (Pittock and Wratt, 2001) but the potential impact on estuaries has not been systematically evaluated.

During previous periods of rising sea level, mangroves have moved landward (Pittock and Wratt, 2001), so they may be able to adapt similarly to 21st century sea level rise, provided that such landward movement is not restricted by topography or coastal development. There could be large effects on coastal wetlands in tidal regions of northern Australia, where even a modest sea level rise would inundate considerable areas.

5. Strategies

Risk management is a technique that is being increasingly applied to climate change problems (e.g. Jones 2001). For instance, for sea level rise, it would be useful if planners could be given a projection of a certain sea level rise associated with a certain probability. This sea level rise probability distribution could then be combined with a GIS description of property values and coastal assets to give expected damage due to the combination of the frequency of extreme events and anticipated sea level rise (e.g. Abbs *et al*., 2000).

For management purposes, coastal regions often can be divided logically into littoral cells, parts of the coast within which sediment is circulated (Woodroffe, 2002). Typically, adaptation strategies have been suggested as follows (e.g. Titus, 1990): accommodation/no protection; protection; adaptation; and retreat. Protection strategies for sea level rise may include beach nourishment, which can be expensive; or sea walls, which would be employed as a last resort, as they would lead inevitably to loss of the beach in front of the wall. Applying these adaptation measures to coastal ecosystems would be more difficult, but one possibility could be to provide landward migration zones for mangroves. Controls and zoning are measures that are already in place in many locations to allow for climate change (e.g. Walsh *et al*., 2004). National guidelines on responses to climate change have been published by the Institution of Engineers (1991).

6. Planning

Previous Commonwealth coastal policy, the Commonwealth Coastal Policy of 1995, makes passing reference to climate change issues. In addition, it mentions regional cooperation with South Pacific island nations that are threatened by sea level rise. State coastal strategies vary. Tasmania's coastal legislation was recently struck down by a legal challenge. Several states have policies that take climate change issues into account. Recently, statutory state coastal plans have been developed that require local authorities to address issues detailed in these policies. Nevertheless, this does not ensure their adoption at the local level. There are certainly few funds available to allow coastal councils to address climate change issues in their local planning arrangements. Legal challenges by sectors of the community have led to some council planning initiatives being reversed. In addition, some councils may be reluctant to introduce measures that may be perceived to disadvantage certain sectors of the community. Even so, numerous councils have made allowances for sea level rise in their planning schemes. For ecosystems, the situation may be more difficult. For instance, it is hard to see how human intervention can stop higher ocean temperatures causing damage to the Great Barrier Reef.

Planning is greatly aided by good data on current conditions. Unfortunately, for many coastal phenomena, good, comprehensive, easily accessible data is not available. This is particularly true for biological data.

7. Recommendations

Allowance for sea level rise is now part of planning for many coastal councils. Other climate change issues, such as the impact of sea level rise and temperature changes on local ecosystems, have been given lower priority. Partly this is because of the lack of funding and lack of coordination for climate impact studies in Australia.

It is difficult to expect many local councils, who have a significant number of other concerns, to allocate resources to climate change issues. Some funding needs to be provided to enable them to implement allowances for climate change issues in their planning schemes. Possible allowances would differ considerably from location to location and thus would have to be evaluated separately.

In addition, data and results of studies need to be collected and made available in easy accessible form. These initiatives could form part of a new National Coastal Policy.

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Facing the Challenge of Managing Water Resources Under Conditions of Climate Uncertainty

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1. Introduction

Water is inextricably linked with food security, human health and the environment: it is fundamental to survival, economic stability and preserving natural ecosystems. Initially, water resources management focused largely on the development of available resources. Development intensified as water demand grew, and issues such as resource depletion, equity in resource access and use, and degradation of water quality have become increasingly important. The need for better management became apparent when gross changes in the availability and/or the condition of the resource, or subtle changes in crop production or native ecosystems, were observed. In many parts of Australia, emerging evidence of changes in climatic regime and global warming, and increasing concern about the impacts of projected climate change have emphasized this need. Decision making under these circumstances is technically complex and subject to high levels of uncertainty and risk. However, this risk can be managed more effectively if it is accepted that: (1) climate is non-stationary, and can exhibit irreversible changes or a set of regimes; (2) prediction problems relate to the statistics of hydroclimatic state variables, and the development and application of methods for change detection, forecasting and record reconstruction; and (3) adaptive rather than static strategies for resource management need to be adopted in practice.

2. Discussion

Extensive hydroclimatic datasets and innovative methods for the analysis of hydroclimatic information are being developed around the globe. These activities are highly relevant to water resources management but the products are only just coming to the notice of practitioners. Examples drawn from Queensland, southern Australia and the USA will be used to show how: historical atmospheric and at-site hydroclimatic records can be used to detect and characterise changes in atmospheric circulation responsible for apparent rainfall shifts and trends; climate reconstructions from the paleo analogs and global climate model experiments can be used to place historical hydroclimate variability in a longer term context; seasonal climate forecasts based on statistical-physical methods can provide useful information in regions where climate predictability is regarded as low, and numerical modelling might be used to identify an adaptive management strategy for algal bloom control that is effective for present day as well as projected future conditions. Emerging technologies will revolutionize water management, and changes in current practices will result when these methods are incorporated into decision support systems and socio-economic analyses.

Implications of Climate Change for Freshwater Ecosystems

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1. Introduction

The average temperature of the globe has risen by around 0.6°C over the last century and will rise further, between 1.4 - 5.8°C before the turn of the next century (IPCC, 2001). Along with the increase in average temperatures, extreme temperatures will rise, heat waves will become more frequent, and evaporation and, hence, water stress will increase. Rainfall is likely to become more variable (Easterling *et al*., 2000), with more wet spells and more intense tropical and temperate storms, but also more frequent and prolonged droughts with greater impacts due to the higher temperatures. Climate change is a reality.

Within the last 20,000 years Australia has experienced climates that were warmer and wetter, and cooler and dryer than they are today, and it is clear that those changes in climate had large effects on the distribution and abundance of flora, fauna and ecological systems (Krockenberger and Kitching, 2003). Climate change today is different and conceivably, even more serious, for two reasons. First, the rate of temperature change is unprecedented in the past 10,000 years, and second, many of the earth's ecosystems are already stressed by other human impacts.

Freshwater and coastal ecosystems support high levels of biodiversity and contribute significantly to the earth's productivity, thus providing many tangible and intangible goods and services to society and human welfare (Baron *et al*., 2002). Yet these systems are increasingly impacted by a wide range of human activities and in general, have experienced higher species extinction rates than other ecosystems, including tropical rainforests. Climate change is an added stress, with serious implications for aquatic biodiversity and productivity (Meyer *et al*., 1999).

2. Implications For Aquatic Ecosystems

Increases in water temperature will alter fundamental ecological processes and the geographic distribution of aquatic species. Such impacts may be ameliorated if species can move and migrate to more suitable habitats. However, may river and floodplain systems have lost their natural longitudinal and lateral connectivity and potential migratory corridors, reducing the capacity of aquatic organisms such as fish and invertebrates to make compensatory movements into more favourable aquatic conditions. This may cause species extinctions and loss of riparian and aquatic biodiversity (Poff *et al.*, 2002).

Impacts on riparian systems will include effects of temperature and water regime changes on vegetation structure and the ecological processes linking riverside vegetation and the in-stream ecosystem. Effects on processes will involve loss or increase in shading, with effects on stream temperature, light environment and primary productivity, whereas loss of riparian cover and diversity will impact on the provision of food supplies (insects, fruit and flowers) that partially sustain riverine food webs (Pusey and Arthington, 2003). Riparian vegetation also governs certain aspects of riverine habitat, especially the density, configuration and type of submerged wood and litter, important habitat elements for fish (Pusey *et al*., 1995).

Aquatic ecosystems are dependent on the water regime of their freshwater environment (Poff *et al*., 1997). They depend on the volume, seasonal timing and variability of freshwater flows and will be strongly affected by changes in rainfall and runoff patterns due to climate change, with impacts to be expected on species composition and ecosystem productivity (Poff *et al*., 2002). Reduced runoff in small headwater streams of forested catchment such as the Wet Tropics Bioregion will result in loss of aquatic habitats and associated rare and restricted freshwater species, including fish (Pusey e*t al*., 1995) and crustaceans. Reduced in-stream flows and associated deterioration of water quality (e.g. increased nutrient loads), may stress aquatic biota and result in more toxic blue-green algal blooms (Maier *et al*., 2001).

Species and populations of aquatic organisms are adapted to seasonal patterns of river flow (Bunn and Arthington, 2003) and are sensitive to the frequency, duration and timing of extreme flow events such as floods and droughts. Changes in these seasonal and episodic patterns of river flow have the potential to disrupt reproductive activities (timing of spawning events, egg and larval survival, growth rates and juvenile recruitment) (Poff *et al*., 2002). Loss of synchrony between the flow and thermal regime could become a major disruptor of reproductive processes.

Climate change will place further stress on sensitive freshwater and coastal wetlands that form the interface between terrestrial and marine systems and provide habitat conditions for many species unable to live in other environments. Wetlands perform an important role in controlling nutrient and sediment flows from the land, and also provide fish habitat and spawning grounds for many commercial species. Increased runoff from cropping systems may deliver large nutrient and sediment pulses into estuarine and marine systems such as the Great Barrier Reef, exacerbating the water management problems already in existence (Reef Water Quality Management Plan, 2003, http://www.deh.gov.au/coasts/pollution/reef/#draft).

Altered freshwater flows to coastal systems will affect fish movements, habitat use, trophic relationships and spawning patterns, and these changes will result in reductions in the productivity of important coastal fisheries (Loneragan and Bunn, 1999). Rising sea levels will impact on estuarine and wetland systems along our coasts, with implications for habitat conditions and availability, life-cycle processes, food web structure and ultimately, biodiversity and fisheries productivity. Lowland and littoral rainforests will be threatened by increasing salt-water incursions (Krockenberger and Kitching, 2003).

Aquatic ecosystems are often viewed as resilient and able to maintain a healthy and self-sustaining system despite large year-to-year variations in temperature and hydrological conditions. However, rapid climate change may impose new environmental regimes that will exceed the limits of resilience of aquatic systems (Poff *et al*., 2002).

3. Water Management, Planning And Policy

In Australia under COAG reform initiatives, new water management policies, practices and markets are being developed during a period of climate change, and will need to be flexible and adaptive to accommodate the issues associated with climate change.

Reducing the likelihood of significant impacts on aquatic systems due to climate change will be dependent upon reducing other ecosystem stresses, and enhancing the resilience and adaptive capacity of these systems. The strategies available include maintaining riparian corridors and floodplain forests, reducing nutrient and sediment loads from the land, minimising groundwater and surface water withdrawals, strategically placing new water infrastructure and maintaining environmental flow regimes to minimise adverse effects on aquatic ecosystems (Arthington and Pusey, 2003).

Provision of water to sustain aquatic and wetland ecosystems will remain a high priority, scientifically and politically. However, determination of the amounts of water needed for environmental flows, already a technically challenging area of science and planning, will become more difficult in situations of increased climatic variability. Australian governments are even now experiencing major confrontations and conflicts over water sharing during a period of extreme drought. Such conflicts are likely to increase and become more difficult to manage as climate change imposes new pressures and an even more variable context for water management.

The spoken paper will discuss strategies for coping in the context of climate change, and the associated R&D needed to support new strategic developments in aquatic science, water planning and water management.

4. Acknowledgments

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Climate Variability, Seasonal Streamflow Forecast and Water Resources Management

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1. Climate And Streamflow Variability

The considerable variation of rainfall and runoff from year to year is part of the natural variability in the climate system. The management of land and water resources involves designing and operating to cope with this variability. The management challenges in Australia are compounded by Australian streamflow (and to a lesser extent climate) being much more variable than elsewhere in the world.

The inter-annual variability of river flows in temperate Australia (and Southern Africa) is about twice that of river flows elsewhere in the world (see Figure 1 and Peel *et al.*, 2001). This means that temperate Australia is more vulnerable to river flow related droughts and floods than elsewhere in the world. To put this high inter-annual variability into context, storages in Australia must be four times larger than elsewhere in the world, to achieve a given system reliability for the same demand and mean inflow.

2. Seasonal Forecast And Managing Climate Variability

The teleconnection between Australia's hydroclimate and El Niño/Southern Oscillation (ENSO) is amongst the strongest in the world (see Chiew and McMahon, 2002). For example, Figure 2 shows that the spring inflows into Wyangala Dam (in central-west New South Wales) are generally higher when the winter Southern Oscillation Index is positive (the SOI describes the Tahiti minus Darwin sea level pressure, and is commonly used as an indicator of ENSO).

The relationship between streamflow and ENSO, and the serial correlation in streamflow (see next Section), can be exploited to forecast streamflow several months ahead. The forecast can be used to help manage water resources systems, and allow decisions on irrigation water allocations, water restriction rules and environmental flows to be more realistically based (see Chiew *et al*., 2003).

The relationship between ENSO and climate is the scientific basis of seasonal climate forecast provided by research institutions and meteorological agencies throughout the world. The Australian Bureau of Meteorology provides seasonal climate outlooks (e.g., probability that the total rainfall over the next three months would exceed the median) (see www.bom.gov.au/climate/ahead). The Australian Rainman computer package provides historical rainfall (and streamflow) data and seasonal forecast based on ENSO (see Clewett *et al*., 2003). Many studies have shown that the use of seasonal rainfall forecast can significantly benefit agricultural and resource management (see papers in Australian Bureau of Resources Sciences, 1997; and Hammer *et al.*, 2000).

3. Enso-streamflow Relationship And Streamflow Serial Correlation

Figure 3 shows the statistical significance of the lag correlation of the linear relationship between three-month streamflow (in Oct-Nov-Dec and in Jan-Feb-Mar) versus SOI value in the previous three months in catchments throughout Australia (see Chiew and McMahon (2003) for more detail). In general, the lag relationship between streamflow and ENSO can be exploited to forecast spring streamflow throughout eastern Australia,

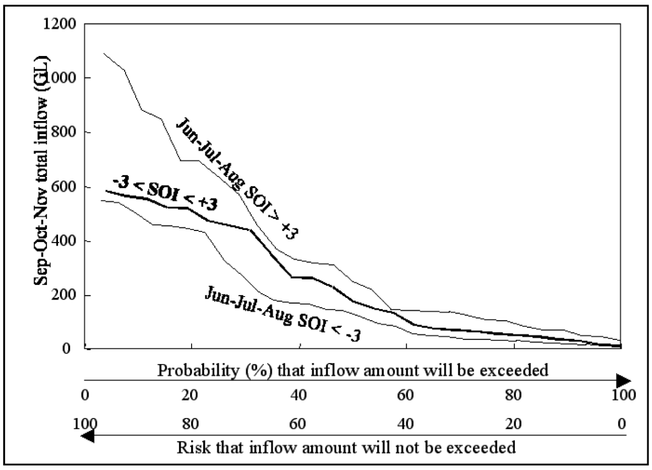

Figure 2. *Distribution of spring inflows in Wyangala Dam (in central-west New South Wales) for three categories of winter SOI values*

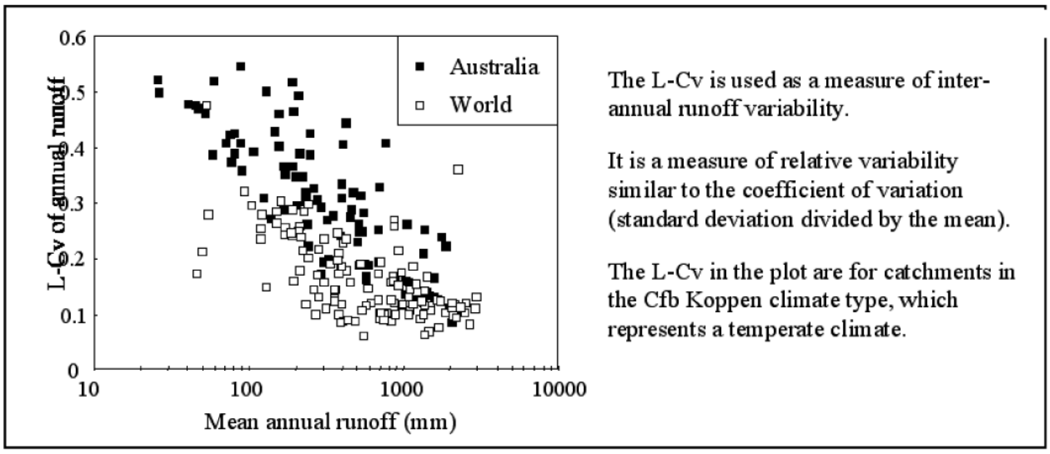

Figure 1. *Inter-annual variability of Australian streamflow relative to the rest of the world*

except New South Wales east of the Dividing Range. Summer streamflow throughout most of east Australia including east of the Dividing Range can be forecast from spring indicators of ENSO. The lag streamflow-ENSO relationship in late summer is considerably stronger in the summer dominated rainfall regions in northern New South Wales and Queensland than in the winter dominated rainfall regions in Victoria.

The serial correlation in streamflow must also be considered in forecasting streamflow because it is generally stronger than the lag streamflow-ENSO relationship (except in north-east Australia). In addition, unlike the streamflow-ENSO relationship, which is statistically significant only in the latter and very early parts of the year, the persistency in streamflow exists throughout the year. The streamflow persistence results from the delayed response in the rainfall-runoff process due to soil and groundwater storage, giving streamflow a memory of conditions over several months. However, this memory disappears relatively quickly and for longer lead times, ENSO indicators may be better explanatory variables for forecasting streamflow.

4. Exceedance Probability Forecast And Water Resources Management

As water resources systems are typically managed with very low risks, forecast at the very high end of probabilities of exceedance is required (right hand side of Figure 2). The exceedance probability forecast could be derived by looking at the streamflow distributions resulting from discrete categories of antecedent conditions (e.g., discrete SOI categories shown in Figure 2), or using non-parametric models that take into account the continuous relationship between streamflow and the explanatory variables (e.g., Sharma, 2000; and Piechota *et al*., 2001).

Various desktop studies have shown that the use of seasonal streamflow forecast can benefit the management of land and water resources in Australia (e.g., Abawi *et al*., 2001; and Chiew *et al*., 2003). Seasonal streamflow forecast could allow water managers to make more realistic decisions on water allocation for competing users, and forecast of variables like water allocation, streamflow volume and number of pumping days (based on number of days daily streamflow threshold is exceeded) would help farmers make better informed risk-based decisions for farm and crop management.

5. Future Challenges

Potential users need to be educated on the use of seasonal climate and streamflow forecast, particularly on the interpretation of probabilistic forecast. Some agencies, like the Queensland Centre for Climate Applications, have made significant inroads into this through their field extension programs. Water agencies should also be encouraged to use seasonal streamflow forecast to help manage water resources systems. Several agencies, like the Murray-Darling Basin Commission and Goulburn-Murray Water, estimate future inflows into their storages based on streamflow persistence. Goulburn-Murray Water uses the inflow forecast together with their water system model to provide irrigators with probabilistic estimates of water allocation later in the irrigation season.

Further research would improve the reliability of seasonal forecast. Areas of research include ENSO-climate modelling, statistical ENSO-streamflow modelling, and understanding of ENSO and ENSO-hydroclimate teleconnection. An emerging area of research is the consideration of inter-decadal variability (for example, ENSO and streamflow characteristics are different in different decadal periods, and different models may be required for the different periods), particularly in the context of climate change.

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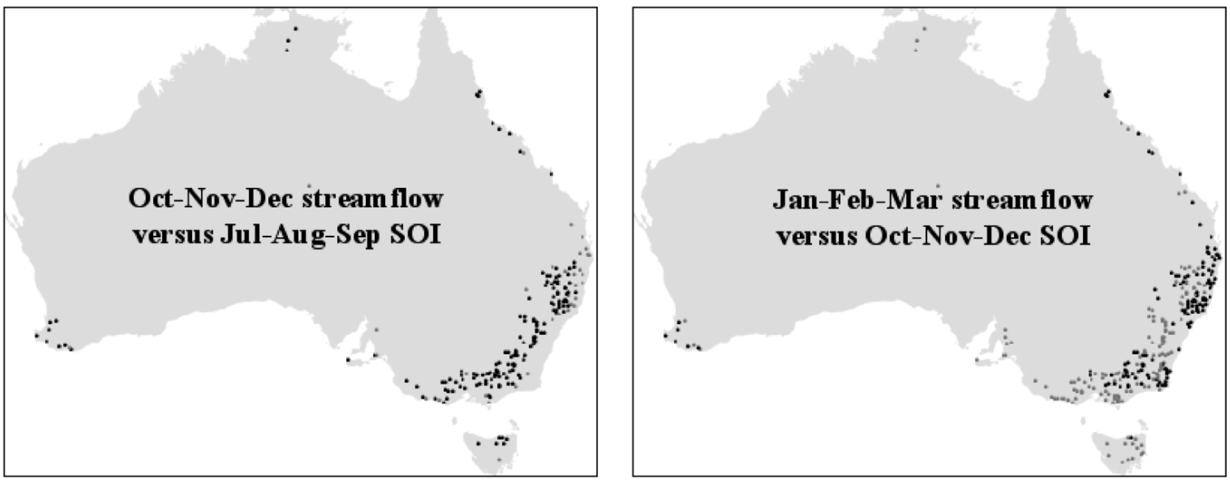

Grey dots indicate all the 284 catchments used for the study.
Black dots indicate that the lag linear correlation is statistically significant at a = 0.05.
98 years of data from 1901-1998 are used for the analyses. They include modelled streamflow data.

Figure 3. *Statistical significance of lag linear correlation of streamflow versus SOI in 284 Australian catchments*

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Biodiversity and Climate Change in Australia

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1. Summary

- Biodiversity conservation practitioners frequently regard climate change as distant, uncertain, largely intractable and of marginal impact compared to other stresses.
- Recent observations and modelling demonstrate that this is not the case: climate change is already having an impact, we are locked into further climate change that will lead to more extreme impacts on many if not all ecosystems in Australia.
- Climate change will interact with other stresses on biodiversity making it a high priority consideration for almost all policy and management concerned with biodiversity conservation.
- A three-fold approach is required to reduce the impact of climate change on biodiversity conservation: in the short-term, protect species that are particularly vulnerable; in the long-term, facilitate adaptation to future climates; and reduce the magnitude of climate change through mitigation.

2. Introduction

Biodiversity in many regions of Australia is under threat from a range of human induced pressures, including habitat loss and introduction of exotic species (National Land and Water Resource Audit, 2003; Australian State of the Environment Committee, 2002). The conservation of biodiversity is recognised as a severe and on-going issue in Australia, attracting considerable investment from the Commonwealth, State and Territory governments, the private sector and the community. Australia is well equipped for biodiversity conservation with systems of terrestrial and marine protected areas, environmental protection and threatened species legislation, and growing interest in conservation on private land. However, climate change poses a new threat to Australia's biodiversity.

A decade ago, the impacts on biodiversity of climate change were seen as distant in time and very uncertain. However, there were some indications that the impacts could be considerable and conservation planning needed to take account of future climate change (eg, Hughes and Westoby, 1994; Williams *et al*., 1994). As a result, anthropogenic climate change was listed by some jurisdictions as a "key threatening process" (eg, NSW in 2000 and the Commonwealth in 2001). However, in reality, despite a growing body of global scientific evidence about both climate change and its impacts on biodiversity (Howden *et al*., 2003), very little attention has been given in Australian biodiversity conservation policy and practice to the impacts of climate change. In short, many involved in biodiversity policy and conservation continue to regard climate change as distant in time, very uncertain, impossible to deal with, and of marginal impact compared to other immediate, certain and tractable stresses.

The Commonwealth government's Biological Diversity Advisory Committee recently commissioned a workshop of scientists and policy makers to examine the impacts of climate change on biodiversity in Australia (Howden *et al*., 2003). From this workshop it was clear that: climate change is already having a visible impact on Australia's biodiversity, the impacts are almost certain to increase dramatically within decades, and there are many options for reducing the impacts of climate change; indeed, addressing the impacts of climate change is essential for almost all biodiversity policy if it is to be effective. In short – considering climate change must become core-business for biodiversity policy rather than an "optional extra".

3. The Impacts Of Climate Change On Biodiversity

Globally, there is a substantial and growing body of evidence that the impacts on biodiversity of recent climate changes can already be observed (Hughes, 2000; Hughes, 2003, Hughes this volume). These include effects on physiology, distributions and the timing of life-cycle events. Some species will be affected by changes in climate and CO_2 concentration more than other species, altering competitive relationships and other interactions between species, leading to flow-on impacts on other individuals, species, communities and ecosystems. Critically, disturbance regimes are likely to be altered, which will affect the way species and ecosystems respond to climate change.

In many situations other anthropogenic stresses (eg habitat fragmentation) have reduced ecosystem resilience and will limit the ability of species to autonomously adapt to climate change. Along with observations suggesting impacts are already occurring, ecosystem and bioclimatic modelling suggests there are likely to be significant impacts under continued climate change (Howden *et al*., 2003, Hilbert this volume). Climate change will alter dominant species in assemblages, disturbance regimes, the "look and feel" of ecosystems, the local distributions and existence of species, tourism and recreational opportunities, and the provision of ecosystem services. Hence, climate change will affect many aspects of Australia's biodiversity that are valued by society.

4. Biodiversity Conservation Objectives

The impacts of current climate change on biodiversity highlight that species and ecosystems are not static. While accepted by many scientists, this is not recognised in much of Australia's biodiversity conservation policy and practice. The imminent impacts of climate change suggest better conservation outcomes could be achieved if biodiversity strategies were consistent with the concept of a mobile and evolving biota.

We suggest three goals are appropriate for conserving biodiversity under climate change:

- In the short-term, protect species that are particularly vulnerable;
- In the long-term, facilitate adaptation to future climates; and
- Reduce the magnitude of climate change through mitigation (reducing greenhouse gas emissions), thereby making the first two goals more achievable.

5. Doing Something About It

Below we set out a range of different types of activities that could be undertaken to help achieve these goals (Howden *et al*., 2003).

5.1. Understand And Manage For Climate Variability

Understanding the current impact of climatic variability on natural and agricultural ecosystems will greatly assist detection and management of future climate change. For example, use of climate variability information could improve the management of bushfire risk, grazing in rangelands, water diversions and environmental flows, and estuaries and coastal areas.

5.2. Preserve Biodiversity That Is Sensitive To Climate Change

Preservation of existing biodiversity will always remain the most effective and cheapest means of future biodiversity conservation. Many current biodiversity activities will help conserve biodiversity under climate change, especially with some enhancement. For example: limit land clearing and habitat degradation, preventing introductions of potentially invasive species, restoring environmental flows and reduce salt, nutrient and sediment flows to rivers, wetlands, estuaries and oceans. Conservation actions specific to climate change could include managing species likely to become invasive under climate change and *ex situ* conservation of species that cannot survive future climates.

5.3. Facilitate Long-Term Adaptation

Many activities could assist or augment the long-term and natural adaptation of biodiversity to climate change. For example, increasing connectivity in the landscape, rehabilitation of degraded habitat, preservation of locations that may become key habitat under future climates, ensuring potential refuges are protected and species can migrate from them, and translocating species.

5.4. Monitoring, Research And Policy Development

For adaptation programs to be successful in the long term, substantial information is needed to address gaps in understanding and some institutional issues may need to be managed. Actions could include: monitoring impacts on carefully selected species and communities, designing adaptation actions to maximise information for future actions (*active* adaptive management), ensuring consideration of climate change is integrated into all biodiversity policies and conservation programs, and raising the priority of climate change in science investment processes. A critical step is to develop policy mechanisms to allow risk management analysis of all greenhouse issues (i.e. integration of the costs *and* benefits of mitigation *and* adaptation and their interactions), as opposed to a segmented, potentially adversarial, approach.

5.5. Mitigate Climate Change And Reduce Other Pressures On Biodiversity

There is no doubt that the tasks of preserving biodiversity under climate change and facilitating adaptation will be more achievable and less costly if the magnitude of future climate change and other anthropogenic pressures on biodiversity are reduced.

6. National Biodiversity And Climate Change Action Plan

Earlier this year a multi-jurisdictional task group was formed by the Land, Water and Biodiversity Committee (convened under the Natural Resource Management Ministerial Council) to develop a Draft Biodiversity and Climate Change National Action Plan. The Task Group released a discussion paper in September (http://www.deh.gov.au/nrm/publications/biodiversity/index.html), and the Draft Action Plan is to be submitted to the Ministerial Council in April 2004.

7. Conclusion

While there remain many questions about future climate change and its impact on biodiversity, uncertainty is no longer an excuse for inaction. There are many actions that can be undertaken to address those impacts that are highly likely. Adaptive management programs should be established that contain a mixture of adaptation actions and monitoring. All existing biodiversity conservation goals, priorities and programs should be reviewed to ensure they are consistent with a dynamic view of biodiversity and the short-term preservation and long-term adaptation goals for conserving biodiversity under changing climates. Impact and adaptation assessments need must be linked to mitigation assessment in an integrated risk management framework.

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Strategic planning of Australia's water resources under

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1. Introduction

Climate change is expected to impact on the availability of water resources over the course of this century, potentially changing the volume, timing and quality of supply. Demand is expected to increase, especially for irrigation water, which forms the bulk of Australia's water use. However, irrigation water use will occur within an environment of increasing plant productivity under elevated levels of atmospheric CO_2. Therefore, first-order impacts in water supply and demand will be modified by climate change feedbacks within catchments and management systems.

Climate risks will not be managed in isolation but will accompany a host of other changes taking place within the policy and regulatory system. The main policy development and implementation process is taking place under National Water Reform Policy. Other important areas include the mitigation of salinity, the Living Murray Project and reduced consumer demand in urban water systems. Private investment also anticipates sustained returns on investment, requiring adequate resources on the one hand and sustained levels of productivity per unit of resource on the other.

The relationships between certainty, climate outlooks and planning horizons for water resources are shown in Figure 1. Most water management concentrates on the tactical management of water resources, even though the infrastructure used to collect and distribute that water has a long engineering life. Good management of climate variability is interpreted as being able handle large deviations of extreme rainfall from the mean on sub-daily to annual time scales.

As strategic management becomes more important, longer-term strategic issues, including climate change, come into play. However, most recent explorations of strategic issues affecting water resources have tended to concentrate on single issues. Salinity futures are assessed with scant regard to climate; the water reform process is viewed as re-allocating existing resources; one recent report on the strategic assessment of land-use change failed to mention changes in climate and atmospheric CO_2 (not cited to prevent embarrassment); and most climate change assessments have not been integrated with these other issues. This paper reviews the current knowledge of how water resources may change under climate change, and what science may be needed in the short-term to take a more integrated approach.

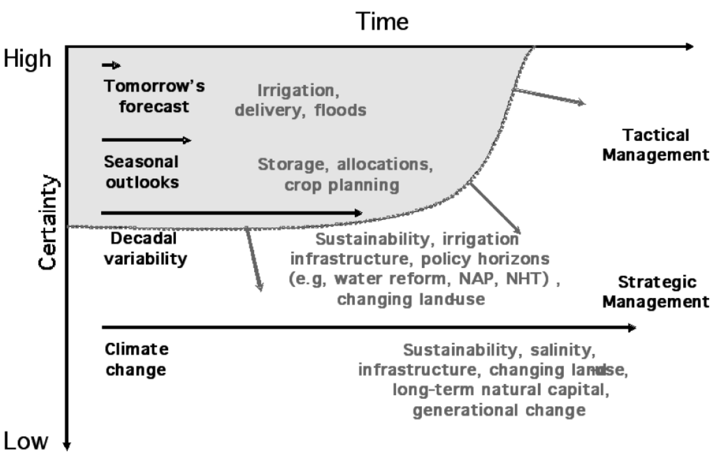

Figure 1. *Schematic diagram showing the relationship between the certainty of climate occurring over different time scales, management horizons and different types of management. The shaded area shows where most current management is concentrated, and the arrows where management is moving to.*

2. Overview Of Recent Research

2.1 Summary Of Climate Changes

Extreme daily rainfall intensity increases in most model simulations even when mean rainfall decreases. This has implications for flood control, especially in modified and urbanised catchments, and for the operation and infrastructure of stormwater and wastewater systems. However, the magnitude of these changes is not well represented in global climate models, as shown by subsequent dynamical downscaling using very high resolution models (Abbs, pers. comm.). Dynamical, statistical and hybrid methods of downscaling can provide realistic output but cannot be scaled independently of a particular climate simulation. This constrains our ability fully explore these uncertainties in impact assessment.

Abrupt changes in rainfall regimes, where mean rainfall may rapidly change by up to 20%–25% from the long-term mean, may last from several decades to half a century (Vives and Jones, 2003). The most noted of these changes occurred in South-west Western Australia (SW WA) in the late 1960s – early 1970s but a series of similar changes occur in the Australian rainfall record dating back to the 19th century. Such changes are now thought to be a normal part of climate. Changes in daily rainfall intensity and number of raindays also appear to change in line with these regimes.

Reductions in late winter-early spring rainfall relative to summer and autumn rainfall over the southern half of Australia are simulated by most climate models. Changes in summer rainfall in northern Australia are less certain and could go either way. Changes in potential evaporation are also related to changes in rainfall. Increases are larger where rainfall decreases and are smaller where rainfall increases. This relationship between rainfall and evaporation occurs across most regions is shared by all models where it exists.

2.2 Water Supply Changes

This summary restricts itself to assessments using scenarios that are consistent with the regional climate projections for Australia in CSIRO (2001). Jones and Page (2001) explored the uncertainties in rainfall and potential evaporation for the Macquarie River in NSW, finding that the most likely range of outcomes comprised about half the possible range of outcomes, being restricted to 0 to -15% in 2030 and +0% to -35% in 2070. The likelihood of crossing critical thresholds related to irrigation supply and environmental flows was highly dependent on the phase of decadal rainfall variability, showing that the combination of climate change and long-term climate variability govern supply. Maheepala *et al.* (2001) simulated changes in flow of between -5% and -60% by 2030 for Ryan's Creek north-central Victoria, although the most likely range was between -10% and -35%. Jones *et al.* (2001) applied the seasonal changes found in the Macquarie catchment to flow patterns of the Upper Murray and found that the dependence of catchments on late winter-spring flows meant that water supply in southern Australia faced a greater risk of reduction than those further north.

2.3 Studies With Limited Integration

Several studies have included some integration of climate change with other important factors. In the Macquarie River catchment, Hassall *et al.* (1998) assessed the economic impacts of reduced water supply, finding that even under reductions in supply, cropping could break even or increase while grazing and environmental flows faced reductions. Beare and Heaney (2002) found that dryland salinity control under climate change reduced flows and salt loads. Salt concentrations in streamflows increased while reduced flows had a negative economic effect. Herron *et al*. (2002) investigated the combined impact of re-afforestation along with climate change in the upper Macquarie catchment concluding that the effect was additive, leading to reduced flows.

2.4 Hydrological Sensitivity To Climate Change

A meta-analysis of the impacts of climate change on runoff and streamflow is currently investigating the issue of the sensitivity of hydrological models to changes in rainfall and potential evaporation. This is being explored through the relationship:

$\partial F = \partial P \times A + \partial Ep \times B$ (1)

where ∂F is change in mean annual flow in percent, ∂P is change in mean annual rainfall in percent, ∂Ep is change in mean annual potential evaporation in percent and A and B are constants. Of three lumped parameter rainfall-runoff models used in recent studies, the Sacramento model used in NSW studies (Hassall *et al.*, 1998, Jones and Page, 2001) and the AWBM model used in Victoria (Maheepala *et al.*, 2001) produce a similar sensitivity. The SIMHYD model used by Chiew and McMahon (2002) is $^1/_2$ to $^1/_3$ as sensitive as these two models. Therefore, the models will produce similar results for very small changes in climate but rapidly diverge under larger changes. One reason may be that lumped parameter rainfall-runoff models are tuned to a stationary climate and the parameters in various models may behave differently when presented with a non-stationary climate. However, all models have a similar ratio between P and Ep change when the A and B factors are compared. The result of this is that models with a high sensitivity will produce large increases and decreases in runoff compared to those with low sensitivity.

Limited resources for research have not allowed the development of more physically-based hydrological models which are likely to be more reliable in estimating changing runoff under climate change. To date the science has been restricted to using the available models with minimal opportunity to validate the use of these models under climate change, even though they validate quite well under current climate. This means that given a change in climate, we are currently unable to constrain the hydrological uncertainties. This is critical if we are to move towards the integration of the different strategic issues mentioned in the introduction.

3. What Next?

A great deal of work has gone into managing the climate change uncertainties in Australian hydrological studies. Some changes, such as the late winter – spring decreases in rainfall in southern Australia, and the relationship between changes precipitation and potential evaporation appear to be robust. However, we cannot be confident in estimating changes in catchment water balance from a given change in climate. Improved accuracy is needed if we wish to build integrated models that take into account changing water supply and demand, changing land-use and the water reform process. Such models do not need to be precise, but need to be accurate for any conclusions to be defensible, especially in an emotionally-charged environment such as the long term allocation of water resources. Trade-offs between competing uses and spreading and hedging risk, need to be illustrated where in such a way that all parties have confidence in the science. Therefore, before building 'simple' integrated models that link climate, catchment and the economy, we need a better physical understanding of the relationship between climate change and catchment water balance. Currently there is a gap between the climate models and the simple hydrological models used by water management bodies. That gap in the science needs to be addressed.

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Climate Change and Biodiversity in Australia

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1. Introduction

Consistent with global trends, Australia's continental average temperature increased 0.7ºC from 1910-1999, with most of the increase recorded since 1950 (CSIRO 2001). 1998 was also Australia's warmest year on record, and the 1990s the warmest decade. Minimum temperatures have increased more than maximum temperatures, also consistent with global trends. While there has been no significant continental-average trend in Australian rainfall since 1910, the proportion of annual rainfall from extreme events has increased at most meteorological stations.

By 2030, annual average temperatures are projected to be 0.4-2.0ºC higher than present, with slightly less warming in some coastal areas of Tasmania, and the potential for greater warming in the north-west (CSIRO, 2001). By 2070, annual average temperatures may increase by 1.0-6.0ºC (CSIRO, 2001). Rainfall changes are also projected, although the level of uncertainty in these projections is greater than those for temperature. Large areas of the mainland may experience significant decreases in rainfall and increases in evaporation during the 21st century. Overall, the scenarios emphasise an increase in variability and unpredictability for Australia's climate, with increased incidence of extreme events such as fires, floods, droughts and tropical storms.

1.1 What Do These Changes Mean For Species?

Continuing climate change over the next century has the potential to dramatically affect biodiversity, although compared to the more obvious threats of habitat loss, over-harvesting, and pollution, that posed by climate change will be slower and more difficult to assess. Evidence is rapidly accumulating that the anomalous warming of the past century is already associated with changes in the earth's physical and biological systems, including accelerated glacier retreat, sea-level rise, thawing of permafrost, lengthening of growing seasons, and earlier flowering of trees, emergence of insects, and egg-laying in birds (Hughes, 2000; Parmesan and Yohe, 2003; Root *et al*. 2003).

Changes in temperature, water availability and CO_2 concentration will directly affect the physiology of most species. In animals, temperature can affect metabolic rate, fecundity, survivorship, sex ratio, length of oestrus, hormone release and parasitic infection rates. In plants, a 1ºC increase in temperature corresponds to an increase in respiration of approximately 10-30%. Increased CO_2 concentration enhances photosynthesis, water use efficiency (in C3 plants) and growth in many plant species, and alters the chemical composition of plant tissues, in turn affecting herbivores. Enhanced CO_2 may also affect nitrogen fixation, decomposition, and respiration rate in micro-organisms and fungi. Warmer conditions may advance flowering and fruiting in some plants, and hasten development time in many animals. Decoupling of relationships between some species, such as plants and pollinators, may also occur.

Many species in natural assemblages will also be affected by changed competitive relationships. C3 plants, for example, may be advantaged over C4 plants under increased CO_2 because their growth will be relatively more enhanced. Early-successional species with fast growth rates and good dispersal may also be strongly advantaged, and landscapes may become increasingly dominated by a few opportunistic, "weedy" species. Species with high reproductive rates and short generation times will also be advantaged, including many parasites and pathogens.

1.2 How Will Species Respond?

The response of individual species to climate change will depend on their life history, genetic and phenotypic variability, and current geographic range. Species that use the environment at a fine spatial scale may tolerate future climate change by simply exploiting a new microclimate. Some species may have enough phenotypic plasticity and/or genetic variability to withstand the predicted changes. Species that currently have a broad geographic range and therefore broad climatic tolerance may undergo some contractions or expansions at the edges of their range, but remain largely unaffected, at least over the next few decades. However broad-ranged species that consist of several ecotypes, each adapted to local climate, may be just as vulnerable to rapid climatic changes as those with more restricted ranges.

Species with short generation times and rapid population growth rates may undergo micro-evolutionary change to the changing environmental conditions *in situ*. However, the speed with which environmental change is predicted to occur, estimated to be 10-60 times faster than any change in the past, means that adequate response through adaptive evolution is unlikely for most species. Microorganisms, some invertebrates, and early successional plant species may be the exceptions.

Fossil records indicate that during past climatic changes, some species were able to track changing environments. In temperate regions such as mid-continental Australia, a 3ºC warming corresponds to ~300 km displacement of present-day temperature zones toward the poles or ~500 m increase in elevation. The general consensus is that most species will be unable to migrate fast enough to keep up with shifting climate zones in the future. Apart from dispersability, the main factor that will limit the ability of species to migrate with the moving climate will be the availability of suitable establishment sites. The fragmentation of natural landscapes presents formidable barriers to natural migration. Furthermore, elevational migration is simply not an option for most species, due to Australia's flat terrain, and Australia's southern boundary will restrict poleward migration.

Species unable to tolerate changed conditions within their current range, or that cannot migrate fast enough to keep up with moving climate zones, face extinction. The most vulnerable species will be those with long generation times, low mobility, highly specific host relationships, small or isolated ranges, and low genetic variation. Remnant populations within reserves may be particularly vulnerable.

1.3 Vulnerable Ecosystems

In terrestrial habitats, a warming of only 1ºC will threaten the survival of species currently near the upper limit of their temperature range, notably in marginal alpine regions and the southwest of Western Australia. Arid and semi-arid habitats, which together comprise 70% of the continent, will be particularly vulnerable to increased moisture stress and the intensification of ENSO events. Increased evaporation is likely to exacerbate salinization and alkinization in these areas. Wetland areas will be vulnerable to rising sea levels and changes in flow rates of river systems.

While polar regions will experience the greatest relative warming, species in these regions currently limited by cold temperatures will be able to expand, as has already been noted for vascular plants on the Antarctic Peninsula.

1.4 Effects On Specific Taxa

Australia lacks the long-term datasets and tradition of phenological monitoring that have allowed the detection of climate-change-related trends in the Northern Hemisphere. Long-term changes in Australian vegetation can be mostly attributed to alterations in fire regimes, clearing and grazing, but some trends, such as encroachment of rainforest into eucalypt woodlands, and establishment of trees in sub-alpine meadows probably have a climatic component. Shifts in species distributions toward the south (bats, birds), upward in elevation (alpine mammals) or along changing rainfall contours (birds, semi-arid reptiles), have recently been documented and offer circumstantial evidence that temperature and rainfall trends are already affecting geographic ranges.

Bioclimatic analyses programs such as BIOCLIM and CLIMEX have been the main tools used for predicting how particular terrestrial species in Australia will respond to future climate change. Most such analyses paint a grim picture, consistently predicting that species will suffer significant reductions in the extent of their bioclimatic ranges (reviewed in Hughes, 2003).

1.5 Into The Future

Evidence of accelerating biological changes associated with warming in the past few decades indicate that the following situations may become increasingly apparent in the relatively short term:

- Extensions of species' geographic range boundaries toward the poles or to higher elevations by progressive establishment of new local populations.
- Extinctions of local populations along range boundaries at lower latitudes or elevations.
- Increasing invasion by opportunistic, weedy and/or highly mobile species, especially into sites where local populations of existing species are declining.
- Progressive decoupling of species interactions (eg. plants and pollinators) due to mismatched phenology, especially where one partner is cued by daylength (that will not change), and the other by temperature.

Most of the trends apparent so far are those of individual species. The cascading of these individual responses to increasingly affect the composition and structure of whole communities seems inevitable. The most sobering thought is that even if only a fraction of the trends seen thus far are indeed a result of the enhanced greenhouse effect, they have occurred with warming levels only *one fifth or less* than those expected over the next century.

Accelerating climate change is shifting the conservation goalposts. Many species currently "protected" in reserves will need to migrate to cope with a changing climate and some will need active human intervention to do so. The majority of funds devoted to "greenhouse issues" in Australia currently flow to programs investigating the measurement and reduction of greenhouse gas emissions, whilst research on strategies to mitigate and adapt to the impacts of climate change has been relatively neglected. A re-evaluation of these priorities is urgently needed.

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Threats to Ecosystems and Biodiversity in the Highly Diverse, Mountainous Wet Tropics Bioregion

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1. Introduction

Globally, forest clearing is thought to be the greatest threat to biodiversity in the tropics (Sala *et al.*, 2000) and rates of clearing are certainly highest there, particularly in tropical Asia (Houghton, 1999). Climate change is sometimes discounted and has been less studied in tropical regions than in temperate, boreal or arctic ecosystems. However, recent studies indicate that climate change is a particularly significant threat to the long-term preservation of the biota in the Wet Tropics World Heritage Area and surrounding region.

Warming can have a particularly strong impact on mountainous regions like the Wet Tropics. The mountain tops and higher tablelands can be thought of as cool islands in a sea of warmer climates. These islands are separated from each other by the warmer valleys and form a scattered archipelago of habitat for organisms that are unable to survive and reproduce in warmer climates. An additional likely effect of warming is a significant lifting of the base of the cloud-bank on tropical mountains. There is significant trapping of cloud-water droplets within cloud forests — so-called 'cloud stripping' — which can considerably augment rainfall, especially in the dry season. Global climate simulations with a doubled CO2 scenario show that the relative humidity surface is shifted upwards on tropical mountains by hundreds of metres during the winter dry season. This is the period when these forests are most reliant on the moisture from cloud contact. Because of their great sensitivity to climate, cloud forests are likely to display climate change effects in the very near future.

Palaeoecological studies in the Wet Tropics have demonstrated the extensive biogeographic changes that have occurred as a result of past climate change (Hopkins *et al.*, 1993, 1996; Hilbert and Ostendorf, 2001). However, there has not been any climate-change monitoring in the Wet Tropics making it impossible to state whether warming in the 20th century had an impact on the Wet Tropics' flora or fauna or ecosystem processes. Monitoring in other parts of the world has identified a large number of ecological and biological changes due to recent climate change. For example, a lifting cloud-base associated with increased ocean temperatures has been implicated in the disappearance of 20 species of frogs in highland rainforests of Monteverde, Costa Rica.

2. The Wet Tropics Bioregion

The Wet Tropics bioregion of North East Queensland (Sattler & Williams, 1999) lies roughly between 15 and 19° S, long. 145-146° 30' E and contains Australia's best developed tropical rainforests. Complex topography (elevations ranging from sea level to 1615 m) produces steep gradients of temperature and rainfall. Mean annual precipitation varies from c. 600 mm to greater than 8000 mm with mean annual temperatures varying from above 25 °C to less than 17 °C at the highest elevations. Soils are diverse and highly variable in nutrient availability. High topography, edaphy, and climatic variability results in a diverse regional mosaic of structural forest types, from low woodlands to complex lowland rainforests.

The Wet Tropics is perhaps the most significant biodiversity hot spot in Australia and is considered to be one of the most significant regional ecosystems in the world (Webb 1984). Within a small area, less than 2000 km2, the region supports 741 species of vertebrates (one third of all Australian vertebrates); thousands of species of plants representing 65% of Australia's ferns, 37% of the conifers and 30% of both the orchids and vascular plants (WTMA, 2002). Invertebrates are especially rich and include an estimated 58% of Australia's butterflies. Perhaps most importantly, the Wet Tropics is the only home to many regional endemics including 43 genera of vascular plants and 85 vertebrate species (WTMA, 2002). Only New Caledonia has a greater concentration of endemic plant genera (Webb and Tracey, 1981). The rainforest vertebrate fauna includes 66 species endemic to the region (Williams *et al.*, 1996). The number of endemic insects is unknown but undoubtedly very large. Land snails are exceptionally diverse and mostly endemic, with 185 (85%) out of 222 known Australian species being endemic to the region (Stanisic *et al.*, 1994). This richness and uniqueness in such a small area is largely unrivalled in the developed world. Currently, 351 plant and 98 animal species are officially listed as rare or threatened in the Wet Tropics (WTMA, 2002). Most of the regional endemics are cool-adapted upland species. The regionally endemic rainforest vertebrates generally are distributed over areas with a very narrow range in annual mean temperatures. Consequently, the biodiversity and regionally endemic species that are keystone elements in the Wet Tropics World Heritage Area may be under severe threat over the next few decades. Extensive loss of habitat leading to significant loss of biodiversity is possible. Ecosystem processes and the provision of ecosystem services (such as clean and reliable water) also could be affected by climate change.

3. Projected Impacts In The Wet Tropics

Forest type, defined by structure and physiognomy, is an important habitat variable, although many trees and other organisms are not restricted to a single forest type. Therefore, the extent and distribution of forest environments in the future is an important indicator of potential changes in biodiversity. Recent work (Hilbert *et al.*, 2001a,b; Ostendorf *et al.*, 2001) found that the tropical forests of north Queensland are highly sensitive to climate change within the range expected early in the 21st century. Overall, the location and extent of rainforests are determined by rainfall and its seasonality, with some influence of soil fertility and water-holding capacity. But the type of rainforest and the kinds of organisms found there depend more on temperature.

In the Wet Tropics, one degree of warming can increase the potential area of rainforests as a whole, as long as rainfall does not decrease. However, large changes in the distribution of forest environments are likely with even minor climate change, and the relative abundance of some types could decrease significantly. Increased rainfall favours some rainforest types while decreased precipitation increases the area suitable for woodlands and forests dominated by sclerophyllous genera such as *Eucalyptus* and *Allocasuarina*. The area of lowland

Mesophyll Vine Forest environments increases with warming, while upland Complex Notophyll Vine Forest environments respond either positively or negatively to temperature, depending on precipitation. Highland rainforest environments (Simple Notophyll and Simple Microphyll Vine Fern Forests & Thickets), the habitat for many of the region's endemic vertebrates, decrease by 50% with only a 1°C warming (Figure 1). Using this model, we have mapped the current and potential future distributions (1°C warming and –10% rainfall) of upland and highland rainforest types. Environments suitable for these forest types decline greatly and become very fragmented in this climate-change scenario. Obviously, if the upper range of predicted warming occurs (5.8°C; IPCC, 2001), no appropriate environments would remain within the Wet Tropics. Whether and where appropriate climates might come to exist further to the south, say in the Border Ranges, is unknown. However, regional rainfall patterns and topographic constraints imply that such new habitat would be very far removed from the Wet Tropics.

There are two published studies of climate change impacts on specific vertebrates of the Wet Tropics (Hilbert *et al.*, 2001a; Hilbert *et al.*, 2003). Estimates of the potential habitat for the endangered, northern bettong in the future depend on whether they require tall open forests and whether rainfall increases or decreases. Assuming that tall open forests are not essential, habitat would decline if warming is accompanied by greater precipitation, and would increase if rainfall decreases. Our modelling of habitat for the golden bowerbird, a charismatic upland and highland endemic, predicts that the current habitat (1199 km2 in several distinct patches) will shrink by 63% with one degree of warming and a 10% decrease in rainfall. Three degrees of warming and a 10% reduction in rainfall reduces potential habitat to only 28 km^2 (see Figure 2).

Bioclimatic models of all regionally-endemic rainforest vertebrates (Williams *et al.*, 2003) predicts that warming result in a significant reduction, or complete loss, of the core environment for all these species and that extinction rates are likely to be very high because of the complete loss of core environments.

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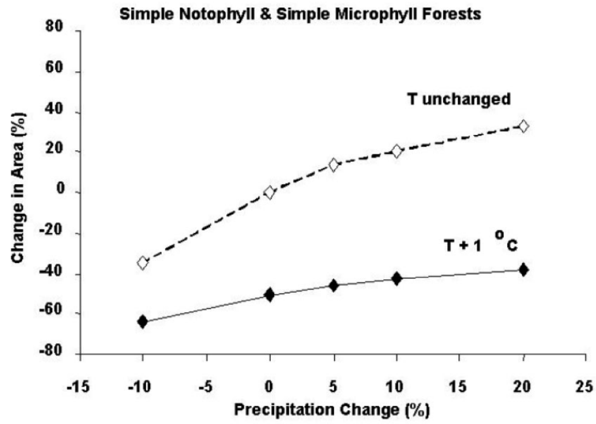

Figure 1. *Change in area of highland and upland forest environments with one degree of warming and five rainfall scenarios. Slightly decreasing rainfall and lower effective rainfall due to greater evapotranspiration is expected. (modified from Hilbert et al., 2001b)*

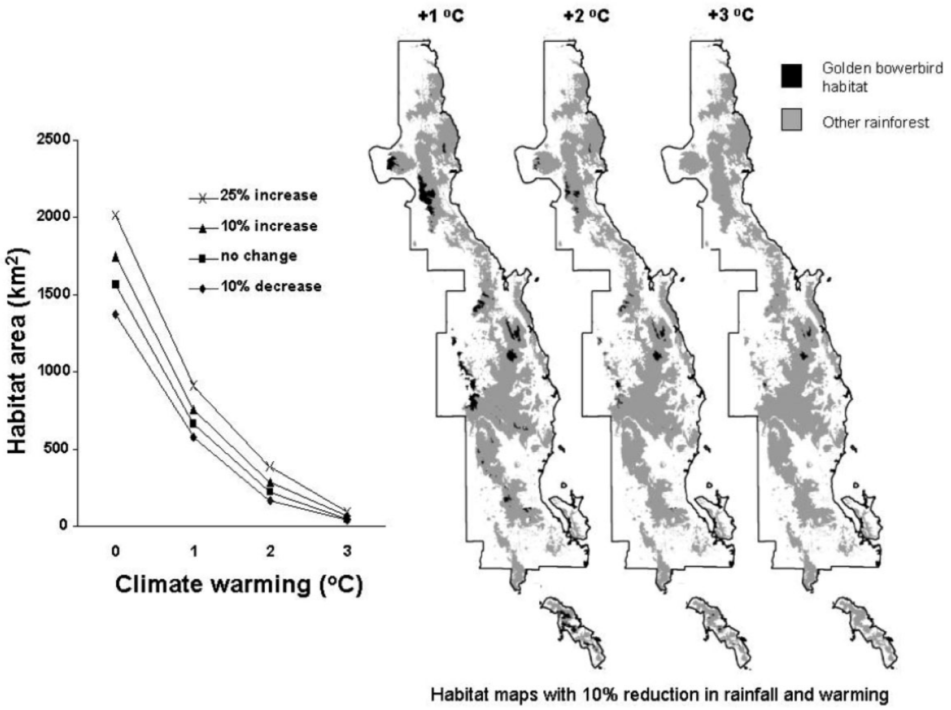

Figure 2. *Projected area of habitat for the golden bowerbird (Prionodura newtoniana) under various climate change scenarios. (modified from Hilbert et al., 2003)*

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Sensitivity of Fire Regimes to Climate Change

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1. Introduction

Recent major fires have added to speculation about the impact of climate change on bushfires in Australia. This paper presents methods for analysing the impact of climate change on Fire Danger and fire regimes and, presents results from analyses conducted over the last decade. Questions for policy makers, funding bodies and researches are posed at the end.

2. Climate Change And Fire Danger

The Forest Fire Danger Index (FFDI) is a number between 0 and 100 that is directly related to the chances of a fire starting, its rate of spread, intensity and difficulty of suppression according to various combinations of temperature, relative humidity, wind speed and both long and short term drought effects (McArthur, 1973). An FFDI of one indicates that, given a standardised fuel load, fires will not burn, or burn so slowly that suppression presents no difficulty while an FFDI of 100 indicates that fires will burn so fast and hot that control is virtually impossible.

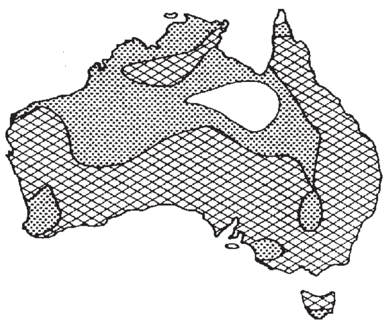

Figure 1. *Changes in $\sum$FFDI over Australia between the 1 × CO_2 and 2 × CO_2 climate simulations from the CSIRO9 Global Circulation Model. The blank areas are regions of decreased $\sum$FFDI, the spotted regions are increases in $\sum$FFDI of between 0 and 10 percent, and areas that are cross-filled have $\sum$FFDI increasing by more than 10 percent (Source Beer and Williams, 1995).*

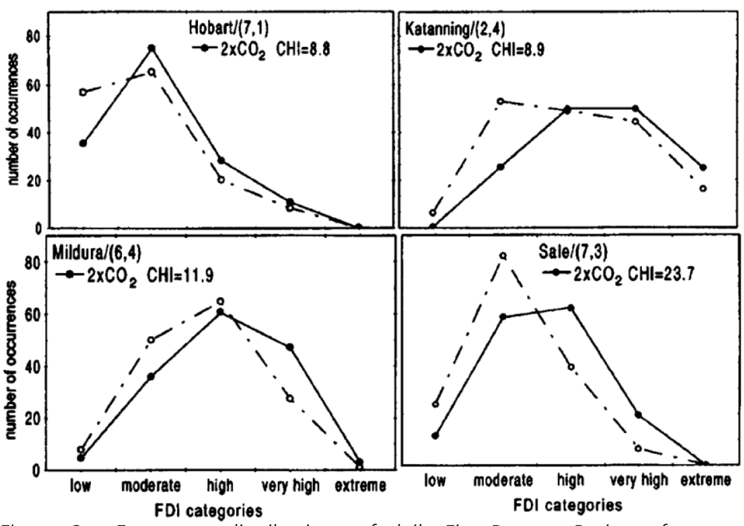

Figure 2. *Frequency distributions of daily Fire Danger Rating of control (dashed) and 2 × CO2 (solid line) simulations for southern Australia (Source: Williams et al., 2001).*

Beer and Williams (1995) modelled changes in annually summed FFDI ($\sum$FFDI) between 1 × CO_2 and 2 × CO_2 climate simulations from the CSIRO9 Global Circulation Model. They predicted that $\sum$FFDI would increase by more than 10 percent across most of southern, central and north-eastern Australia, while the remainder of northern Australia might experience a lesser increase or, in the central north, a decrease (Figure 1).

Williams et al. (2001), again using the CSIRO9 GCM, compared frequency distributions of Fire Danger Rating (FDR) (Low, Moderate, High, Very high and Extreme) during the fire season, for simulated 1 × CO_2 and 2 × CO_2 climates for southern and northern Australia. In southern Australia, distributions of FDR were significantly different (critical value of $\chi 2$ at 10% level is 12.02) between climates for Sale and marginally so for Mildura, but not for Hobart and Katanning (Figure 2). Nevertheless, the common trend across all sites was for a decrease in the number of low FDR days and a general, but not necessarily consistent, increase in the number of higher FDR (High, Very High and Extreme) days.

These analyses suggest that under a 2 × CO2 climate, some regions of Australia might expect more fires and greater difficulty associated with fire suppression. Given the relationship between increasing FFDI and increasing asset destruction associated with bushfires (see, for example, Figure 3), this will likely result in increased adverse economic impacts associated with bushfires.

3. Climate Change And Fire Regimes

The sequence of fires at a point in a landscape comprises the fire regime, which can be characterised by its components of between-fire interval, intensity, season and type (underground, e.g. peat, or surface) (Gill, 1975). There has been little quantitative analysis of the relationship between measures such as $\sum$FFDI and components of the fire regime and, therefore, limited insight into likely effects of a changing climate on fire regimes in Australia.

Cary (2002) analysed the sensitivity of simulated fire regimes in the ACT region to climate change scenarios. Daily weather in a landscape fire regime simulation model (FIRESCAPE – Cary and Banks, 1999) was adjusted according to the differences between 20 years of daily data simulated under 1 × CO2 and 2 × CO2 climates using a regional climate model (DARLAM) nested in the CSIRO9 GCM (Figure 4). Sensitivity to three climate change scenarios (small, moderate and large change in climate) were tested. A moderate change in climate (increase in daily maximum temperature of 2oC and other variables equivalently scaled to represent the same fraction of the full effect of climate change that 2oC does for maximum temperature) halved the simulated interval between fires across the landscape (Figures 5 and 6a). Further, a linear relationship between $\sum$FFDI for each climate change scenario and inter-fire interval, averaged across the landscape, was simulated (Figure 6b).

These results suggest that inter-fire interval is highly sensitive to this particular scenario of climate change which is representative of that expected for the ACT region. Change resulting in other combinations of weather parameters will have different results and are worth examining. Further, altered pattens of biomass accumulation and lightning incidence (Goldammer and Price, 1998) will also affect future fire regimes.

4. Research Questions

Researchers and policy makers might consider the following questions for areas relevant to them:

1. Is climate changing because of the enhanced greenhouse effect?
2. What is the nature of future climate?
3. What impact will this have on Fire Danger and subsequent economic outcomes?
4. What impact will climate change have on fire regimes and subsequent ecological outcomes?

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Figure 3. *Trend in the proportion of unplanned fires in Sydney which resulted in house destruction between 1954 and 1995, in relation to FFDI (Source: Bradstock and Gill, 2001).*

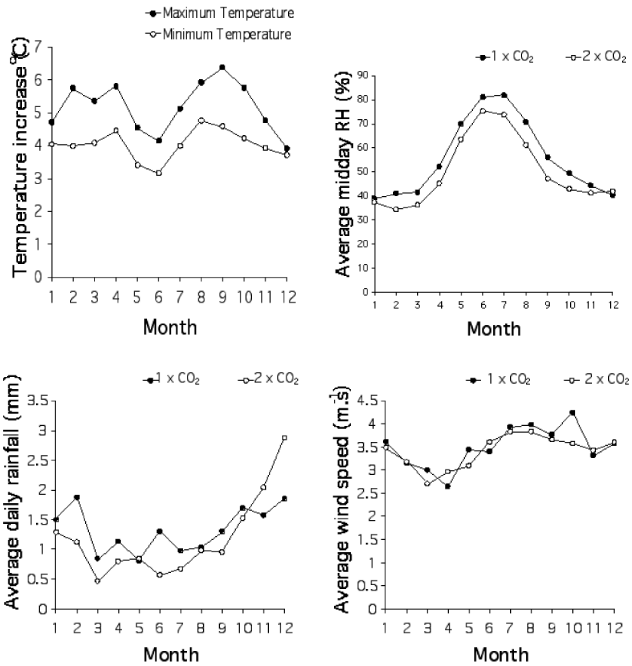

Figure 4. *Climatic averages for the ACT region from 1 × CO_2 and 2 × CO_2 equilibrium experiments using the CSIRO DARLAM regional climate model nested in the CSIRO9 GCM: (a) average daily maximum and minimum temperature increase; and daily averages (b) midday relative humidity (RH) (%); (c) average daily rainfall (mm); and (d) average daily wind speed (m.s-1). Climate sensitivity for the 2 × CO_2 simulation was 4.338 °C (Source: Cary, 2002).*

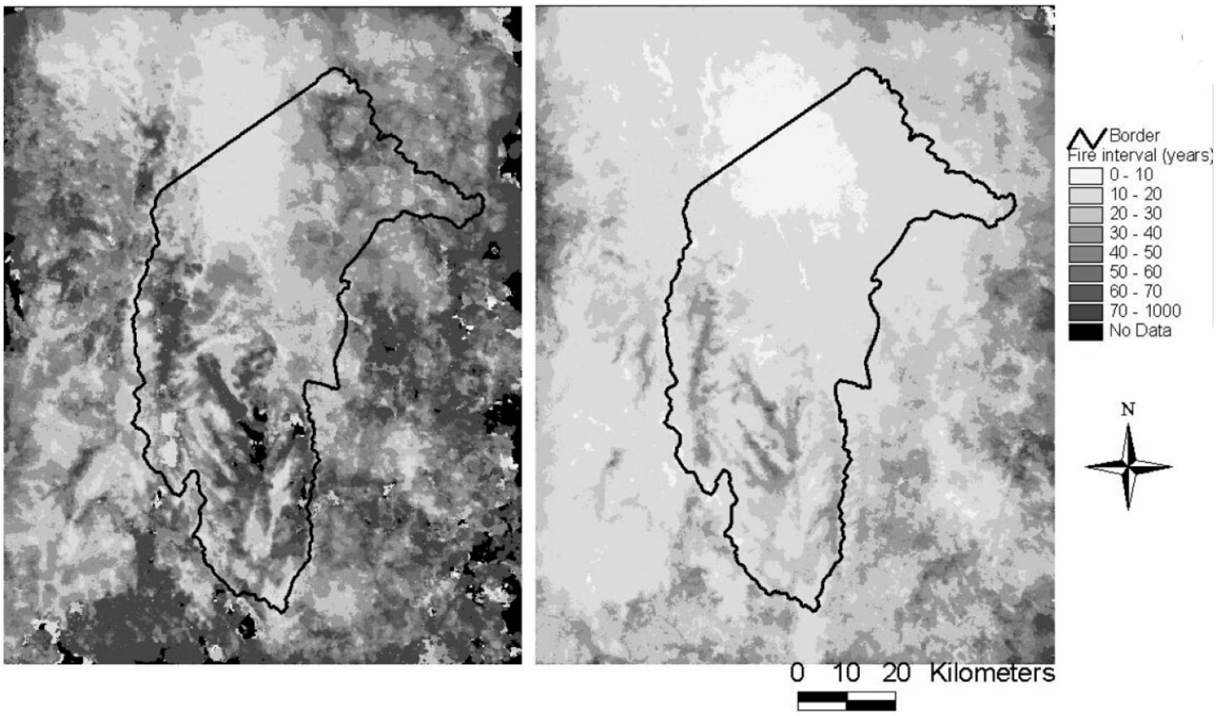

Figure 5. *Spatial patterns of average inter-fire interval (IFI) (years) predicted for the ACT region for present climate (left) and a moderate change in climate (right) (Modified from Cary, 2002).*

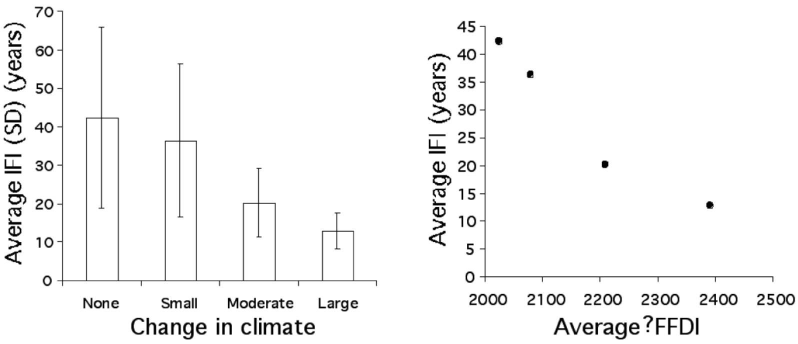

Figure 6. *(a) Landscape average inter-fire interval, and (b) relationship between average inter-fire interval and ∑FFDI, for the full range of climate change scenarios for the Australian Capital Territory region (Source: Cary 2002).*

Impact of Climate Change on Forest Fire Size and Severity

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1. Introduction

Fire is just as much part of our physical environment as are earth, air and water. These four elements of our environment interact with each other and interact with the biological environment. With so many interactions occurring, the result of "climate change" on such a complex system is difficult to predict.

For a fire to occur, there needs to be a source of ignition and fuel, once ignited, the behaviour of the fire depends on the nature of the fuel, the weather, the topography and the nature of the fire itself. Climate change can result in greater sources of ignition through increased lightning, longer periods of dry fuel, more biomass production to become fuel, hotter, drier and windier weather conditions to drive the fire spread. The converse is also possible. However, the impact of fire across the landscape is not a simple sliding scale related to the effects of fuel, weather and topography. Typically, various positive feedback mechanisms result in fires being numerous and small or few and large as shown in Table 1. In Victoria in 2002/3, fewer than 1% of the wildfires burnt more than 99% of the total area burnt and 85% of fires burnt less than 0.01% of the total area. This relationship between fires size and frequency is common in temperate Australia and shows how important extreme conditions are in their impact. It is important to understand what effects climate change will have on the balance between the two extremes of fire size and abundance.

2. Factors Affecting Fire Behaviour

2.1 Fire Weather

The McArthur (1973) forest fire danger rating system is used widely in Australia and is based on weather and climatic variables. It was developed using experimental fires in the field and so it does have fuel and topography incorporated in it as standard conditions. The standard conditions are for open eucalypt forest of about 18 m height with predominantly surface litter fuels of 12 t/ha and flat ground. Because these conditions are fixed, it is the weather variables that affect variations in the fire danger index. McArthur divided the fire danger index into suppression difficulty classes relevant to an open eucalypt forest on flat ground. These suppression difficulty classes are the basis of the rating system such that a fire danger rating of High indicates a high level of suppression difficulty and so on for the five ratings of Low, Moderate, High, Very High and Extreme.

The question is how to best incorporate changes in climate and weather into our understanding of how fire regimes may change. Several previous studies have been based on the effects of climate change on the Forest Fire Danger Index such as Beer *et al.* (1988), Beer and Williams (1995) and Williams et al. (2001). These authors have used a cumulative Forest Fire Danger Index (∑FFDI) as their measure. On the other hand, Goldammer and Price (1998), Cary and Banks (1999) and Cary (2002) have looked at changes in fire regimes across the landscape. The choice of how to best demonstrate the likely changes in the fire environment is probably more appropriate by looking at the regime, but not the regime at a point in the landscape, but across the landscape.

Gill (1981) defined a fire regime of a point in the landscape as comprising the Intensity, Season, Frequency and Type of fire. However, as our understanding of how fires affect the landscape develops, there is a need to define the regime not only in terms proposed by Gill (1981), but to also include scale and spatially dependent factors of fire size and patchiness.

In the landscape context, the importance of climate change in affecting the size class distribution of fires shown in Table 1, becomes even clearer. In the recent Alpine fire in Victoria, 558,000 ha was burnt in major runs on just three days out of the 60 days these fires remained uncontrolled. This represents half the total area burnt. In addition, the tree canopy was either burnt or completely scorched on 50% of the 1.1 million hectares burnt. This compares with smaller, lower intensity fires where little or no scorching may occur. Large fires also tend to be intense fires in forested areas.

So what are the weather factors important to the development of large, intense fires and how will climate change affect these factors? The diagrams from McArthur (1967) in Figure 1, show the importance of two weather factors: wind speed and relative humidity. In particular, the diagram showing the relationship between fuel moisture content and rate of spread rises very steeply once the fuel moisture content drops below 10%. This is a very critical range and is associated with relative

Table 1. *Number and size of fires on Victorian public land in 2002/3 fire season (Source: Dept. Sustainability and Environment, FireWeb database).*

Size Class (ha)	Number	Ave Size (ha)	Total Area (ha)	%Number	%Area
0-0.1	312	0.05	16	39	0.0
0.1-5	370	1.4	525	46	0.0
5-40	85	15	1,295	11	0.1
40-200	25	98	2,438	3	0.2
200-400	6	293	1,760	1	0.1
400-4000	7	189,715	1,328,008	1	99.5

humidities of less than 20% (very difficult to predict even on a daily basis). Similarly, the second diagram shows that the rate of spread of a fire increases proportionally at higher wind speeds than at lower wind speeds. Both wind speed and fuel moisture content is important in the efficiency of heat transfer and the spotting process.

Fine fuel moisture content is affected by the amount of exposure to wind, solar radiation, recent rainfall and atmospheric relative humidity. However, the McArthur fire danger rating system only incorporates relative humidity along with air temperature, and recent rainfall. What is even more troubling, is that these factors affecting fine fuel moisture content, vary rapidly over the course of the day and even a few hours of extreme weather is sufficient for fires to burn very large areas. Climate change models do not deal with this level of detail and yet it is of critical importance to wildfires.

Wind drives a fire by leaning flames towards unburnt fuel, preheating them before ignition. Wind also carries burning embers, which start new fires and increase the rate of spread of the fire (Tolhurst and Macaulay 2003). The wind speed profile in the atmosphere and the degree of atmospheric instability is of critical importance to the development of "Blowup" fires. Again, climate change models do not deal with this level of detail.

2.2 Fuel

The quantity, arrangement and composition of forest fuels are also important to fire behaviour and hence the scale and severity of fires. Projections of future forest productivity (CSIRO 2001a) indicate that forest biomass may increase by a factor of 25 to 50% in SW Western Australia and eastern and southern Australia by the year 2070. This increased productivity is attributed to increased CO_2 levels, 3°C warmer temperatures and greater summer and autumn rainfall.

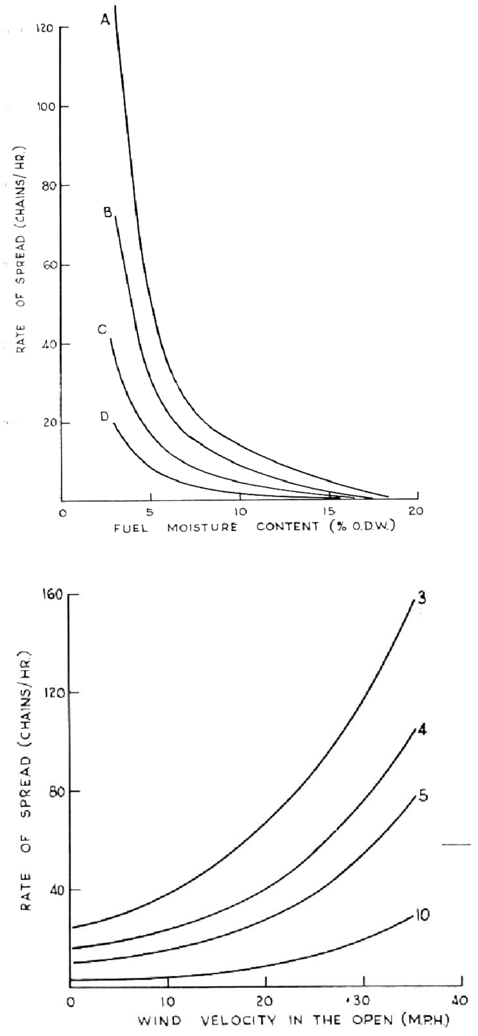

Figure 1. *Diagrams from McArthur (1967) showing the relationship between fine fuel moisture content and rate of spread (left) and wind velocity and rate of spread (right).*

Increased fuel does not necessarily mean greater numbers of fires. For fires to increase, there needs to be more fuels and more opportunities for fuel to dry out and become available for burning. Current climate projections suggest that summers and autumns will be relatively wetter in the temperate forest areas with higher average daily maximum, minimum and mean temperatures. The notable exception to this is SW Western Australia where it is likely to become considerably drier than at present (CSIRO 2001b)

2.3 Averages Versus Extremes

Previous studies of the likely consequence of climate change on bushfires have concentrated on the effects of increases in the average conditions. Because the average temperatures are likely to increase, the average Forest Fire Danger Indices will also increase. However, the pattern of fire size and severity is driven more by the association of prolonged drought with a few hours or days of severe fire weather. Given the trends in our climate and the projected climate change, it seems likely that southern Australia will see greater variability in its climate with hotter and drier droughts at one extreme (Hennessy 2003). This trend to hotter drier extremes, with the associated increase in forest biomass, is likely to lead to a growing trend of larger more intense fires across the landscape.

3. Conclusions

The output from climate change models does not currently provide a good basis for making predictions about the likely changes to the fire environment. It is not clear whether there will be an increase in ignition by lightning or whether increased forest productivity will result in more or less flammable fuels.

An increase in climate variability and extremes is likely to lead to fewer, larger, and more intense fires across the landscape. This will have a significant impact on water and biodiversity values. The trends in fire size and intensity currently seen, needs to be analyzed to differentiate between changes in land management practice and changes in climate.

It is unlikely that climate change models will ever be able to produce relative humidity, wind speed and atmospheric stability predictions at a time-scale and level of accuracy relevant to fire behaviour. Therefore, fire regime scenarios, based on the output of climate change models, for forested lands in southern and eastern Australia will always have a high level of uncertainty.

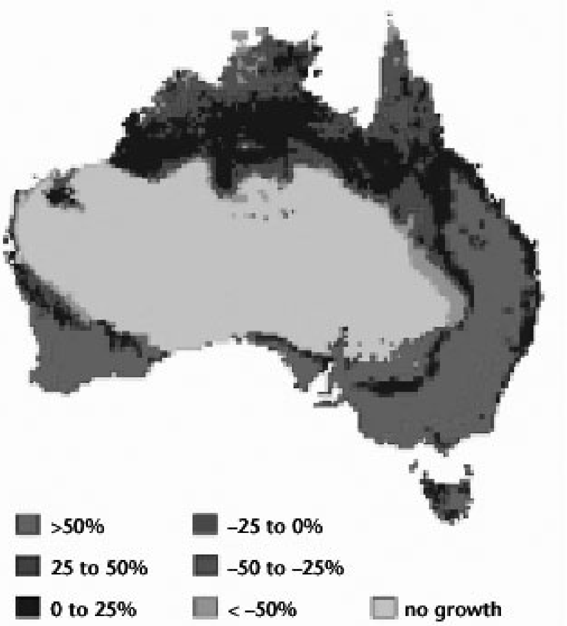

Figure 2. *Predicted growth response of forest with a doubling of CO_2 concentrations and a 3°C increase in temperature by 2070 (CSIRO 2001a)*

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Climate Change & Weeds: Can we predict future problems?

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1. Introduction

Weeds are a major cost to agriculture and a major threat to biodiversity conservation (anonymous 1999; Low, 1999). One estimate put their cost to Australian agriculture at around $3 300 000 000 per annum (Combellack, 1987), and this does not include environmental and recreational costs (McIntyre, 1990; Holm,1991; Plucknett *et al*., 1991; Low, 1999; Randall, 2001). The impact of weeds is growing as more and more exotic species are establishing in the wild or in agricultural regions every year, in spite of careful quarantine measures and novel assessment procedures before new plant introductions are made (Rozefelds, 1999; Cave *et al*., 1999; Jacobs, 2000; Everett *et al*., 2000; Morgan, 2000; Waterhouse, 2003). But weeds also have unique environmental and habitat niches and these will be affected by greenhouse-induced climate change, just as other plant and animal species will also be affected. Our ability to predict which weed species will benefit from climate change, which will be disadvantaged by climate change and which will newly establish as a result of climate change depends on our understanding of the ecological determinants (amplitude) of each species and the reliability of our predictions of imminent climate change.

2. Predictability Of Weediness And Weed Species Distributions

Some weed introductions pre-date European settlement (Cheal and Coman, 2003) and others date from perhaps the first arrival of Europeans in Australia (Kloot, 1983). With these taxa it is reasonable to expect that they have reached (close to) their ecological limits under current climate, particularly for those capable of long distance dispersal. It is thus reasonable to rely on collection records to generate likely distributions and environmental (habitat) envelopes. However, many species are of recent introduction (Lonsdale, 1994; Groves and Hosking, 1997; Waterhouse, 2003) and it is likely that they have not yet reached their full geographic extent and are still expanding into unoccupied territory. There have been some attempts to predict the eventual geographic distributions of such novelties, based on simple applications of *BIOCLIM* or a derivative, notably in (Thorp and Lynch, 2000) and (Blood, 2001). These have operated at a continental scale and have not been useful at a regional, local or finer scale and, even at the continental scale, have sometimes generated extraordinary "likely distributions" that are difficult to accept (eg. Thorp & Lynch, 2000 failure to predict that *Hymenachne amplexicaulis* is likely to be a weed, or to even occur, in the Northern Territory – when it is already a major weed of floodplains and wetlands throughout the Top End).

Recent refinement of a *BIOCLIM*-based tool enables accurate prediction of weed (and animal pest) species likely distributions under a variety of climate change scenarios.

3. Development Of Biological Climate Change Modelling At Ari

In the early 1990s, preliminary work on the effects of Greenhouse-induced climate change on a selection of native fauna from south-eastern Australia (Bennett, 1991; Brereton, *et al*., 1995) seemed ground-breaking. The authors utilized an early version (2.0) of *BIOCLIM* (a software package developed over more than a decade at CSIRO Division of Land and Water and, latterly, the Australian National University). The climate scenarios developed by Bennett *et al*. (1991) were fairly simple manipulations of rainfall and temperature applied on a regional scale (the pixel blocks were each 6 minutes latitude by 6 minutes longitude, approximately 100 km*2*). Species were selected for analysis on the basis of being thought prone to adverse responses to climate change (eg. restricted distributions, poor dispersers, specialized ecologically). Of the 42 species selected, 41 decreased in distribution and some went extinct in response to the hypothesized climatic change (a general warming and change in rainfall annual distribution and totals).

Since then, few other researchers have looked at the impacts on Australian biodiversity of greenhouse-induced climate change. With the notable exceptions of tropical rainforests (Hilbert, 2002) and (Kanowski, 2001), and coral reefs (Hoegh-Guldberg, 2002) and (Done, 2002), research into the impacts of climate change on biodiversity has been scanty to non-existent in the rest of the Australian landscape.

(Newell *et al.*, 2001; Griffioen et al., 2001) is a further development of the approach taken by Bennett et al. (1991). The initial intention of the latter study was to repeat the earlier fauna work, but using either vegetation communities or plant species as the test organisms. However, there had been significant advances in *BIOCLIM* (now a constituent part of *ANUCLIM 5.1*) since the earlier work and methodological improvements were thus incorporated into the process. A fine scale Digital Elevation Model (DEM) was incorporated into the analyses (permitting the calculation of a range of other variables that are responsive to elevation and aspect, such as solar radiation) and the spatial resolution was dramatically improved (from 6 minutes to 1 minute). As a result, the derived 'habitat envelope' for each species was based on 35 climatic variables and more obviously responsive to both climate change and elevation change.

Climate change modelling has also substantially advanced over the last ten years and the simple rainfall and temperature manipulations of Bennett *et al.*, (1991) were be replaced by Newell *et al.* (2001.) with the more sophisticated climate change scenarios that have been developed in the intervening decade or so. There is a large number of available climate change scenarios, each based on different probabilities of

Table 1. *Comparison of BIOLCLIM 2.0 with ANUCLIM 5.1*

Factor	BIOCLIM 2.0	ANUCLIM 5.1
Spatial resolution	6 minutes	1 minute
Digital Elevation Model	No	Yes, 1 minute resolution
No. of derived climate variables generated	16	35

change in 'greenhouse-forcing' parameters and different sensitivities of global and local climates to change in these parameters. CSIRO's *OZCLIM* software contains a diverse array of the better known and more solidly-based global climate models and from these a small subset (including IS92d, IS92f and SRES1a) was chosen to incorporate into the predictive modelling for effects on plant species and communities.

The later modelling was also based on regional climate models (which have proved better able to simulate regional weather patterns than global climate change models). Testing of the various regional climate models for ability to model current climate revealed a best fit for the DARLAM125 model, although the CSIROrx1 run was also used to ensure that output was not based solely on one regional climate model.

Earlier work, such as Bennett *et al*., (1991.), was based on simple (minimally-interactive) changes to existing climates (eg. uniform increases in temperature or rainfall within a region). Newell *et al*., (2001) greatly increased spatial resolution of plant occurrences and both the intricacy and local variability of current and future climate change scenarios (including a sophisticated regional climate model to ensure that local features substantially drove the biological output). The twelve species selected to be modelled were chosen for a variety of reasons. Some were thought to be peculiarly susceptible to climate change, others were faithful to communities that were thought to be threatened by climate change. Some were selected as they were assumed to be resistant to climate change (and were thus used to further 'test' the modelling process). Bennett *et al*., (1991) only modelled species thought to be susceptible to climate change and thus could not disentangle predicted decreases as a result of climate change from predicted decreases deriving from some intrinsic feature of the modelling process.

Contrary to expectations, all test species decreased in range, some to extinction, under the modelled climate changes. This may be reasonably expected for alpine species (such as *Celmisia sericophylla*), wet montane species (*Wittsteinia vacciniacea*), cool temperate rainforest species (*Lastreopsis hispida*) and southern, wet heathland species (*Sprengelia incarnata*), but was a surprising outcome for many others. *Poranthera microphylla* is recorded from the most southerly and most northerly parts of Australia – from Melville and Bathurst Islands to southern Tasmania, and in a wide variety of habitats, from the central deserts to high altitude, cool, moist forests. Yet the modelling by Newell *et al*., (2001) predicts it to retreat from the northern Victorian Plains. Other, similarly widespread and ecologically catholic species (such as *Dianella 'revoluta'*, *Enchylaena tomentosa, Oxalis perennans* and *Salsola kali*) are also predicted to retreat and greatly contract in range.

Whilst it should be borne in mind that such modelling may define a species 'climatic envelope' it does not include other determinants of a species' local occurrence. These other critical determinants include soil requirements, fire history, grazing or browsing pressure, and all should be incorporated to transform the climatic envelope into a suitable habitat envelope. Nevertheless, even with such considerations in mind it is difficult to accept that a species which occurs on deep sands, laterites and loams, from Bathurst Island north of Darwin to the Huon Valley in Tasmania, will retreat from the northern Victorian Plains under anticipated climate change.

4. Further Developments

4.1 Over-Specification Of A Climatic Envelope

The 35 basic, composite and derived variables that *ANUCLIM* uses specify a very tight climatic envelope that, edaphic and other considerations aside, usually accurately describes each species' current distribution. Nevertheless, the logic behind *ANUCLIM* is not very 'forgiving' and as global and regional climates change (into the future) the likelihood that a peculiar combination of climatic variables will greatly decrease or disappear is high, and this likelihood increases the further into the future the model is run. The climatic envelopes for all species will eventually disappear if one runs the model long enough. However, not all climatic variables contribute evenly as critical determinants of a species' climatic envelope. Some have very little impact and could be readily dropped from consideration with little decrease in the accuracy of prediction of the species' current distribution. Yet it may be precisely these uninformative variables that change under future climate change and hence drive the disappearance of a specific climate envelope. The latest incarnations of the model have used frequency curves to select the most informative bioclimatic variables, thus focusing on a minimal data set of critical climatic determinants.

Table 2 *Plant species selected for modelling by Newell et al. (2001)*

Plant Species	Reason for Selection	Expected Response of Sp' Range	Scenario response
Banksia ornata Desert Banksia	Largely restricted to Mediterranean-climate heathlands	Contract & move to the south-west	Contract
Wittsteinia vacciniacea Baw Baw Berry	Restricted to cold/wet subalpine communities	Contract	Contract
Eucalyptus blakelyi Hill Red Gum	Widespread on the inland slopes	Expand, particularly to the south-west	Contract
Celmisia sericophylla Silky Snow Daisy	Restricted to alpine communities	Contract	Contract
Dianella revoluta Black-anther Flax-lily	Common and widespread	No change	Slight Contraction
Enchylaena tomentosa Ruby Saltbush	Widespread in arid communities	Expand coastwards	Contract
Lastreopsis hispida Bristly Shield-fern	Restricted to cool temperate rainforests	Contract	Contract
Maireana cheelii Chariot Wheels	Restricted to the Riverina plains	Expand, particularly to the west	Contract
Oxalis perennans Grass Wood-sorrel	Common and widespread	No change	Contract
Poranthera microphylla Small Poranthera	Common and widespread	No change or expand	Contract
Salsola kali Roly Poly	Widespread inland adventive	Expand	Contract
Sprengelia incarnata Pink Swamp Heath	Common in southern swampy heathlands	Contract	Contract

4.2 Full Species' Ranges

The preliminary study by Newell *et al.* (2001) established each species' basic climatic envelope solely from Victorian occurrences of that species. This is unlikely to be a source of inaccuracy for species with very restricted ranges that incorporate only a small part of Victoria, or may even be endemic to the state (eg. the localized endemic *Celmisia sericophylla* or the restricted mainland distribution of *Lastreopsis hispida*, otherwise known from Tasmania and New Zealand). Nevertheless, the available budget greatly limited accessing precise locality data for each species beyond Victoria. The climatic envelope that was specified for each species was the Victorian climatic envelope. Not surprisingly, current Victorian climates change in location and decrease in extent as climate change predictions extend into the future. By accessing, extra-Victorian confirmed occurrences via the Australia-wide, web-based Virtual Herbarium (sponsored by *Environment Australia* and accessible via the various state herbariums), recent modelling has produced far more reliable predictions of species' future occurrences.

4.3 Temporal Scales

Most climatic modelling enables species' climatic envelopes to move across the landscape rapidly. Sometimes envelopes disappear from the landscape and it is easy to understand that such species are in danger of extinction. Sometimes climatic envelopes rapidly relocate. The ability of species to 'follow' the rapid movement of their determinative climatic envelopes is dependent on a number of intrinsic characteristics of each species, such as generation times, germination requirements and dispersal capabilities. Such movement is further hampered by the imposition of anthropogenic gaps in habitat continuity – the typical fragmented habitat of much of lowland temperate Australia. This aspect of climate change is rarely considered. Hughes, (2000) discussed criteria that might be used to determine whether there was a biotic response to climate change and Reid, (2002) considered extensive flat regions (such as the broad open plains of inland Australia) as a "potential arena for large shifts in geographic range over tens to hundreds of kilometres for those organisms or ecological indices capable of rapid adjustment". Plant species, particularly long-lived community dominants, are not as rapidly dispersible as most birds or short-lived ruderals. Even if a suitable climatic envelope exists in a landscape subject to rapid climate change, many species may not be able to readily cross gaps of unsuitable habitat nor establish in a novel locality if their propagules arrive there. *ANUCLIM* outlines more or less suitable climatic envelopes for species or communities. It does not specify species' occurrences nor ranges and ignores species' abilities to adapt to novel local climates (although such adaptation is problematic when climates change as rapidly as is likely in the foreseeable future).

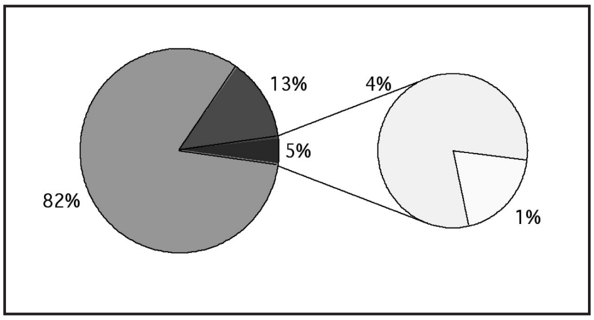

Figure 1. *463 exotic grasses & legumes introduced to northern Australia between 1947 & 1985 60 spp (13%) became weeds 21 spp (5%) were useful & of these 17 spp (4%) were also weeds, only 4 spp (<1%) were useful without becoming weeds (from Lonsdale 1994)*

4.4 Use Of Modelling Tools In Managing Weeds And Animal Pests

There are some useful guidelines as to which species are likely to become weeds and which are unlikely weeds, and reasonably useful predictions can be made (Weiss, 1984; Plucknett *et al*., 1991; Daehler, 1998; Thorp and Lynch, 2000). Using such tools, entry of new species to Australia has come under increasingly effective control – quarantine works (Cheal and Coman, 2003). In the past, one of the most damaging and important sources of weeds and animal pests, both agricultural and environmental, was intentional import in the belief that these would assist agricultural productivity. Sometimes, this was true (as with *Trifolium spp* in southern Australia), but often it not only failed to add to agricultural productivity but detracted from it by adding extra costs, in weed control (Aston, 1981; McIntyre, 1990; Lonsdale, 1994; Bowman, 1999; Faithfull, 2002). The environmental costs of escaped agricultural plants are huge, altering dynamics across landscapes, and are perhaps the greatest current threat to the integrity of native habitats, communities and landscapes (Bowman, 1999; Fogarty and Facelli, 1999; Low, 1999; Lunt and Morgan ,1999; Smith, 2000; Moyle-Croft *et al*., 2003; Waterhouse, 2003). However, assuming the recently-developed stringent quarantine controls are effectively implemented, additions to Australia's weed flora from plants recently-introduced for agricultural purposes should reduce.

However, weeds have also been added to the local landscape from escapes from domestic, amenity horticulture and, every year, a burgeoning list of novel species is available thru the nursery trade. This is now the principal source of weeds in Australia and many more species can be expected to establish in the near future (Groves and Hosking, 1997; Low, 1999; Cave *et al*., 1999; McDougall and Appleby, 2000; Morgan, 2000; Randall, 2001). Governments and land management agencies have not effectively addressed this major threat, although palliative programs are in place or under development. The problem of novel weeds, derived from amenity horticulture, will worsen and the associated costs greatly increase, perhaps hyperbolically.

5. A Role For Modelling Weeds And Climate Change

The development of an effective, and relatively simple, model for predicting species' distributions under a variety of likely climate change scenarios (Newell, Griffioen *et al.*, 2001), enables prediction of which species will increase their ranges, and to which areas, as greenhouse-induced climate change has increasing effect. The only base data required are accurate site records with associated accurate climatic data. These are already available for species currently in Australia and data from overseas can be interpolated into the model.

The terms 'accuracy' and 'reliability' are not to be used glibly. In recent species modelling, based solely on cureted herbarium records, accessible via the Virtual Herbarium, as many as one in 20 or 30 of the records were found to have incorrect locality data, thus greatly affecting the potential climatic envelopes for the subject species. In addition, records from horticultural plants were often not separately identified from records from within the plants' indigenous ranges (the natural range of *Melaleuca wilsonii* does not extend to Hobart in Tasmania). All modelled data must be carefully checked for such anomalies and dubious records excluded.

With these provisos, current species' (climatic) ranges and predicted (climatic) ranges under a variety of climate change scenarios can be accurately determined. Former, simplistic assumptions and predictions about changing species distributions with greenhouse-induced climate change can now be greatly improved and, in some cases, overturned. For example, whilst there is little doubt that species restricted to mountain tops will 'fall off' the tops of the mountains (Griffioen *et al*., 2001; Hilbert, 2002), it's also clear that plains species will not 'climb the slopes' (Newell *et al.*, 2001).

Whether the predictive, modelling-based work will be done (as distinct from 'can be done'), depends on the priority given such work. The ARI model has been developed on an inadequate budget, exploiting the personal commitments of the researchers and funding has now ceased.

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Insect Pests, Diseases and Weeds under Climate Change

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1. Introduction

Pests, (including insects, plant, animal and human diseases and weeds) are important to Australia because they cost in the vicinity of $6 billion per annum in lost production and costs of control. Weeds represent half of that cost and insects and diseases represent the other half. The cost of human vector-borne diseases in Australia is unknown but must be significant with the lost time from Ross River virus alone. Pest species prosper under conditions where ecosystems are disturbed, providing temporary gaps for them to invade and become established. Such conditions occur after extreme climatic events like severe cyclones and droughts. Climate scientists are warning us to expect an increase in the frequency and intensity of such events with global warming, so climate change is also an important additional issue for Australian environmental managers to address.

1.1 Pest Risk Assessments

Climate change is now considered by the majority of climate scientists to be happening already. It is occurring in a context of many other changes around the world, such as increasing concentrations of carbon dioxide in the atmosphere, intensification of agriculture, expanding irrigation, land clearing, accelerating globalisation bringing trade with new partners, and increasing travel. This means that Australian local and regional communities need to plan to manage the changes in composition and behaviour of pest species, and their potential spread in a dynamic rather than static environment to prevent or reduce pest impacts on agriculture and natural ecosystems.

1.2 Pest Responses To Climate

Climate plays a critical role in determining the growth and survival of both plants and animals. While temperatures are expected to rise steadily and accelerate the growth of many tropical and sub-tropical species, they will inhibit the growth of some temperate species in warmer parts of their ranges. There is much more uncertainty about the seasonal pattern, total amount and frequency of rainfall events. Rainfall determines the abundance of pests, and where they will grow. This raises major difficulties when planning how to respond to a future environment in which there is no clear direction of change. We are now faced with a conundrum in that we know that the climate will change but we do not know whether it will get drier and reduce most pest problems or wetter and make them worse.

1.3 Adaptation Of Pest Management To Climate Change

Society is faced with having to adapt to climate change in a degrading environment with continuing development of pesticide and drug resistant strains of pests and diseases. At the same time new horizons are being opened up by genetics, biotechnology and information technology. So, while there may be opportunities to develop new tools to manage pests there are also increasing risks that the pests will catch up and exhaust the supply of new technology. The question is how do managers best adapt to such a changing environment? The answer is to become more *knowledge-based* rather than product-based in their decision-making.

Adaptation of pest management to climate change needs a number of steps to be taken now. The first is to *benchmark* the present situation to provide a baseline against which to measure future change. The next step is to develop *indicators* of change and complementary monitoring systems so that the changes can be tracked over time. Thirdly, a *framework* is needed to guide and design holistic adaptation measures and so avoid *ad hoc* interventions that can be both costly and wasteful. This requires that we understand the systems that we manage better and the tools to do that rest with ecologists. Because the direction of climate change is so uncertain at the local level, we need to plan for greater climate variability rather than for specific climate scenarios. The use of computer models gives us a tool to explore the likely responses of pests to a range of climate changes but there is a severe shortage of the necessary data with which to build the models. This has resulted from too much emphasis being put into looking for quick fixes and magic bullets to make the problems go away. Finally, we need tools with which to *accelerate change* by winning community support for the measures that need to be put in place.

Sustainable management of pests must be based on a combination of preventative measures and biological controls. As with every human endeavour, an ounce of prevention is worth a pound of cure. Stopping the spread of existing pests in Australia is the most effective way of avoiding the expansion of their geographical ranges. While this is only possible for sessile species, the potential for spread of a number of serious pests like Mesquite, cattle tick and many diseases of tropical crops like bananas and sugarcane is frightening. As has been shown so often in the past, many pests can take over a landscape and make it their own, just as prickly pear did early last century. Vast amounts of money are then needed to reverse the problems, and often the cost of removing tropical weeds for example can exceed the value of the land that we are trying to protect. In some cases there is little prospect of finding a biological control agent that will not also damage local flora, so this ideal option is excluded from consideration. Much more expensive systems based on prevention are the next best option. There are many examples of miraculous destruction of impenetrable weeds like prickly pear, *Salvinia*, water hyacinth and insects like whiteflies that formed such large swarms in the USA that they were visible from space! No amount of money and technology could have achieved such results without using the natural enemies that keep those species in check in their native environments.

2. Conclusions

The issue of climate change is forcing scientists to re-evaluate the way in which they look at agricultural and environmental problems. They are returning to their research benches to address the question of *'why do species behave as they do?'* rather than *'what do they do?'* in order to design more sustainable ways of managing pest species when they are placed into new environments by climate change. This has led to a resurrection of the need for quantitative ecologists but there is a bottleneck forming in Australia because we can no longer find suitable recruits to turn into the next generation of scientists.

Australian environmental managers need to strengthen the science underpinning their decision-making if we are to develop flexible, affordable and sustainable solutions to cope with insect pests, weeds and diseases of plants, animals and humans in a changing environment. We then need to address the issues of how measure change and how to accelerate the community's responses to those changes. If we are having problems coping with pest problems in today's climate, what hope do we have of managing them in a changing climate without a sound knowledge-base on which to make decisions?

Climate Change and the Great Barrier Reef: Biodiversity Conservation and Ecological Resilience

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1. Introduction

Pressures of climate change are compounding matters that have been issues for Great Barrier Reef (GBR) industry, conservation and management for decades: sustainable fishing and other harvesting; safe operation of ports and shipping; appealing reefs for tourism operations; crown-of-thorns starfish; runoff of pollutants (freshwater, silts, sewage, herbicides, pesticides and nutrients). Recent summer heat waves leading to coral bleaching and death are a worrying glimpse of a future with changing global climate (Berkelmans *et al*., 2003; Marshall and Baird, 2002; Hoegh-Guldberg, 1999). So are prospects of increased intensity and breadth of extreme cyclones and flood plumes (Pittock, 1999); increased sea level that will change flow, emersion and sediment transport regimes of intertidal and shallow habitats of reefs, headlands, estuaries and beaches (Done, 1999).

2. Rate Of Warming Affects Outlook For Coral Reefs

Warming of seas will lead to more frequent coral bleaching (Brown, 1997), and corals at many reefs may periodically die *en masse* (Hoegh-Guldberg, 1999). The nature, extent and duration of the setbacks will depend on local rates of warming and capacity of the reef system to adapt to the changing conditions (Done, 1999; Coles and Brown, 2003). A recent study focusing on reefs of the GBR (Done *et al*., 2003) suggests that the closer global warming is constrained to an optimistic 1°C by the year 2050, the better the prospects for its reefs. However whether it will be closer to 1°C or an equally plausible 2°C is already largely in train (Johns *et al*., 2003): actions to mitigate global greenhouse gas emissions commencing now will have little effect on the rate of global warming until the second half of this century, when their benefits will be very important. The outlooks for long-term trends in indicators of reef quality are relatively optimistic only with lower rates of warming, and only if it can be assumed that the reef communities have some capacity to adapt. The 'adapted' reef may achieve local ecological resilience by gaining increases in physiologically more resistant species, through a mixture of differential mortality and recolonisation of the damaged area (Loya *et al*., 2001). A resilient reef is one that can bounce back following disturbance, the way reefs have done in the past (Nystrom *et al*., 2000).

3. Biodiversity Conservation, Resilience, And The Rap

The outlooks vindicate the priority that is being given to conservation strategies that aim to improve ecological resilience in the system (Done, 1994; Hughes *et al*., 2003), and that are operationally focused on biodiversity conservation, sustainable fishing and water quality (www.gbrmpa.gov.au). System resilience at many scales will be a key measure of effectiveness of the management arrangements for the GBR, and strong resilience in the reef-building coral populations is of particular importance. It is needed to counteract algal proliferation (McCook, 1999) and to bring about rapid restoration of degraded reefs to the coral filled reefscapes that are prime, complex, three-dimensional habitats for much other reef biodiversity (Done *et al*., 1996). The criteria for successful biodiversity conservation and sustainable fisheries differ. For fisheries, they are primarily the maintenance of sustainable catch rates of favoured species; for biodiversity conservation, they are long-term maintenance of the diversity and viability of all species and habitats. Functional roles of species other than as food for humans are thus recognized, as is the value of biological diversity *per se*.

The representative areas program (RAP) of the Great Barrier Reef Marine Park Authority (Day *et al*., 2002) is a key plank of management for building resilience through the conservation of biodiversity, along with measures to improve water quality and reduce fishing pressures (i.e. to increase fish diversity and abundance in their habitats). Representative areas are protected by the exclusion of fishing, but none is thereby made immune to a chance exposure to unmanageable impacts such cyclone waves, flood plumes, or heat stress. A network of protected areas that includes replication and spatial spreading of similar habitats within bioregions provides 'insurance' for biodiversity conservation. It reduces the chance that an 'act of god' will decimate the biodiversity conservation effectiveness of all protected examples of a particular biodiversity ensemble. It also reduces the likelihood that failure of larval replenishment will limit recovery of damaged areas. Any configuration that includes substantial protected areas across and along the Great Barrier Reef should be very effective in strengthening larval source areas, reference areas and reservoirs of biodiversity and species abundance. While it may be desirable to factor 'risk of bleaching' into design of the configuration (West and Salm, 2003), our understanding of patterns of risk and how it might be applied are not yet well developed. Corals at a coastal study reef bleaches at higher temperatures, apparently because of their acclimatization to somewhat higher variability in summertime temperatures compared to two offshore reefs. Coastal corals may endure more days of a certain North Queensland had a record hot summer of December 2001 to March 2002 that brought with it widespread reports of coral bleaching on the Great Barrier Reef. AIMS characterized the spatial pattern of summer SSTs for Great Barrier Reef, and made assessments of bleaching impacts. We are using Bayesian Belief tools to explore bleaching risk, with remotely sensed sea surface temperature data, and categorical data for habitats, classes of biodiversity, and a variety of environmental proxies for the propensity of a place be cooled by mixing processes (Wooldridge and Done, 2003).

The overall RAP strategy for biodiversity conservation includes exclusion of fishing from at least 25% of the GBRWHA. At coral reefs, closure to fishing increases the abundance, mean size and life expectancy of previously targeted fish and bycatch (Mapstone *et al*., 2003), and enhances the protected areas as sources of replenishment for those species outside the area (Russ, 2002). In addition, the closures will lead to changes in the both the total fish community and the food species on which they feed, with further flow-on effects through food webs and other interactions such as competition (McClanahan et al., 2002).

4. Fish, Food-webs And Corals

There is growing evidence from around the world (McClanahan *et al*., 2002) that reefs with an intact fish community are likely to be more resilient than fished reefs – more likely to bounce back to a reef-building coral state, and not become stuck in an algal dominated or eroding state (Hughes, 1994). To settling coral larvae, reefs present a patchy substratum of inhospitable and hospitable surfaces, in varying proportions, and in patch sizes of centimetres to metres across. The relative proportions of these different types of surfaces is in part a function of the biomass and feeding rates of herbivores, and in part, a function of how that biomass is apportioned between 'farmers' (that maintain high algal biomass) and 'scrapers' (that keep algal biomass low) (Ceccarelli *et al*., 2003). This balance may be affected by the abundance and composition of predatory fishes in the area, which in their turn may be affected by the rate of fishing. Total protection that allows predator populations and biomass to return to more 'pristine' levels may thus cascade through to the state of the substratum, and hence the recovery of rich, complex reef architecture.

5. Conclusion

Unmanageable impacts such as heat stress, floods, cyclones, disease, and coral predators will continue to happen in Great Barrier Reef waters, possibly at increasing frequencies as climate changes. The most tractable and appropriate conservation strategies for the first half of the century are those that seek to build ecological resilience. On the GBR, resilience building in the broader coral reef ecosystem is being addressed through major initiatives in expansion of no take reserves in the Representative Areas Program, fisheries management and water-quality management. However it will be an uphill battle if the worst scenarios of global warming transpire. Desirable ecological outcomes for reefs in the second half of the century will require sustained mitigation of greenhouse gas emissions that commence as early as possible in the first half of the century.

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Potential Impacts of Climate Change and Sea-level Rise on Australia's Mangroves

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1. Introduction

Mangrove forests occur on low energy, sedimentary shorelines of the lower latitudes, between mean tide and high tide elevations. Australia has the third largest mangrove area in the world, covering an area of 8 195 km^2, of which 42% occur in Queensland, 36% in the Northern Territory, and 19% in Western Australia (Zann, 1995). Mangroves in Australia are valued primarily for their importance as fish and crab habitats, and outwelling of mangrove detritus has been shown to support foodchains including commercial species offshore. Mangroves also stabilize and trap sediments, lowering suspended sediment levels in coastal waters to benefit shallow water communities such as coral reefs. Furthermore, mangrove shorelines provide protection for inland areas from storm surges and flooding. The mangrove biodiversity in Australia is one of the richest in the world, though the size of trees and diversity of species declines away from the northern tropics.

1.1. Climate Change Impacts

Rise in temperature and the direct effects of increased CO_2 levels are likely to increase mangrove productivity, change phenological patterns (such as the timing of flowering and fruiting), and expand the ranges of mangrove species into higher latitudes (Ellison, 2000). Mangroves in NSW and Victoria in particular are likely to become taller and more productive, and support species that are currently limited to latitudes further north. Mangrove expansion will occur into what is presently salt marsh habitat in these States (Saintilan, 1997).

1.2. Sea-Level Control Of Mangroves

Mangrove species display a distinct zonation from their seaward margin to the high water mark, based on controls including the frequency of inundation and salinity exposure (Duke *et al*., 1998). This zonation is largely controlled by the elevation of the substrate surface relative to mean sea level.

The control of sea-level elevation on the seaward margin of mangroves has been demonstrated by detailed survey of marine-dominated low island mangrove systems on the Northern Great Barrier Reef. The mean elevation of the mangrove/ lagoon margins at Low Isles, Three Isles and Pipon was found to be 0.36 m below MSL, with insignificant differences in means between islands. Mangroves are therefore shown to be closely controlled by sea-level elevation at their seaward margin, which demonstrates the importance of stable sea-level in controlling mangrove distributions.

1.3. Sea-level Rise Projections

Sea-levels have been fairly stable on the Australian shoreline for the last few thousand years, and the National Tidal Facility has demonstrated that the average rate of sea-level rise over the last few decades has been 0.3 mm a^{-1} (Mitchell *et al*., 2000). The latest projections from the Intergovernmental Panel on Climate Change are for a global rise in sea level of between 9 and 88 cm by 2100 (IPCC, 2001), which equates to a rate of 0.9-8.8 mm a^{-1}. The greatest impact of sea-level rise is on coastlines of low relief, which are occupied in the lower latitudes by mangroves.

1.4. Mangrove Retreat With Rising Sea-level

Impacts of sea-level rise on mangroves have been investigated on Bermuda, where measured rates of sea-level rise over the last century have been within the projections for Australia for this century. The largest mangrove area at Hungry Bay had existed for the last 2000 years, and during the last century lost 26% of its area due to retreat of its seaward edge. Survey showed that swamp elevations were lower in the tidal spectrum than normal, and mangroves at the seaward margin were under inundation stress (Ellison, 1993; Ellison, 1997).

Accelerated coastal erosion is known to be associated with rising sea-level (Stewart, *et al*., 1990), and observations in Bermuda indicated that mangrove sediments are as susceptible as beach sediments. Increased efficiency of wave erosion with a higher sea-level causes removal of sediment from the upper part of the tidal spectrum and deposition in the lower part (Bruun, 1962). The Bruun rule was initially proven from wave tank experiments (Schwartz, 1967), and has since been shown for natural beaches. Erosion of beach sediment has been shown during long-term sea-level rise (Leatherman, 1987), short-term sea-level variation (Clark and Eliot, 1983), and for short-term fluctuations in levels of the Great Lakes (Wood, 1991). The Bruun rule is expected to cause significant coastal erosion problems if the IPCC projected sea-level rise occurs.

Mangrove response to sea-level rise has been investigated by reconstruction of Holocene analogues in the Cayman Islands and Tonga as well as Bermuda. Radiocarbon dating of stratigraphy determined a sediment accretion rate of 1 mm/ year for all locations. Mangrove recession events and replacement by lagoon environments are shown to occur during more rapid sea-level rise, the largest in Cayman, where 20 km^2 of mangroves under the present North Sound receded between 4080 and 3230 years before present (BP). In Tonga, a large mangrove swamp persisted between 7000 and 5500 yr BP during sea-level rise at a rate of 1.2 mm a^{-1}, then retreated when the rate of sea-level rise increased (Ellison, 1989). Retreat of mangrove zones with slowly rising sea-level has also been demonstrated from the extensive coastal swamps of southern New Guinea (Irian Jaya) (Ellison, 1998). This indicates that while low island mangroves are likely to be the most sensitive to sea-level rise, continental margin mangroves will also suffer disruption and retreat.

2. Conclusion

Direct climate change impacts on mangrove ecosystems are likely to be less significant than the devastating effects of associated sea-level rise. Mangrove forests occupy an inter-tidal habitat, and are extensively developed on accretionary shorelines, where sediment supply determines their ability to keep up with sea-level rise. Mangroves of low relief islands in carbonate settings that lack rivers are likely to be the most sensitive to sea-level rise, owing to their sediment-deficit environments

Certain identification of climate change and sea-level rise effects on mangroves requires monitoring of biological and physical parameters at a network of locations using standard techniques, which can be achieved by a combination of on-ground and remote sensing techniques (Lucas *et al*., 2002). This would provide environmental managers with ecological data to allow early identification mangrove response to climate change.

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Climate Impacts On Australia's Tropical Wetlands

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1. Introduction

Freshwater wetlands in northern Australia are being degraded and are under increasing pressure (Finlayson, 2003). These pressures arise from - the introduction of alien species, water pollution, urban encroachment, reclamation and infilling, hydrological disruption, and over harvesting (Storrs and Finlayson, 1997). Over-riding and acting cumulatively and synergistically with these pressures is the adverse change that is expected to occur as a consequence of global climate change (Bayliss *et al*., 1998, Eliot *et al*., 1999). Based on an analysis of the vulnerability of the wetlands of Kakadu National Park to climate change the latter authors contend that this change is likely to be catastrophic and many currently accepted wetland values will be degraded or lost.

Finlayson (2000) has pointed out that wetlands in northern Australia have in the recent past been assigned great value, but there has not been a consistent and integrated effort to ascertain the extent or worth of these values as a basis for ongoing management. The value of particular uses has been outlined, but not generally quantified (Storrs and Finlayson, 1997). Further, Eliot *et al*., (1999) claimed that governance across the region was not well equipped to deal with wetland change of the type and magnitude that is currently occurring. Issues are regularly dealt with on a sectoral and inequitable basis and it was questioned whether or not the governance was equipped to address the problems that manifest across the region. Finlayson *et al*., (1998) provide a specific analysis of these problems across three wetland systems located to the east of Darwin.

With this background the implications of climate change for freshwater wetlands in northern Australia is discussed with particular reference to the analyses undertaken in Kakadu National Park and adjacent areas, including the coastal part of van Diemen Gulf.

2. Wetlands And Climate Change

As the wetlands of Kakadu National Park had been the focus of extensive ecological investigations a large amount of scientific information was available for an assessment of the vulnerability of the wetlands to climate change and sea level rise (Bayliss *et al*., 1998, Eliot *et al*., 1999). The climate change scenario was summarised by Eliot *et al*., (1999) based on widely available and broad-scale scenarios; more recent and specific analyses from the vicinity of the Jabiluka uranium mine indicate a scenario where there is a +1 to –6% change in wet season rainfall, a temperature increase of 0.35 to 0.8°C, and the likelihood that the intensity of extreme storm events will increase (Jones *et al*., 1999).

Changes to the wetlands due to sea level rise, shoreline erosion and saltwater intrusion were considered important and would combine to change both the salt and freshwater wetland resources. Given this situation and the ecological and hydrological links that exist between the freshwater and coastal saltwater wetlands it is suggested that these are treated together. Change to the wetlands from climate change would likely include:

- reduction or loss of some components of the mangrove fringe along the coast line;
- colonisation of mangrove species along creek lines as an accompaniment to salt water intrusion;
- replacement of freshwater wetlands with saline mudflats; and
- extensive loss of *Melaleuca* (paperbark) trees in freshwater wetlands.

With changes in the wetland vegetation and habitats there would also be changes in animal populations, particularly noticeable would be changes to the community composition and distribution of bird species and fish in the freshwater wetlands. Additionally, there would be changes in morphology of the streams and billabongs. However, detailed analyses of habitat-species interactions have not been done and on the whole consistent data sets do not exist.

It is also expected that changes in the vegetation and faunal resources may have cultural, social and economic consequences for the Aboriginal and non-Aboriginal people living in or visiting the area. Given different jurisdictions and land uses the information derived from the Kakadu assessment are unlikely to be exhaustive. Nonetheless, they serve to indicate the extent of possible changes to the wetland resources of northern Australia.

3. Management Issues

Given the potentially catastrophic changes to wetlands in northern Australia broad environmental management issues that may assist in developing effective responses for dealing with change have been identified. As the broad scenario includes large-scale modification of wetland habitats and environmental change that extends across jurisdictional bounds it is anticipated that existing management structures will be severely challenged and unable to implement radical actions that sufficiently address concerns of the broader community. The responses that may be necessary are introduced below.

1. *Systematic examination of perceptions and values with respect to management of the region*. Raising awareness of the implications of climate change is an important step in changing governmental and community perceptions. A transparent and collaborative approach is likely to be needed.
2. *Responsibility and accountability for increased natural hazards*. Within the region natural hazards include extreme weather events (e.g. tropical cyclones, monsoonal depressions, heavy rainfall) that could disrupt orderly use of coastal and wetland resources for habitation, industry and commerce, and necessitate change to planning and financial mechanisms, including insurance and compensation.
3. *Broader and transparent governance structures and processes.* Current governance and jurisdiction is not well equipped to deal with environmental change across broad areas in a multi-sectoral manner. Broader and community-based management mechanisms that can provide consistent and appropriate responses irrespective of jurisdictional boundaries are needed.
4. *Balance between economic imperatives and ecological conditions*. Strategic management should include the

interrelated components of regional development and resource conservation. There is a need for the broad community to accept mechanisms that can resolve conflict within the context of a regional development strategy that encompasses adequate conservation of resources.

5. *Acquisition and custodianship of information.* Access to existing data and information should be improved and reports made readily available and unconfined to the grey literature. Much data and information is currently difficult to access.

6. *Environmental investigation, including research and monitoring*. Data and information on the processes and extent of environmental change, development of management strategies, implementation and auditing of management actions, and assessing performance of the overall management processes, is required. Such investigation will require a high level of innovation in order to integrate the cultural implications of change with ecological outcomes that may not support many current practices and views.

4. Research And Monitoring Responses

(Finlayson and Eliot, 2001) have proposed a coastal monitoring program to facilitate ongoing assessment of the coast of northern Australia, in particular the wetlands, to the effects of short-term changes in climate and other environmental factors that occur within planning horizons of approximately 100 years. A key component in this program was the involvement of local communities in assessment and monitoring (Finlayson and Eliot, 2001). The model revolves around formal consultation involving interested and relevant community groups and governmental agencies coupled with scientific rigour and feedback to participants. It includes the following steps:

- Establishment and empowerment of an expert assessment and monitoring centre
- Consultation with and empowerment of key stakeholders, including the local community.
- Identification of major processes and causes of ecological change
- Collation and coordination of available data and information – involving rigid data management protocols to enhance access and store/file information.
- Identification of potential collaborators and partners.
- Design and implementation of technical assessment and monitoring projects.
- Audit and, if necessary, termination of assessment and monitoring projects.
- Implementation of management prescriptions based on results of the assessment monitoring projects.
- Provision of feedback to stakeholders, partners and community groups.
- Audit of management outcomes and readjustment of the monitoring program in the context of impacts arising from the management strategies adopted.

The relative merit of each step of the model is dependent on local circumstances, such as the interest of the local community groups in adverse change to the wetlands and their services, and their interaction with governmental officials.

In support of this model ongoing research has been conducted to illustrate the extent of change in the coastal environments and to provide a baseline for further assessment of the consequences of climate change. This has not been coordinated across the wider region and much information has not yet entered the public domain. Information that has been collected and made available includes: historical change to tidal creeks of floodplains; historical change in the distribution of mangroves along the coast and in the lower estuarine reaches of rivers; surveys of species distribution and community structure of mangroves and freshwater wetlands; historical changes in the distribution of salt affected wetland vegetation communities; incorporation of spatial information and temporal descriptions into GIS; and collation of bibliographic materials and information for specific locations.

Further analyses are underway with current emphases being on integrated inventory, and risk assessment of pressures on tropical floodplains and involvement of local communities and expert groups, (Eliot *et al*., 2000). Overall the assessment of tropical wetlands to climate change is bedevilled by a lack of information, with the exception of a few locations, and the absence of an integrated inventory, assessment and monitoring program. It is has also been held back by jurisdictional weaknesses and sectoralism. Assessing the scenario and responses for change should include the obvious interactions between freshwater and saline wetlands and the catchment.

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Climate Change and Australia's Natural Resources: A Review

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1. Climate Change Science: The Global Perspective

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC TAR), published in 2001, concluded that global warming has taken place over the last century, and there is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities. It is likely that the 1990s was the warmest decade in the last 1000 years. Additionally, the TAR reported that statistically significant associations between regional warmings and observed changes in physical and biological systems have been documented in freshwater, terrestrial, and marine environments on most continents. Surface and satellite-based observations since the TAR supported this conclusion.

Projected warmings in the 21st century are dependent on scenarios of future emissions of greenhouse gases and aerosols. Using the Special Report on Emissions Scenarios (SRES) scenarios, global average warming projections range from 1.4 to 5.8ºC by 2100 relative to 1990. These scenarios were regarded as 'plausible' by the IPCC, but not assigned any probabilities. Recent technical criticisms are unlikely to significantly alter the results.

The TAR stated that it is likely there will be higher maximum temperatures and heat indices over many land areas, and reduced frequency of low temperatures and frosts. More intense precipitation events are likely over many mid- to high-latitude land areas. Increased risk of drought is likely in mid-latitude continents. Tropical cyclones are projected to become more intense with higher peak winds and rainfall intensities. Other patterns of climate variability, including the El Niño-Southern Oscillation, may vary in intensity and frequency, with some climate models suggesting more El Niño-like average conditions, and others no change.

Papers since the TAR find that increasing greenhouse gas concentrations and stratospheric ozone depletion may both be contributing to a strengthening of the polar vortex in both hemispheres, with a polewards movement of the mid-latitude westerly winds, and associated effects on regional climates, including southern Australia.

Most coupled ocean-atmosphere models suggest a weakening of the convective overturning of the ocean in the North Atlantic and around Antarctica, which could have significant regional impacts on climate. Such changes may be initiated in the 21st century but the effects may not become evident until centuries later. The same may be true for melting of the Greenland ice cap and disintegration of the West Antarctic Ice Sheet, both of which could contribute several metres to mean sea-level rise over coming centuries. Conditions may also be set for an acceleration of the increase of greenhouse gases in the atmosphere due to the terrestrial biomass changing from a carbon sink to a source, a slowing of oceanic absorption of carbon dioxide, and possible release of large quantities of methane from the sea floor.

Time lags in the climate system mean that climate change, and especially sea-level rise, will continue long after stabilisation of greenhouse gas concentrations. Time lags in socio-economic systems, will in general mean that adaptation and mitigation strategies will take time to implement and would be more costly if they need to be taken rapidly. The longer adaptation and mitigation measures are delayed, the more rapidly they may have to be undertaken later.

2. Observed Changes In Australian Climate and Ecosystems

Australian average temperatures have risen by 0.7ºC over the last century, and the warming trend appears to have emerged from the background of natural climate variability in the last 50 years. Rainfall has increased over the last 50 years over north-western Australia, but decreased in the southwest, and in much of south-eastern Australia, especially in winter. The changes are consistent with an observed increase in mean sea-level pressure over much of southern Australia in winter. Effects on runoff include a 50% drop in water supply to Perth since the 1970s and near-record low water levels in storages in much of south-eastern Australia in 2002-2003 due to low rainfall and high temperatures since 1996.

Attribution of the rainfall changes is under lively discussion. In the case of the southwest a combination of natural variability and a trend due to the enhanced greenhouse effect is considered to be the likely cause, although recent papers suggest that stratospheric ozone depletion may also be causing a southward shift of the westerlies and associated rainfall systems. If rainfall decreases are due to anthropogenic effects they may well continue, and extend to southeast Australia, with serious consequences for natural and managed systems.

It is at least as difficult, with the current state of knowledge, to attribute changes in Australian ecosystems to climate change, as other local causes are possible in many cases. However, a number of observed changes in vegetation, wetlands, terrestrial vertebrates, marine birds and coral reefs are consistent with regional warming trends (Hughes this volume).

3. Scenarios For The Australian Region

Extreme events are a major source of current climate impacts, and changes in extreme events are expected to dominate impacts of climate change. Return periods for heavy rains, floods and storm surges of a given magnitude at particular locations would be reduced by possible increases in intensity of tropical cyclones and mid-latitude storms. Changes in the location-specific frequency of tropical cyclones could cause either increases or decreases in return periods locally. Australia is particularly sensitive to an uncertain but possible change toward a more El Niño-like mean state suggested by the TAR.

CSIRO has projected a range of possible warmings and rainfall changes across Australia (Whetton this volume). When rainfall changes are combined with increased potential evaporation, a decrease in available moisture is projected across Australia, with more severe droughts likely.

4. Water Resources

Farmers and ecosystems will be increasingly vulnerable if interannual droughts occur more frequently or are more intense in the future. In some areas, water resources are already stressed and highly vulnerable, with salinisation, and competition for water supply between agriculture, power generation, urban areas, and environmental flows. Increased evaporation and possible decreases of rainfall in many areas would adversely affect water supply, agriculture, and the survival and reproduction of key species. Water quality may also be affected due to increased soil erosion following drought and fire, lower flows and higher temperatures, leading to more eutrophication and algal blooms. While there are many pressing problems regarding water supply, climate change is likely to add to them, making solutions more difficult.

5. Ecosystems, Conservation And Sustainability

Australia had been isolated from the rest of the world for millions of years until relatively recent human settlement. Some species are found over quite limited ranges of average climate. These two factors leave many of the region's ecosystems vulnerable to climate change and to invasion by exotic animal and plant species introduced by human activity. This vulnerability has been exacerbated by fragmentation of ecosystems through land-use changes.

Warming of as little as 1°C would threaten the survival of species currently living near the upper limit of their temperature range, notably in some Australian alpine regions where some species are already near these limits, as well as in the southwest of Western Australia. Species that have restricted climatic niches and are unable to migrate because of fragmentation of the landscape, soil differences, or topography could become endangered or extinct. Other ecosystems that are particularly threatened by climate change include coral reefs, mangroves and freshwater wetlands in the coastal zone and inland.

A major proportion of exports from Australia are agricultural and forestry products, production of which is sensitive to any changes in climate, water availability, carbon dioxide fertilisation, and pests and diseases. Returns from these commodities could be adversely affected by a projected increase in agricultural production in mid- to high-latitude Northern Hemisphere countries and resulting impacts on commodity prices and world trade. Climate change will be only one factor affecting Australian agriculture, but it may exacerbate an already difficult situation, particularly in regard to the availability of water for irrigation.

Agriculture and forestry are especially threatened by general warming that will increase potential evaporation and water demand. Drought frequency and severity, and consequent stresses on agriculture and forests, are likely to increase in many parts of Australia. This would be exacerbated by any tendency toward a more El Niño-like average state. Enhanced plant growth and water-use efficiency resulting from carbon dioxide increases may provide initial benefits that offset any negative impacts from climate change, although the balance is expected to become negative with warmings in excess of 2-4°C and associated rainfall decreases. Thus by the mid- to late 21st century net effects are likely to be negative. This and other stresses are likely to lead to major changes in land use patterns as limits to normal adaptation are reached, some farms have to be abandoned, and forests burn repeatedly.

6. Vulnerability

Climate change will add to existing stresses on achievement of sustainable land use and conservation of terrestrial and aquatic biodiversity. These stresses include invasion by exotic animal and plant species, degradation and fragmentation of natural ecosystems through agricultural and urban development, increased fire frequency and intensity, dryland salinisation, removal of forest cover, and competition for scarce water resources. Soil erosion from dust storms and water runoff may increase due to more severe droughts and loss of vegetative cover, coupled with high winds and more intense rainfall events. While climate change is just one of many stresses, it may in some cases cause systems to exceed critical management thresholds.

7. Adaptation and Integrated Assessments

Adaptation to climate change, as a means of maximising gains and minimising losses, is important for Australia but is relatively little explored at the location-specific level, in a cost-benefit framework, and especially in the area of natural resources. Options include improving water-use efficiency, with greater allocations for environmental flows; more appropriate land-use policies; provision of climate information and seasonal forecasts to natural resource managers; and improved bio-security, pest and disease control and fire management. Such measures will often have other benefits, but they will also have costs and limitations. Costs and benefits need to be explored in a multi-dimensional non-monetary values framework, recognising potential loss of species, heritage and other values.

While Australians are experienced in dealing with climate variability, human-induced climate change is likely to take us outside the range of previous experience, and thus require new strategies to cope with new situations that cross over previous management thresholds. This will apply especially in relation to the long-term sustainability of natural resources.

Decision-making needs to consider climate change in conjunction with other issues affecting the same decision strategies. Adaptation to, and mitigation of, climate change are both necessary complimentary strategies, so both should be included in any integrated assessment (e.g., biofuels, reafforestation). Integrated assessments will enable co-benefits and possible clashes of interest to be identified, and the most beneficial overall strategies to be chosen.

Any assessments must take account of uncertainty. This requires a risk management framework. Climate change, and our understanding of it, is evolving rapidly in the real world, and on the scientific, technological and policy fronts, so policies and decisions need to be decided pro tem, acknowledging that they will need to be periodically updated.

8. Conclusion

Australia is vulnerable to changes in temperature and precipitation projected for the next 50-100 years because it already has extensive arid and semi-arid areas, high year-to-year rainfall variability, and existing pressures on water supply in many areas. In addition, vulnerability arises due to high fire risk, Australian ecosystems sensitive to climatic change and to invasion by exotic animal and plant species. Impacts of climate change will be complex and to some degree uncertain, but increased foresight would enable us to optimise the future through planned adaptation and mitigation. Adaptation is essential to cope with unavoidable climate changes, but it has limits. It is essentially a task to be performed by Australians in each local situation. Mitigation can reduce the ultimate extent of climate change and is thus necessary to avoid changes to which we cannot adapt. Mitigation requires cooperative global action.

9. Acknowledgements

This review is based on the Third Assessment Report of the Intergovernmental Panel on Climate Change, published in 2001. It has been substantially updated with summaries of the latest relevant international and Australian observations and scientific developments. A book-length version, including other sectors, will be available shortly from the Australian Greenhouse Office. Much of this material will also have been discussed earlier in this Conference. Thanks are due to CSIRO and the AGO for their support, and to many colleagues for papers, reports and contributions.

Climate Change: Challenges and Opportunities for Australian Agriculture

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1. Introduction

Analysis of observational data has revealed that the global climate has changed, with these changes strongly linked to human activities. These trends in climate will continue for the foreseeable future due to continued emissions of carbon dioxide (CO_2) and other greenhouse gases from fossil fuel use and other sources (IPCC 2001). Research has already shown that Australia has significant vulnerability to the changes in temperature and rainfall projected over the next decades to 100 years (IPCC 2001) with agriculture and the natural resources on which it relies identified as likely to be strongly impacted. These impacts will add to the existing, substantial pressures on Australia agriculture. Hence, the future resilience of agriculture will require adaptation to these climate changes.

2. Managing Climate Variability And Climate Change

The management of climate variability is a cornerstone of Australian agricultural practice and policy. Consequently, there have arisen substantial mechanisms to manage climate variability at different spatial and temporal scales (Table 1: Meinke *et al*., 2001). Climate change can be viewed as just another element of climate variability that will need to be managed. The tools and approaches for assessing management options for existing climate variability are likely to be well-suited to manage human-induced climate changes. However, some additional capabilities will need to be incorporated to deal with factors such as increased atmospheric CO_2 concentrations. This is important as higher CO_2 levels make plants more water and light-efficient resulting in increased grain production, especially in dry years (e.g. Gifford, 1979).

A key set of tools to assess likely climate change impacts and/or adaptations include validated models that encompass key processes. These range from Global Climate Models (GCM's) which describe large-scale ocean-atmosphere-land surface interactions to farm-level systems frameworks which integrate climate (and CO_2), the resource base, management decisions, technological options and external factors. Examples of such farm-level approaches include APSIM (Keating *et al*., 2003) and GRASP (McKeon *et al*., 1990) amongst many others. The integration of different climate elements (e.g. rainfall, temperature, and vapour pressure deficit) into a biologically meaningful aggregate such as a growth index or simulated plant growth has been shown to be considerably superior for climate-based decisions than analysing climate factors such as rainfall alone (Ash *et al*., 2000). These modelling approaches are particularly powerful when allied with tools such as risk analysis and used in a participatory, interdisciplinary research framework (Carberry *et al*., 2002). Whilst modelling analyses of potential climate change impacts on agriculture have been undertaken, work on a participatory research approach is still in its infancy. Similarly, the linkage of GCM output with the farm-level systems analysis capabilities has just begun.

3. Climate Change Impacts And Adaptations: Farm Level

The direct impacts of climate changes on Australian agriculture will be the result of the combined effect of enhanced CO_2 concentrations, increased temperatures, changes in evaporation and changes in the mean, variability, seasonality and intensity of rainfall (Howden, 2002). The tendency for significant reductions in growing season rainfall (autumn, winter, spring) across southern Australia (as indicated by a variety of GCMs) will result in potentially significant reductions in yield, changes in the areas cropped and reductions in irrigation allocations. However, the same rainfall reductions may also result in a reduction in groundwater accessions (hence lower dryland salinity risk) and alleviation of waterlogging. The rainfall scenarios for the northern cropping belt are less directional and may even result in higher yields making potential impacts more difficult to assess. However, increases in rainfall intensity may enhance erosion risk. Ssome of the possible negative impacts from reductions in rainfall may be offset by increases in atmospheric CO_2 concentrations but such increases tend to reduce grain protein content and this will need to be managed.. In many regions, small increases in mean temperature (up to 2ºC) may be beneficial to production, particularly if the increases are in night-time temperatures and management adaptations occur (with the exception of some industries such as stone-fruits where cold weather in necessary). However, larger increases will have negative impacts, particularly in the northern margins of production systems.

It will be the integrated impacts of these changes that we will need to adapt to. Pragmatic adaptation strategies such as changing varieties and planting times could offset some of the negative impacts of climate change, especially in WA, whilst enhancing the positive impacts. Such strategies could be highly valuable: for example, they may be worth $100 to 500 M p.a. to the national wheat industry at the farm gate (Howden and Jones, 2001). They would also decrease the likelihood of production falling below current levels as a result of climate changes. Additional adaptations through further development of risk amelioration approaches, suitable varieties, pest and disease management, seasonal climate forecasting and through building capacity within the farming community could further improve these responses (Howden *et al.*, 2003a).

4. Regional Level Landuse Change

Historically, there have been substantial and quite rapid changes in land management and landuse with climate variations. Examples include expansion and contraction of cropping zones in South Australia in the mid to late 1800s (Meinig, 1962), alteration from sheep to cattle grazing in south-east Queensland in the late 1800s (McKeon *et al*. 1993), movements in the peanut industry over the past decades in Queensland (Meinke and Hammer, 1997) and changes in the viability of Central Queensland for dryland cropping compared with grazing (Howden *et al*., 2001b). The scope and scale of potential future climate changes suggests that significantly greater landuse change may happen in the future, particularly at the margins of current industry distributions (e.g. Reyenga *et al*., 2001) or in regions that may undergo large reductions in rainfall (e.g. WA wheat belt; Howden and Jones, 2001). One way to avoid problems associated with sudden, unanticipated landuse change is to integrate climate change into regional planning (e.g. Howden *et al*., 2001a), however, there are significant issues in 1) identifying climate change thresholds given the complexities of climate change interacting with the many ongoing issues (e.g. dryland salinisation, change in water allocation processes etc.) and 2) the high levels of uncertainty inherent in climate change scenarios due to large ranges in future greenhouse emissions and fundamental uncertainty in the science of the global climate system. There are emerging approaches to deal with this uncertainty (e.g. Howden and Jones, 2001) but these have yet to be applied to a regional context.

5. National - Developing More Resilient Systems

The high levels of uncertainty in future climate changes suggest that rather than try to manage for a particular climate regime, we need more resilient agricultural systems (including socio-economic and cultural/institutional structures) to cope with a broad range of possible changes. There is a substantial body of both theory and practice on resilient systems. However, enhanced resilience usually comes with various types of costs or overheads such as building in redundancy, increasing enterprise diversity and moving away from systems that maximise efficiency of production at the cost of broader sustainability goals. One approach to developing more resilient agricultural regions is to develop an adaptive management strategy where policy is structured as a series of experiments, which have formal learning and review processes. However, this could provide a serious challenge to some institutions, which are, based on precedent (and hence only look 'backwards' not 'forward'), have a short-term focus only and which are risk averse (e.g. Abel *et al*., 2002). Nevertheless, there is a large range of policy activities, which could be undertaken to enhance the capacity of Australian agriculture in dealing with a changing climate. These include linkages to existing sustainability initiatives, maintenance of an effective R&D base, ongoing climate monitoring, effective quarantine protocols, continuing breeding and selection programs and appropriate institutional arrangements, particularly for water resources (Howden *et al*., 2003a). It will also require a more coherent approach to simultaneously influencing policy and risk management approaches based on common data sources and tools.

6. Acknowledgements

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Table 1: *Agricultural decisions at a range of temporal and spatial scales that are affected by climate variability (Meinke et al., 2001).*

Decision Type (eg. only)	**Frequency (years)**
Logistics (eg. Scheduling of planting / harvest operations)	Intraseasonal (> 0.2)
Tactical crop management (eg. fertiliser / pesticide use)	Intraseasonal (0.2 – 0.5)
Crop type (eg. wheat or chickpeas) or herd management	Seasonal (0.5 – 1)
Crop sequence (eg. Long or short fallows) or stocking rates	Interannual (0.5 – 2)
Crop rotations (eg. Winter or summer crops)	Annual/bi-annual (1 – 2)
Crop industry (eg. grain or cotton; native or improved pastures)	Decadal (~ 10)
Agricultural industry (eg. crops or pastures)	Interdecadal (10 – 20)
Landuse (eg. Agriculture or natural systems)	Multidecadal & climate change (20 +)

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Creating Solutions for Australian Resource Futures Under Climate Change and Other Challenges

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1. Introduction

It is crucial to recognize that climate change is one of a number of important issues facing the management of Australia's natural resources and the socio-economic system as a whole. To illustrate this, our paper presents the results from several recent National Futures projects concerning natural resource use as well as experience from integrative work examining (for the AGO) the economic impact of climate change across the spectrum of the Australian economy. For the purposes of this conference, the issues are structured around landscape management. We demonstrate that it is possible to move beyond problem description and to start designing and testing possible solutions.

2. Developing And Evaluating Quantitative Future Scenarios

The National Futures group has adopted a design approach (Gault *et al*., 1987) to developing and evaluating scenarios of the Australian socio-economic system. This involves the use of the computer-based Australian Stocks and Flows Framework (ASFF) to track the physical transactions of the economy. Importantly, potential (behavioural/economic) feedback loops are deliberately left open so that analysts or decision makers must resolve physical tensions. The design approach using ASFF is implemented in the *whatIf*® suite of software applications (from ROBBERT Associates; www.robbert.ca).

2.1 A National Physical Accounting Framework

ASFF is a highly disaggregate simulation that keeps track of all physically significant stocks and flows (Poldy *et al*., 2000). Stocks are the quantities of physical items, such as land, livestock, people, buildings, etc. Flows represent the rates of change of stocks resulting from physical processes, such as land use change, migration, investment, depreciation, etc. ASFF covers all sectors of the economy across continental Australia, incorporating only the physically significant elements of each sector. Physical accounting relationships represent the key processes, such as converting the requirement for transport of goods into the size of the freight transport fleet and the fuel requirement. All variables (some 800) of the framework are completely and consistently calibrated over at least 1941–2001, with data collected from a wide range of sources, drawing heavily on the Australian Bureau of Statistics. ASFF is used to create long-term scenarios to 2100.

2.2 Example of Integration: Costs & Benefits of Climate Change

In a preliminary study funded by the Australian Greenhouse Office that is currently exploring methods for evaluating the economic impacts of climate change, ASFF was used to amalgamate the productive impacts across several sectors, namely broad-acre cropping, irrigated agriculture, forestry and domestic energy requirements. The integrative process began with CSIRO Atmospheric Research generating two indicative climate scenarios (using different models: DARLAM125 and Mark3), based on scenarios of global CO_2 production. The climate variables were provided for two years (2030 and 2070) and on various spatial grids as appropriate across the continent. Separate research groups then inferred the corresponding bio-physical response, such as change in regional wheat yield, growth rate of forest plantations, and energy demand associated with space heating/cooling. These changes were implemented as impacts on regional/national production volume using ASFF by changing specific control variables (e.g., for energy demand, the building energy intensity and electricity power station load factors). The resulting production changes were compared with current production levels. Finally, economists inferred the marginal costs or benefits using current prices.

This process was largely based on an assumption of no adaptation to climate change, with the aim of exploring the sensitivity to climate change of as many sectors as possible. The design process and structure of ASFF permits this approach, and importantly points to investigation of adaptation and mitigation scenarios.

3. Some Other National Resource Challenges

In this section three seemingly independent resource issues are outlined. In the following section, an illustrative solution is described to demonstrate the interplay between these challenges and climate change.

3.1 Primary Energy

A large body of work suggests that world production from traditional supplies of oil will soon peak, and that the production decline will force difficult transitions in many modern economies. Based on current estimates (50% probability) of ultimately recoverable oil and gas resources, the production of domestic crude oil may peak within a decade (Foran and Poldy, 2002). Further growth in the Australian economy produces an expanding requirement for imported oil or replacement fuel (Figure 1). Transition to domestic natural gas can ease the tension, but not likely beyond the middle of this century. The decision to export natural gas might be balanced against a requirement to import it at a higher price 40 years hence.

The option to implement alternative technologies (e.g., oil shale and coal gasification) should be assessed, but it is possible their use will further increase greenhouse gas tensions. Through international pressure related to climate change, there may

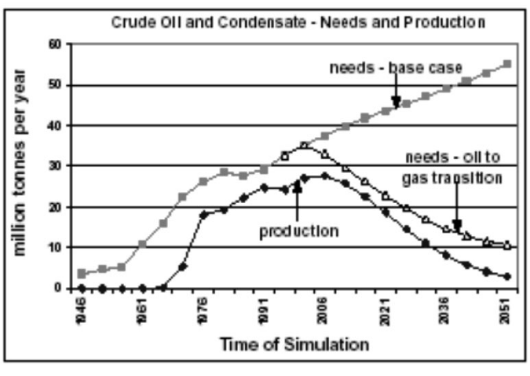

Figure 1. *Domestic production and requirement of oil, shown historically and for two scenarios: with and without transition to natural gas as a replacement for oil.*

be constraints placed on Australian exports and domestic combustion of fossil fuels. Aggressive introduction of more energy-efficient technology can halt growth in emissions for some decades, but economic growth and potential feedback effects such as increased demand for space cooling are likely to force emissions upward.

3.2 Agricultural Landscapes

The Decision Points for Land and Water Futures project (Dunlop *et al*., 2002) explored three long-term scenarios for land and water resources in Australia. Past (200 year) steady increase in area at ~2% p.a. cannot physically continue indefinitely; for example, at historical growth rates, the area of crop and sown pasture would double in roughly 35 years to constitute about one third of all Australian productive land area (including all rangelands); and within the century, the area would theoretically encompass half the Australian land mass.

Of future possibilities, one dryland agriculture scenario sees significant growth in rain-fed agriculture, and a substantial contraction of irrigation, re-allocation of water to environmental flows and consequent improvements in waterway health. An irrigation scenario sees considerable growth in high-value irrigated agriculture, including in northern Australia, and a contraction of dryland agriculture with large areas of cleared land being revegetated. The post-agriculture scenario encompasses a redefinition of the role of agriculture in the landscape, with a smaller but more secure production sector emerging; at the same time regional Australia progresses beyond its dependence on agriculture for economic prosperity.

Crop and sown pasture yields were affected by the combined effects of four types of land degradation, resulting from the interplay of land retirement, additions of new land (initially un-degraded), and the impact of crop and pasture activity. Initially, as more-degraded land was retired from intensive agriculture, the fraction of crops and sown pastures affected decreased (Figure 2). However, in the longer term, only the post-agriculture scenario shows the area affected remaining low as a result of markedly improved landscape function.

All three scenarios suggest significant change from 'business-as-usual' to ameliorate or mitigate landscape function constraints. With modelled climate change impacts superimposed, these changes become more pressing, particularly as broad-acre cropping yields in south-east and west Australia diminish and water availability in the southern region of the Murray-Darling Basin reduces. Positive feedbacks to climate change may result from increased cropping in northern Australia and greater application of fertilisers.

3.3 Fisheries

Australian Fisheries Futures: 2020 and beyond (Lowe *et al*., 2003) provides the first nationally comprehensive physical accounting (through ASFF) of the vast majority of the Australian fisheries industry. A simple logistics population model constrained by past production and expert knowledge for each of over 200 species-fishery combinations was adopted for the key driver of fisheries productivity.

Three primary scenarios were developed to explore the implications of adopting different strategic management options: continuous fishing attempts to maintain the catch rate at the average of the previous decade; precautionary fishing modifies this by reducing fishing if the species biomass becomes critical; and optimal fishing adjusts fishing effort to achieve 80% of the maximum sustainable yield. All three scenarios demonstrate that the commercial wild capture production cannot achieve the peak rates of the 1990s, although on-going marginal increases are possible in the optimal fishing scenario (Figure 3).

By considering total requirements and supply of fish production, the key implication for all scenarios is that historical trends cannot be maintained: if this is attempted, domestic consumption and exports outstrip domestic production and imports. Sub-scenarios show that aquaculture production is likely to be a key contribution to local production and thus export capacity in the future. However, this is likely to rely on significant innovations in fish-farming and environmental control for access to water of sufficient quality. Climate change may impose compounding challenges through reduction in environmental water flows and failure of marine breeding grounds due to temperature-based thresholds.

4. A Possible Solution To Simultaneous Challenges

Australia's relatively optimistic resource picture must be moderated by four factors as follows: world greenhouse politics, future oil availability, widespread landscape problems in agricultural regions and declining economic fortunes of rural communities. The transition to an economy based mostly on

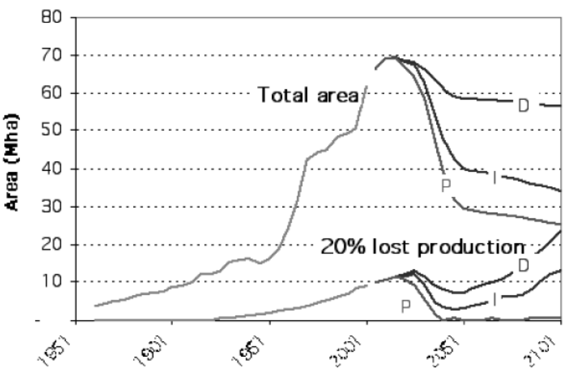

Figure 2. *Area of crop and sown pastures, historically and for three scenarios (D: dryland; I: irrigated; P: post-agriculture). Area of degraded land is also shown.*

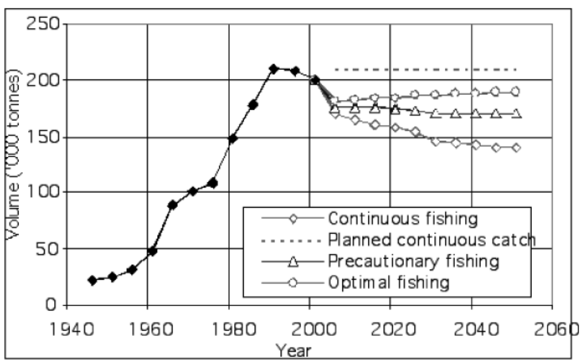

Figure 3. *Total volume of Australian fish catch historically and for 3 scenarios. Dashed line shows the planned catch for the continuous scenario (compare with realised catch, shown with diamonds).*

Table 1. *Land & Water scenario features*

Scenario	Dryland	Irrigated land	Forested land	River water flow
Dryland	– 11 Mha Sth Aust + 9 Mha Nth Aust	– 40%	—	6600 GL inc
Irrigated	– 23 Mha	+ 2 Mha (>50% in Nth Aust)	+ 15 Mha	800 GL inc
Post-agriculture	– 30 Mha	– 60%	+ 19 Mha	8700 GL inc

biofuels potentially offers one way to amalgamate these issues and develop a crosscutting set of solutions (Foran and Crane, 2002). This suggestion illustrates the feasibility of designing and testing solutions, cognisant of a range of resource and socio-economic issues.

The proposal involves the progressive establishment of biomass plantations over the next 50 years that cover between 15 and 30 million hectares of Australia's croplands and high rainfall pasturelands. The production of methanol and ethanol from biomass offers the possibility of a largely carbon neutral production system. The deep-rooted perennial production systems could help control hydrological problems currently responsible for dryland salinity. River health may be enhanced, with subsequent benefit to growth in the aquaculture industry, as depicted primarily in the post-agriculture scenario of the Decision Points study. Also biomass plantations could help create employment in rural Australia, and could aid Australian trade balance by replacing future energy imports. The parallel evolution of domestic transportation systems from internal combustion engines to methanol powered fuel cells could require less land area to underpin the biofuels transition.

5. Acknowledgments

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Climate Impacts on Queensland's Grazed Landscapes

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1. Introduction

Variability in Queensland's climate on yearly and decadal timescales (Manins *et al.*, 2001) has had major impacts on natural resources including agricultural productivity (Day *et al.*, 2003a,b), natural and agricultural resource condition (Vandersee and Kent, 1983; Tothill and Gillies 1992), water resource and water supply planning (Claydon *et al.*, 1999; Abawi *et al.*, 2003), landscape and river health (Freebairn and Smith, 2003) and downstream impacts of land use such as on the Great Barrier Reef Lagoon (Hunter and Walton, 1997; Roth *et al.*, 2002).

This paper concentrates on climate impacts on the grazed natural resource. Over 85% of the 173 Mha land area of Queensland and in 2002 grazed by 11 million head of beef cattle, ≈10 million head of sheep, over 20 million kangaroos and an unknown number of other native and feral herbivores (SOE, 2003). These grazing lands of Queensland are mostly native and naturalised pastures and are subject to high year-to-year variability in climate (Hall *et al.*, 1998) including severe and extended drought periods (Day *et al.*, 2003). Queensland's grazing lands are of major economic and environmental significance. In 2002/3 meat and wool livestock industries had a gross value of about $3 billion representing 35% of the total income from primary industries. The grazed resource includes much of Queensland's woodlands (60 of the 81 million hectares of woodland), and areas within many of the catchments that provide water for rural, industrial and urban use. As grazing is a major catchment land use it also may have considerable downstream effects such as increased nutrient and sediment flow to the Great Barrier Reef Lagoon from the Burdekin River (Roth *et al.*, 2002; McCulloch *et al.*, 2003).

Tree clearing, primarily for grazing, has continued in Queensland during the 1990s and early 2000s. Emissions of carbon dioxide resulting from land use change are a significant part of Australia's total greenhouse emissions. In 1990, conversion of forested lands was estimated to have contributed approximately 14.5% of Australia's total reported greenhouse emissions (B. Henry pers comm.). Concern regarding global warming as well as for conservation of biodiversity and prevention of degradation to landscapes has resulted in recent legislation to restrict tree clearing in Queensland. On the other hand, the process of vegetation thickening (Burrows *et al.*, 2002), also occurring in Queensland's woodlands, represents a large carbon sink. Carbon sequestration due to thickening is not included in Australia's national greenhouse gas inventory but is estimated to be equivalent to approximately a quarter of 1990 greenhouse emissions (Burrows *et al.*, 2002). Thus not only is management of Queensland's natural resources used for grazing sensitive to future climate impacts (variability and change), but management is also affected by greenhouse mitigation efforts in response to national and international concern and policy on climate change (Henry *et al.*, 2002).

1.1 Climate Issues For The Grazed Resource

There have been at least eight major drought/degradation episodes in the history of Australia's rangelands (Stone *et al.*, 2003, McKeon *et al.*, 2003), of which the two most recent have occurred in Queensland, i.e. south-west Queensland in the 1960s and north-east Queensland in the 1980s. These degradation episodes have involved soil erosion, pasture composition change and woody weed infestation.

These episodes have been strongly driven by the interaction of climate and economic forces. Stock numbers have built up during favourable periods e.g. early 1950s, mid 1970s. Economic pressures including rapid collapses in commodity prices for wool (e.g. 1960s) and beef (e.g. mid 1970s), have resulted in graziers retaining stock in the hope of better prices. High grazing pressures including a build-up of native and feral herbivores have resulted in resource degradation with loss of desirable perennial grass and shrub species (McKeon *et al.*, 1990; Ash *et al.*, 2001). Extended drought periods including extremely dry years have resulted in further degradation, e.g. loss of surface soil protection, wind and water erosion, establishment of undesirable plant species and likely increases downstream sediment flows (Gardener *et al.*, 1990).

To help develop and implement more sustainable management systems that minimise the ecological and economic impacts of climate variability, R&D providers have worked with R&D funders to:

1) understand the climate forcings that have resulted in historical drought/degradation episodes (McKeon *et al.*, 1990; Power *et al.*, 1999; Crimp and Day 2003; White *et al.*, 2003; McKeon *et al.*, 2003; Meinke *et al.*, 2003);
2) develop climate forecasting systems and better approaches to climate risk assessment (McBride and Nicholls 1983; Clewett *et al.*, 1991; Stone and Hammer 1992; Stone *et al.*, 1996; Day *et al.*, 2000; Syktus *et al.*, 2003);
3) deliver national drought and degradation alerts using spatial models of soil water and pasture growth (Carter *et al.*, 2003);
4) provide objective assessment of current conditions to support applications for assistance under Drought Exceptional Circumstances (Carter *et al.*, 2003; Day *et al.*, 2003), and analysis of Drought Declaration policies (Day *et al.,* 2003b);
5) provide grazing management guidelines that incorporate climate risk assessment developed from successful grazier experience and field grazing trials (Johnston *et al.*, 2000; Ash *et al.*, 2001; Quirk and O'Reagain, 2003; O'Reagain *et al.*, 2003);
6) develop a training package (Grazing Land Management education program) that provides producers with both a comprehensive understanding of grazing ecology, including climate variability, and the tools to calculate and manage both long-term and short-term carrying capacities (EDGEnetwork, 2003)
7) initiate targeted field R&D to enhance the ecological understanding of different grazed ecosystems e.g. research work in the Channel Country (Phelps, 2003)

8) develop information systems to allow individual resource managers to access historical climate data through computer packages such as RAINMAN (Clewett *et al*., 1994) and LongPaddock – www.LongPaddock.qld.gov .au) (Peacock *et al*., 2002);

9) monitor resource condition with rapid assessment (Hassett *et al.*, 2000), repeated transects (e.g. Qgraze, Cliffe and Hoffmann, 1999; Quirk and O'Reagain, 2003) and remote sensing (e.g. satellite assessment of bare ground and pasture burning, Taube 1999, Collett, 1999), and provide up-to-date advice to land managers and advisers;

10) further develop existing hydrological and vegetation models to include the effects of increasing atmospheric CO_2 concentrations on plant water use and vegetation dynamics using current enhanced CO_2 field experiments (A. Ash pers comm.);

11) assess future climate change scenarios in terms of livestock carrying capacity, drought frequency, hydrology and degradation risk (Howden *et al*., 1999, Crimp *et al*., 2002).

We describe case studies of climate impacts on natural resource management. Underpinning the approach is the emerging understanding of the sources of variability in the climate system at different timescales (quasi-biennial, inter-annual, quasi-decadal, bi-decadal and trends, e.g. White *et al*., 2003; Meinke, 2003: Meinke and Stone, 2003; and expectations of climate changes derived from simulations of global warming (IOCI, 2002), stratospheric ozone depletion (Gillett and Thompson, 2003) or anthropogenic aerosol emissions (Baines *et al*., 2003). Various statistical forecast and climate risk assessment systems are being developed using this understanding. For example: a) Seasonal Pacific Ocean Temperature Analysis version 1 (SPOTA-1; Day *et al*., 2000) uses sea surface temperature gradients at various locations in the Pacific Ocean relevant to variability in Queensland's rainfall; and b) Global Climate Models downscaled with Regional (Queensland) Climate Models have been operational since September 1998 (Syktus *et al.*, 2003). These forecasting systems capture components of the climate system operating at the inter-annual, e.g. El Niño - Southern Oscillation (ENSO), and inter-decadal timescales, e.g. inter-decadal Pacific Oscillation (Power *et al*., 1999). The interaction of ENSO and inter-decadal behaviour of the Pacific Ocean has been used to explain some of the variability that has contributed to the historical degradation episodes in eastern Australia (White *et al*., 2003; McKeon *et al*., 2003).

2. Climate Variability For Grazed Resource Management

Analysis of grazing trials and historical experience has indicated that major damage to desirable perennial grasses occurs in dry 'growing seasons', e.g. low summer rainfall (McKeon *et al*., 1990). For regions of Queensland, statistical forecasting systems have been developed based on ENSO effects on rainfall (Southern Oscillation Index, 'SOI', McBride and Nicholls, 1983; Clewett *et al*., 1991; SOI phases, Stone *et al*., 1996; sea surface temperatures; Drosdowsky and Chambers, 1998; Day *et al.*, 2000; Drosdowsky 2002). In addition to statistical systems based on historical rainfall, Global Climate Models (e.g. Syktus *et al*., 2003) have been operational since 1998. These systems are being used to provide a warning of the increased risk of resource damage in El Niño years (i.e. SOI consistently negative in spring, e.g. 2002). However, low summer rainfall can also occur in non-El Niño years (e.g. mid 1980s in north-east Queensland) and provision of early warning in these years remains a major challenge. Early warning of dry summers allows graziers to make pro-active decisions to reduce stock numbers, thus preventing loss of desirable perennial grasses and subsequent landscape degradation (Ash *et al*., 2001). Thus the use and further improvement of climate forecasting skill and climate risk assessment will provide major benefits for property and landscape-scale natural resource management in Queensland. However, climate information is but one component of a sustainable grazing system. Key components also include the more active management and monitoring of land condition and pasture availability.

2.1 Importance Of Climate Change In Grazed Resource Management

A key cause of the eight degradation episodes, was the increase in livestock numbers in response to long periods (e.g. 5-10 years) of above-average rainfall (Pressland and McKeon 1990; Tothill and Gillies 1992; McKeon *et al*., 2003). The attempt by some graziers to retain these high numbers through drier periods contributed to degradation. In some cases, government policy had also supported the over-estimation of resource carrying capacity. Climate change poses a similar and additional threat as inter-decadal variability has in the past.

Some climatic elements have been changing over the last 30 years. For example, minimum temperature averaged across Queensland's grazing lands has been increasing since the mid 1970s (McKeon *et al*., 1998; SOE, 2003). Little change had occurred in maximum temperature until 2002 when the highest values in the available record (starting 1957) occurred. Current research is extending the historical record back to the early 1900s to place current events in a longer historical perspective. The high daytime temperatures and vapour pressure deficits during 2002/3 summer were likely to have exacerbated the effects of low rainfall in 2002/3 (SOE, 2003). Current and future expected climate change (in rainfall, temperature, wind and other climatic elements) will provide a challenge to estimate future livestock carrying capacity (LCC) of the grazed resource and hence hopefully prevent future degradation episodes.

The impact of climate change on LCC of Queensland has been assessed through several studies (Hall *et al*., 1998; Crimp *et al*., 2002; Howden *et al*., 2003). The effects of changing carbon dioxide, temperature, humidity, solar radiation and consequent potential evaporation have been represented in a soil water - pasture growth model (GRASP; McKeon *et al*., 1990). Relationships between pasture growth and LCC were derived from the existing spatial distribution of stock density. Historical industry practice indicates that higher rates of pasture utilisation have occurred in regions with long growing seasons or on fertile soils (Johnston 1996; Hall *et al.*, 1998). The resulting simulations suggest that increasing CO_2 and temperature (with no change in rainfall) are likely to increase the LCC of Queensland by extending the growing season of tropical grasses. However, declines in rainfall are likely to be amplified by temperature increase resulting in a loss of carrying capacity.

3. Providing Climate Information For Use In Management

To aid decision making of resource managers through better climate information, historical climate databases have been developed to make daily climate data available for a wide range of activities (Clewett *et al.*, 2000 and www.bom.gov.au/silo). These data have been extended to regions where information has been sparse using interpolation processes (Jeffrey *et al*., 2001). This approach has resulted in data being available for applications such as: 1) spatial modelling for drought alerts (Aussie GRASS, Carter *et al*., 2003); 2) drought EC applications; and 3) climate impact studies requiring daily climate data.

The major challenge to be addressed now is to provide the best estimates of climate over the next 30 years for use in management. The objective is to use the most recent climate understanding, given the caveats usually associated with new research, coupled with likely future (and uncertain) climate forcings to provide the most plausible estimates of future climate for use in sustainable management of land and water resources. Getting maximum value from these enhanced understandings and predictions will require their integration into a dynamic and interactive extension process with producers. The GLM education program is designed to help kick-start such a process, and several partnership projects in the Regional NRM process (under NAP/NHT2 regional arrangements) are designed to foster and develop a process, which delivers continuous improvement in grazing land management.

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(Full list of references can be found on: http://www.longpaddock.qld.gov.au/AboutUs/

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Deriving Llandscape Thresholds for Poplar Box (Eucalpytus populnea) Woodlands in a Changing Climate – Risks and Challenges

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1. Introduction

Clearing remnant vegetation and subsequent land management changes lead to habitat loss, fragmentation and the disruption of important ecosystem processes, which pose substantial threats to biodiversity conservation. Current project work in the Queensland Murray Darling basin aims to improve the knowledge of ecological thresholds for habitat retention and management in southern Queensland. Observations from this project form the basis of this paper.

A suite of environmental markers of ecological condition, genetic diversity, and vegetation and soil health are being collected from sixty *Eucalyptus populnea* remnants and regrowth patches in the Maranoa Balonne catchment in the Queensland Murray Darling Basin. The study area is 4.5 million hectares (extending from Miles in the east to Morven in the west, Injune in the north to Surat in the south). The aims of the investigation are to determine remnant vegetation status and condition, measure remnant viability and where possible, and determine ecological thresholds for landscape planning. Data will be analysed against landscape metrics (e.g. measures that describe landscape patterns) and the interactions among components of the landscape mosaic (eg. how isolated is a patch from other similar patches). The fundamental principles used to derive metrics come from studies in island biogeography where distance and area of habitat patches are combined to understand the ecological stability of species through habitat analysis, incorporating immigration and extinction of species (MacArthur and Wilson 1967). In our investigations we have derived metrics at three scales: paddock (500 ha); property (8000 ha); and subcatchment scales (275,000 ha), reflecting different management and planning requirements. Landuse of the surrounding matrix, distance to neighbouring remnants and historical disturbance (1988 to present) were also determined.

2. Current Status Of The Poplar Box Woodlands

Prior to European settlement, Poplar box (*Eucalyptus populnea*) dominated communities accounted for 63% of the landscape within the study area. Agricultural development has dramatically influenced the land use in the region, leading to a reduction in the extent of Poplar box communities to 23% of the landscape in 1999, and total remaining native vegetation coverage to approximately 36% of the study area. Between 1999 and 2001, 2% of the total area of remaining native vegetation was cleared, equating to 35000 ha (Department of Natural Resources and Mines, 2003). While some clearing of native vegetation has occurred during the study period, it has generally stopped, although clearing of regrowth continues.

The effects of current land use change, clearing, grazing and changed fire regimes have not had their full affect on the biodiversity currently represented in these landscapes. However some early signs of degradation are apparent:

- The health of poplar box trees surveyed throughout the study area is generally poor, with a number of dieback agents identified, principal amongst these being insect defoliators. What is not clear from our investigations so far is the extent to which this dieback can be attributed to recent drought conditions acting directly or indirectly to cause tree disorder, or whether the fragmentation of remnants makes trees vulnerable to attack. It is not clear how further fragmentation, changes to disturbance regimes of remnants and climate change will interact to influence tree health and vigour.
- Loss of landscape function such as loss of ground cover, compaction and degradation of soil surface condition (causing excessive water runoff and soil erosion) and the decline in soil biological function is evident. It is more than likely overgrazing by livestock is contributing to the loss of soil condition. It is not clear how overgrazing and climate change will interact in the future to affect soil condition and nutrient cycling processes such as litter decomposition.

The analysis of landscape patterns and structure reveals that the degree of fragmentation across the study region is not constant across scales. For example, a remnant patch may be considered fragmented at the paddock scale but variegated at the property and sub-catchment scales, becoming increasingly isolated. Landscape design models are based on mature landscape that are now stable or undergoing rehabilitation (see eg. McIntyre, 2002, or McIntyre and Hobbs 1999 and James and Saunders, 2001 for some recent examples). But the study area has a combination of landscape classifications (intact, variegated, fragmented and relictual) depending on the scale under investigation. Thus sensible application of landscape design principles needs careful consideration of scale to avoid detrimental conservation outcomes at the sub-catchment scale or onerous conservation measures at the paddock or property level.

3. Future Challenges And Risks From Climate Change

The clearing and subsequent fragmentation of habitat remains the major threat to biodiversity in the study area. The current research into thresholds for native vegetation retention has not considered the implications of climate change on landscape design or habitat condition. We assume that modification of complex native ecosystems can occur to some threshold, where most species and function are retained. Below that threshold, species, species assemblages or key ecosystem function will be lost. Our approach also assumed current habitation of a species, species assemblages or function, implies persistence, although we don't believe this is necessarily the case. A significant challenge still exists to incorporate consideration of ecological in landscape planning, especially under climate change scenarios. Of particular importance will be the integration of climatic gradients that allow species movement and that maintain key ecosystem functions (van Jaarsveld *et al.*, 2003).

Chilcott *et al.*, (2003) outlined some other potential impacts of climate change on natural resource functioning, which are relevant to the poplar box woodlands:

- The failure to adequately manage for climate variability in the rangelands has been a major source of reduced resource condition and degradation. Climate variability has been identified as the most important driver of change in Queensland's native and naturalised pastures (collectively know as the 'rangelands'). McKeon and Hall (2002) demonstrate how processes of degradation and recovery interact with climate variability. In particular, a combination of heavy utilisation and drought during the normal growing season has been demonstrated to accelerate loss of desirable perennial species, leading to increased soil loss, reduced burning opportunities and woody weed invasion.
- Ecosystem function, litter decomposition and soil fauna communities are highly sensitive to changes in environmental conditions (especially soil water, soil temperature, nutrient and carbon status). These biota drive important ecosystem functions such as decomposition, nutrient mineralisation and maintain soil structure through burrowing and forming water stable aggregate. Climatic pulses are an important determinant of the function of these biota, and how population will change under climate change
- Recruitment and death in grazed woodlands is, for most parts, driven by climatic pulses, with series of above average rainfall required for recruitment. These same processes can drive recruitment of weed species, an example being *Acacia nilotica* invasion into Mitchell grass plains. Incidences of tree dieback in mature canopies of grassy woodlands have been observed following extended periods of drought and may be contributing to the current decline in tree health in the study region.
- The capacity of many of these ecosystems to absorb large disturbances caused by clearing is probably due to the ability of many land types to regenerate. Anecdotal evidence indicates that some vegetation types regenerate successfully following broadscale clearing disturbance. While regeneration of woody communities is considered a management problem in a production landscape, many ecosystem functions critical for sustainability will be retained. This ability to regenerate is a function of native vegetation retention levels and vegetation condition. As with other key ecosystem processes, regeneration capacity is principally driven by climatic factors and may be affected by climate change within the confines of varied land management regimes (eg. fire and grazing).

4. Conclusion

The opportunity to prevent over-clearing and concomitant problems of biodiversity loss, salinity and land degradation still exists in this region. It is more than likely that clearing has not already been extensive enough to cause major irreversible changes to the poplar box woodlands. However, the level of disturbance (from either land management or climate change) within a remnant could have a greater impact upon the functionality of remnant vegetation than the extent of fragmentation, thus changing thresholds. Sympathetic management of native vegetation will greatly increases the persistence of plants and animals, even in the smallest and most isolated remnants.

Modifications to the landscape coupled with climate change could result in the loss of species and assemblages from the landscapes, substantial imbalances in landscape water balance and nutrient cycling, invasion of remnants by exotic species, and changes to the disturbance regimes (mainly fire and grazing). As most clearing has occurred recently (and during a relative dry period), the full consequences of the land cover change may yet to be observed, and may not be apparent for decades. The major challenge for land managers and is to ensure conservation measures undertaken now can account for future shocks from climate change.

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Regulatory, Financial and Legal Drivers For Climate Change Corporate Responsibility

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1. Introduction

A clear understanding of climate variability, trends and climate change for the next 30 years is required to enhance our current approach to natural resource management. As a result of significant progress in the science of climate change, governments have determined that it is prudent to act. This paper examines Australian policy framework and government regulations which have a direct financial impact on the natural resources sector. The paper focuses on measures that directly impact Australia's natural resources sector, such as opportunities for carbon sequestration and regulatory regimes.

This paper also examines financial and legal pressures facing the natural resources industry to assume corporate responsibility for climate change. Investors are taking climate change into account on their investment decisions in the belief that an organisation which integrates its economic, environmental and social success factors will have a competitive edge. In addition, elements of Ecologically Sustainable Development (ESD) are finding their way into Australian jurisprudence. An example of one element of ESD that has been applied into an Australian court is the precautionary principle.

2. Government Regulations

The Kyoto Protocol looks likely to enter into force in early 2004. As at 5 September 2003, 117 countries, constituting over 60 percent of the global GDP, have ratified, approved or acceded to the Treaty.

Notwithstanding the Commonwealth Government's position on the Kyoto Protocol, some Australian natural resources companies have operations in countries which have ratified the Protocol. In addition, the Commonwealth and State governments have introduced greenhouse measures such as the Commonwealth Mandatory Renewable Energy Target, NSW Greenhouse Gas Abatement Scheme and Queensland Gas Scheme.

These domestic obligations represents a challenge to the natural resources industry given the energy intensive nature of the extraction and processing activities, as well as embodied carbon in the case of fossil fuels. However, there may be opportunities for the natural resources sector, such as the recognition of geological carbon sequestration as a eligible abatement activity under the NSW Scheme.

Some Australian natural resources companies, such as Newmont Australia Limited, Western Mining Corporation, Rio Tinto and BHP Billiton have undertaken voluntary programs to reduce energy consumption and their ecological footprint.

3. Financial And Legal Drivers

The momentum of change extends not only in respect of government climate change management measures, but also to the broader community such as investors and environmental groups. The impending introduction of International Accounting Standards in Australia from 2005 further heightens the level of corporate accountability.

On 31 May 2002, 35 institutional investors representing assets in excess of US$4.5 trillion wrote to the chairmen of the FT500 Global Index companies seeking investment relevant information relating to greenhouse gas mitigation. There is a growing overseas trend where institutional investors expect companies to manage climate change as a business risk. This extends well beyond the obvious emissions intensive sectors and natural resources industry to include companies in the financial services, transportation, semi-conductor, telecommunications, electronic equipment, food, agriculture and tourism sectors. Businesses are now examining their supply chain to ensure that they are environmentally responsible.

Stakeholder activism is also evident in Australia where the Climate Action Network Australia (CANA) have lodged the threat of legal action against company directors who have not taken steps to reduce the environmental harm caused by their organisation.

Attention is also drawn to high legal proceedings, such as the case of *Greenpeace Australia Limited v Redbank Power Company Pty Ltd* 1994 NSWLEC 178. In this case, the precautionary principle and Ecologically Sustainable Development arguments were put forward as part of a campaign against private investment with perceived environmental impacts.

In addition, the introduction of International Accounting Standards in Australia from 2005 will further rise levels of corporate accountability as contingent liabilities in respect of environmental obligations and contamination remediation matters will need to be recognised in the financial statements.

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