Synthesis and Integrative Research
Final report

iClimate

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iClimate

Final Report to the National Climate Change Adaptation Research Facility

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This work was carried out with financial support from the Australian Government (Department of Climate Change and Energy Efficiency) and the National Climate Change Adaptation Research Facility.

The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

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Contents

Figures

Tables

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Executive summary

The *iClimate* project conducted a review of climate change impacts and adaptation literature for Australia during 2010-2011 covering natural and managed ecosystems, human health and well-being, and human built environments, industry and infrastructure. Although we did not review information for New Zealand, we include discussion on New Zealand where information was uncovered. The information was synthesized into 'statements ' - in a user-friendly and efficient form to underpin adaptation planning in Australia and preparation of the Australasia chapter of the IPCC Fifth Assessment Report (due 2014). Statements focused on observed and projected impacts of climate change with particular emphasis on information published since the end of 2006 i.e. new literature since the publication of the IPCC 4th Assessment Report .

The project developed a web-based database called *iClimate* which presents the statements and underlying publications in a searchable form. Statements are fully references and presented in user-friendly language and be searched by assigned categories, author or key words.

Fact Finding Team

The *iClimate* team comprised a multidisciplinary team of scientists across three institutions.

Climate Adaptation Flagship, CSIRO

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Cynthia Wong, Department of Mathematics and Computing


CSIRO

1 iClimate Statements

What is a Statement?

Statements can be thought of as storylines tracing the impacts and consequences of climate change. The DPSIR framework, described in Section 3, is used as the framework to structure facts in iClimate. DPSIR describes a causal chain from 'drivers' (here climate change) to impacts and through to responses (here adaptation responses).

Statement Organisation

Statements are organised by Sector as shown in Figure 1. The three major sectors are i. Natural and Managed Ecosystems, ii. Human health and well-being and iii. Human built environments, industry and infrastructure. Each of these is split further into sub-sectors.

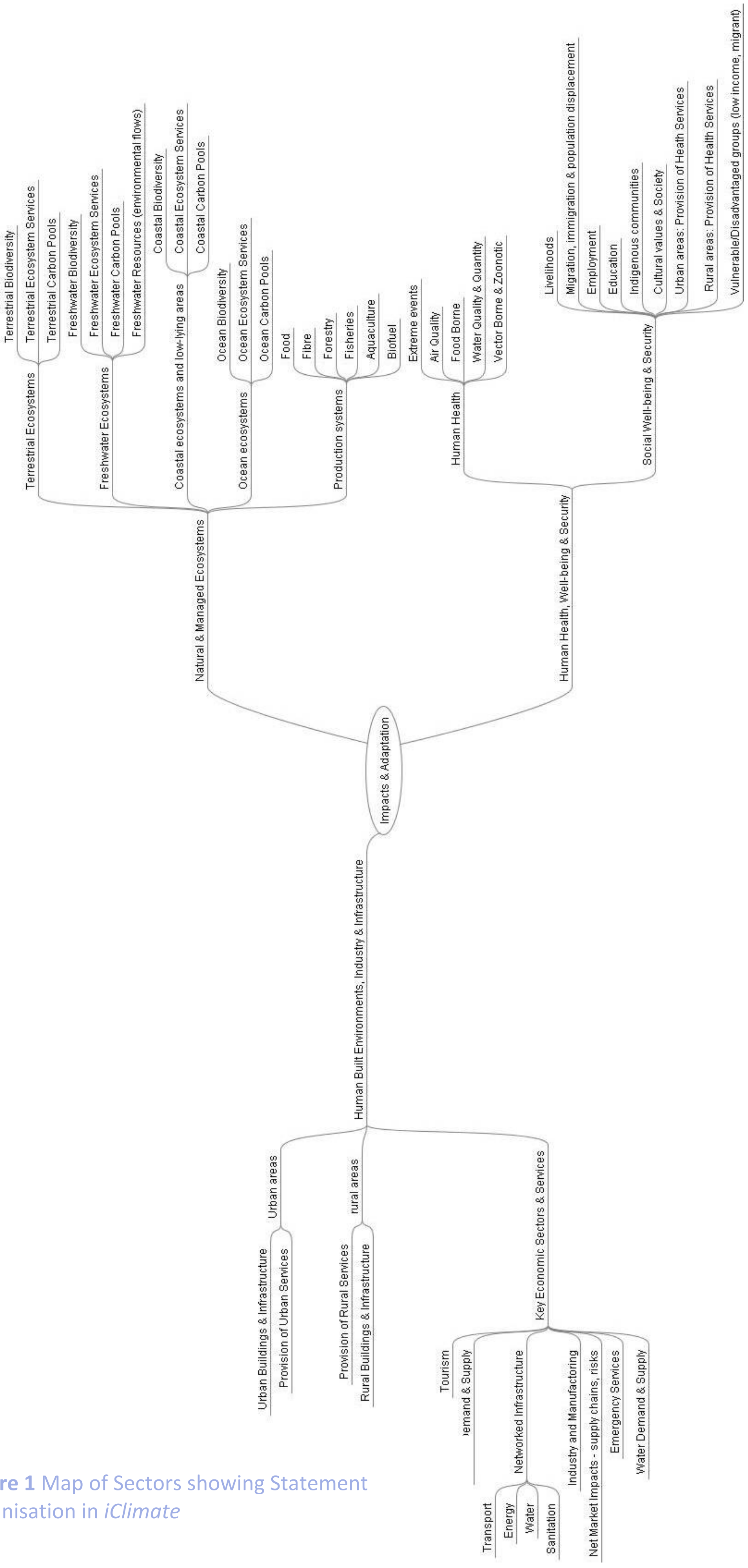
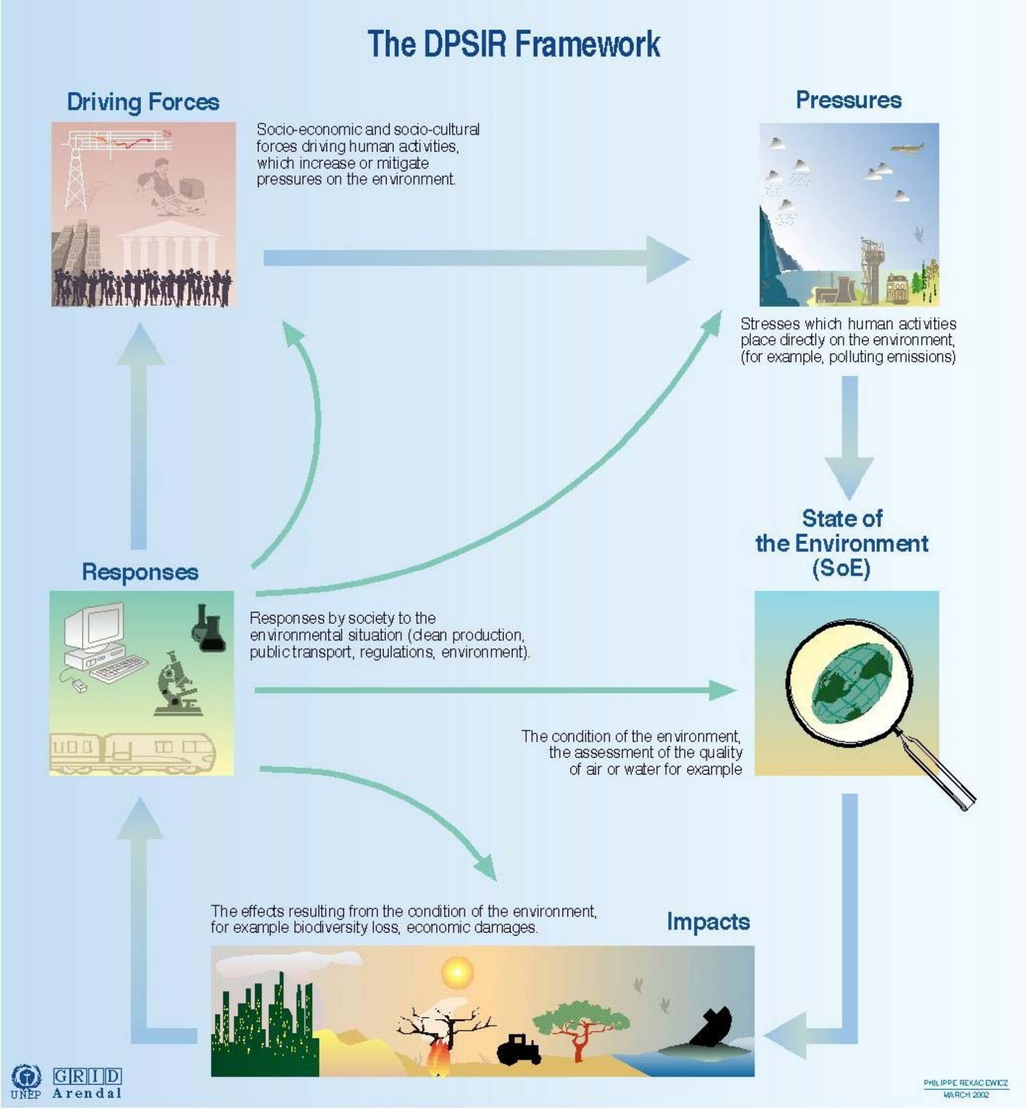


Figure 1 Map of Sectors showing Statement organisation in *iClimate*

2 Structuring Statements

The DPSIR Framework

Statements are structured using a framework called DPSIR. DPSIR is widely used in environmental assessments by European Environment Agency http://root-devel.ew.eea.europa.eu/ia2dec/knowledge_base/Frameworks/doc101182. DPSIR stands for Drivers-Pressures-State-Impacts-Responses and identifies a causal chain along these steps (Figure 2)



Socio-economic and socio-cultural forces driving human activities, which increase or mitigate pressures on the environment.

Stresses which human activities place directly on the environment, (for example, polluting emissions)

The condition of the environment, the assessment of the quality of air or water for example

The effects resulting from the condition of the environment, for example biodiversity loss, economic damages.

Responses by society to the environmental situation (clean production, public transport, regulations, environment).

Source : Global International Water Assessment (GIWA), 2001 ; European Environmental Agency (EEA).

Figure 2 The DPSIR framework for reporting on environmental issues. Downloaded from **http://maps.grida.no/go/graphic/the_dpsir_framework**

For environmental assessments, the Drivers (D) in DPSIR describe the social, demographic and economic developments of societies that exert pressures on the environment. The primary driving forces are population growth and developments in the needs and activities of individuals which result in changing levels of production and consumption. Pressures (P) are emissions of substances, release of physical and biological agents, (e.g. rate of CO_2 emissions) and the use of land and resources by humans. Pressures on the environment cause the State (S) of the environment to alter. State indicators describe the quantity and quality of physical phenomena (eg temperature), chemical phenomena (e.g. CO_2 levels in the atmosphere) or biological (e.g. community structure). Alteration of the environment Impacts (I) the functions of the environment. Impacts are changes in the environmental use functions (eg biodiversity loss, health impacts). Responses (R) are the policy, societal and technological responses by governments, groups and individuals to prevent, compensate, ameliorate or adapt to changes.

DPSIR distinguishes causal chains among driving forces, pressures, states, impacts and responses but the interactions may be non-linear both among elements in the DPSIR framework and within elements e.g. there may be several pressures driving a change in the state of the environment while reductions in pressures and drivers may occur from a mix of policy responses.

Advantages of DPSIR

- Displays the causal chain leading to an impact or response
- Establishes a basis to develop policy-relevant indicators
- Informs development of policy responses

The links between elements in the DPSIR framework reveal processes and indicators describing these. For example, ‘release of nutrients from agriculture’ may be the pressure with the state element being ‘levels of nutrients in coastal waters’ and an impact being ‘eutrophication of coastal waters’. Knowledge of run off and dispersion patterns can inform potential changes in the state of coastal waters so therefore would be an appropriate basis for monitoring programs. Policy responses to control nutrient release at the agricultural level (pressure) are likely to be most effective.

DPSIR has been widely adapted in Europe and further afield to identify indicators for environmental management, provide a support framework for decision making and conceptually underpin decision making software (Table 1).

Table 1 Examples of applications of DPSIR framework

Application	Use of DPSIR	Region and Reference
Environmental assessment of golf course installation policy	Development of indicators	Taiwan (Chen et al., 2011)
Development of a conceptual framework for the assessment of the impacts of environmental change on ecosystems services and policy responses	Concepts underpin development of the framework for ecosystem service provision	UK (Rounsevell et al., 2010)
Sustainable management of water resources at the catchment scale	To define common organizational structure of decision support software	Europe (Giupponi et al., 2004)
Feasible fisheries management responses	To identify driving forces leading to degraded fish stocks and environment and pathways for fisheries management responses	Turkey (Knudsen et al., 2010)
Ranking of water shed management alternatives	To structure decision framework	Korea (Chung et al., 2011)
Identification of social, economic and legislative factors for management	Integrate drivers of development and land use change in coastal zones	South Africa (Palmer et al., 2011)
Management of marine environment	To provide framework to support decision making (examples aggregate extraction and marine biodiversity)	UK (Atkins et al., 2011)
Assessment of environmental restoration in China	To identify cause and effects	China (Zhang et al., 2010)

In Australia, DPSIR has been modified for environment reporting in Victoria (Browne and McPhail, 2011), and as a threat and disturbance framework for the Queensland Wetlands Programme (Lynch, 2011) .

DPSIR for Climate Change

DPSIR has been applied, in a limited number of cases, as an integrative framework for identifying policy relevant indicators and policy responses of climate change impacts on natural and managed ecosystems. The effects of climate change on natural and managed ecosystems are complex and challenge the identification of suitable indicators of impacts to drive societal responses. Policy makers require assessments which integrate across all drivers of change and produce policy-relevant guidance on the local impacts of global climate change (Holman et al., 2008; Holman et al., 2005). Holman et al. (2005, 2008) applied DPSIR as a generic framework to develop a research methodology for stakeholder-led, regional climate impact assessment that evaluated cross-sectoral interactions driving landscape change and inform policy responses. Bongartz et al. (2007) developed scenarios for integrated water resources management, coupling downscaled projections for General Circulation Models to a DPSIR framework. Omann et al. (2009) applied DPSIR to evaluate climate change as a pressure on biodiversity and identify possible adaptation and mitigation policy responses. Huang et al. (2011) applied DPSIR to assess climate change impacts of energy consumption on environment and assess regulatory strategies of pollution control.

DPSIR for *iClimate*

We modified the DPSIR framework for iClimate (Figure 3) as a framework to structure statements. Climate change is always the **Driver** which exerts **Pressures** on natural and built environments, human health and societal systems (**State**) which leads to **Impacts** that elicit **Responses** through adaptation (Figure 3 red arrows) or mitigation (Figure 3 black arrows) action. Responses are only included in iClimate if they fit one of the three categories below:

1. Already implemented in Australia
2. Implemented overseas and recommended for Australia
3. Evidence-based from modelling studies

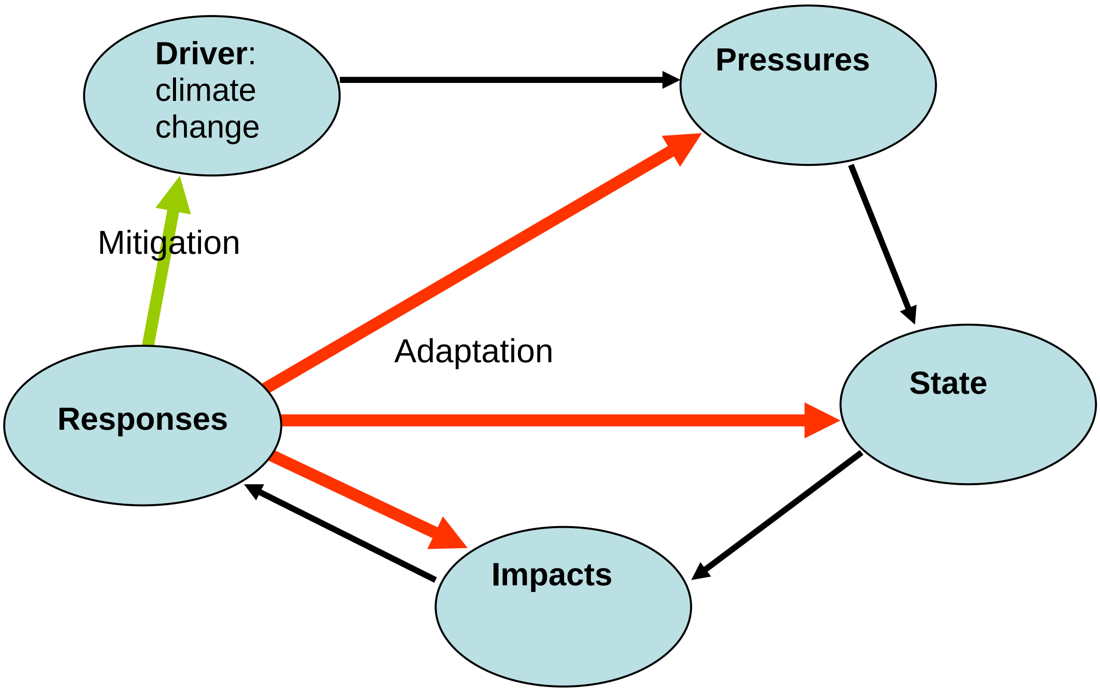


Figure 3 DPSIR framework for *iClimate* statements

DPSIR can encourage and support decision-making by identifying policy actions where the chain can be broken. DPSIR encourages users to consider of key questions: How fast are things changing? What aspects of the state of the environment we are concerned with or the target state? What are managers concerned with managing? What do we measure? What are we doing or could be doing to adapt to the impacts? What pressures have altered the state of the environment?

The DPSIR framework provides a structure for iClimate statements. However, each statement should be considered **its own context** that is, the nature of the state and pressure should be taken in the context of the impact. There may be multiple lines of evidence within each of the DPSIR stages. For ease of use, these are identified in iClimate text using D,P,S,I or R followed by a number (1,2,….). The numbering system also allows quick identification as to which step in the chain is addressed by Responses. Two hypothetical examples are given below (Table 2 and Table 3):

Table 2 Example of DPSIR framework in iClimate for Natural Ecosystems

DPSIR Stage	Example: Coral Bleaching
Driver	D1. Increased levels of CO_2
Pressure	P1. Strengthening current systems P2. Warming ocean temperatures
State	S1. Warmer and saltier waters in the SE
Impact	I1: Southern range extensions observed in a variety of species I2: Loss of macroalgae due to increase in sea urchins
Response	R1 to I2: Experiments to control urchin numbers by maintaining predator populations

Table 3 Example of DPSIR framework in iClimate for Built Environment

DPSIR Stage	Example: Concrete Structures
Driver	D1. Increased levels of CO_2
Pressure	P1. Increasing trend of atmospheric CO_2 P2. Rising sea levels
State	S1. Corrosion of concrete structures, particularly in coastal regions
Impact	I1: Reduction in safety of structures I2: Increased repair costs and reduction in viable lifetime of structures
Response	R1 to I1 and I2: Changing design standards for increased concrete cover and use of high strength grade concretes in coastal areas R2 to I1 and I2: Application of conventional maintenance and retrofitting options to enhance durability of concrete structures such as surface barrier or cathodic protection

3 Constructing Statements

Identification and synthesis of the literature

Project team members were assigned to each of the three major sectors (see Figure 1) based on their area of research expertise.

Table 4 Three sectors for organizing Statements in *iClimate* and assigned lead team members

Sector	Team Responsible
Natural and Managed Ecosystems	CSIRO (Poloczanska, Martin, Booth)
Human health, Well-being and Security	USC (Roiko, Carter)
Human built environments, industry and infrastructure	CSIRO (Wang)

Statements were identified and key literature gathered through reviews of the peer-reviewed climate change literature (journals, books) and also the peer-reviewed grey literature (reports, working papers). Calls for information were also made through all the NCCARF networks.

Producing Statements

In constructing Statements, it was found most useful to break the task down and consider the relationships between sequential stages. Firstly, the State (see Figure 3) of concern was defined. Then the Statement was worked upwards to Driver and downwards to Response.

To date, 46 Statements have been produced for iClimate. The Statements are accompanied by >800 publications. Statements are attached in Appendix 1.

Statements were sent to key experts for review.

4 iClimate database and website

Location

iClimate can be found at:

http://climate.adfi.usq.edu.au/

Overview

iClimate website consists of two parts:

1. Statements of climate change impacts and adaptations
2. References and electronic copies of publications (copyright permitting) supporting the Statements

Both of these sections are powered by ePrints (www.eprints.org), free digital repository software widely used by Universities to construct repositories of research papers, reports and other materials.

Statement Layout

Statements are structured in four sections:

- Title and summary which gives main findings
- Details which are context for the statement (if needed), whether the statement is based on observational or modeled evidence or both, the categories or sectors (see Figure 1) to which the Statement relates and the geographic regions to which the Statement relates.
- DPSIR section is the main body of the Statement containing fully referenced text.
- Other information contains fully referenced background information (if needed), hyperlinks to related Statements in the database and a full reference list which is hyperlinked to the publication database.

Publication Layout

The following information is displayed for each publication:

Title

Full reference

Abstract

Item Type

DOI or URL

Keywords

Category (from Figure 1)

Eprints URL (for iClimate editors)

Note: copies of the publications are only stored in *iClimate* where copyright permits.

Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices

Last, PR and White, WT and Gledhill, DC and Hobday, AJ and Brown, R and Edgar, GJ and Pecl, G (2011) *Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices.* Global Ecology and Biogeography, 20 (1). pp. 58-72. ISSN 1466-822X

Full text not available from this repository.

Abstract

Aim South-eastern Australia is a climate change hotspot with well-documented recent changes in its physical marine environment. The impact on and temporal responses of the biota to change are less well understood, but appear to be due to influences of climate, as well as the non-climate related past and continuing human impacts. We attempt to resolve the agents of change by examining major temporal and distributional shifts in the fish fauna and making a tentative attribution of causal factors. Location Temperate seas of south-eastern Australia. Methods Mixed data sources synthesized from published accounts, scientific surveys, spearfishing and angling competitions, commercial catches and underwater photographic records, from the 'late 1800s' to the 'present', were examined to determine shifts in coastal fish distributions. Results Forty-five species, representing 27 families (about 30% of the inshore fish families occurring in the region), exhibited major distributional shifts thought to be climate related. These are distributed across the following categories: species previously rare or unlisted (12), with expanded ranges (23) and/or abundance increases (30), expanded populations in south-eastern Tasmania (16) and extra-limital vagrants (4). Another 9 species, representing 7 families, experienced longer-term changes (since the 1800s) probably due to anthropogenic factors, such as habitat alteration and fishing pressure: species now extinct locally (3), recovering (3), threatened (2) or with remnant populations (1). One species is a temporary resident periodically recruited from New Zealand. Of fishes exhibiting an obvious poleward movement, most are reef dwellers from three Australian biogeographic categories: widespread southern, western warm temperate (Flindersian) or eastern warm temperate (Peronian) species. Main conclusions Some of the region's largest predatory reef fishes have become extinct in Tasmanian seas since the 'late 1800s', most likely as a result of poor fishing practices. In more recent times, there have been major changes in the distribution patterns of Tasmanian fishes that correspond to dramatic warming observed in the local marine environment.

Item Type:	Journal Article
Subjects:	UNSPECIFIED
Divisions:	UNSPECIFIED
Depositing User:	Elvira Poloczanska
Date Deposited:	24 Jan 2011 13:49
Last Modified:	24 Jan 2011 13:49
URI:	http://climate.adfi.usq.edu.au/id/eprint/47

Actions (login required)

Figure 4 Display of a publication in *iClimate*

Updating iClimate

iClimate has been developed so additional publications and statements can be easily added and the text in iClimate can be easily edited. Behind the user interface of iClimate sits two work areas: author work areas, and live archive. Statements and Publications in the Live Archive only are visible on the user interface.

iClimate has two levels of access for modifications and updates: author and editor.
Author rights will allow the upload statements and publications to an author-specific work-area. Once the author has checked the upload they then move the Publications or Statement to the Review area. Author

rights also allow the modification of any Publication or Statement deposited by that author. Editor rights allow further rights beyond Author rights. Only Editors can move all Publications and Statements into the Live Archive for user view. Editors can modify any publication or statement in the database.

New publications can be uploaded into iClimate either individually or as a batch from Endnote. However, the assignment of categories to each publication needs to be done individually within iClimate.

New statements can be uploaded by cutting and pasting text into the appropriate fields on iClimate. References are easily added by searching for the unique reference number or by lead author within iClimate. Similarly, hyperlinks can be added to related Statements.

5 Challenges and recommendations

Challenges

Defining the Framework

iClimate, in agreement with NCCARF, was never conceived to be a review of the Australasian climate change literature. Therefore, indentifying an appropriate framework was crucial to *iClimate* development. The framework has to sit across very diverse sectors from natural ecosystems to human to energy infrastructure. The DPSIR framework was finally agreed to be suitable for this purpose and the project team was able to apply this in all sectors.

Defining Statements

Adaptation responses tend to be implemented at local and regional scales by councils and state governments and many plans are not available in peer-reviewed literature. In agreement with NCCARF, the project team focused on the impacts of climate change.

Recommendations

Updating iClimate

We recommend two approaches for updating iClimate.

Firstly, filling in the current gaps in iClimate statements. These relate to both the information contained in the Statements and the gaps in the suite of Statements. Once iClimate is launched, we suggest obtaining feedback from the research, management and policy communities, for example through the NCCARF networks. This should identify adaptation responses currently only published in the grey literature, allow correction of any discrepancies in iClimate statements, and identify new Statements

Secondly, regular update of iClimate. We recommend that iClimate is updated annually to capture the rapidly increasing literature on climate change impacts and adaptation and to keep iClimate relevant.

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Appendix 1 Statements in iClimate

Human built environments, industry and infrastructure Page

Managed and natural ecosystems

Human health, well-being and security

BUILDING ENERGY CONSUMPTION

SUMMARY

- Climate change will impact local climate around buildings including temperature, humidity, solar radiation and wind.
- Any change in local climate may impact building energy consumption including peak demand which can be further exacerbated by population growth and urbanisation. In areas where demand for cooling is high, climate change may lead to a decrease in energy performance and an increase in carbon emissions, thus potentially compromising carbon mitigation efforts.
- Building energy efficiency and the climate adaptive capacity of buildings can be enhanced by use of new technology, adoption of renewable energy, change of behavior (of occupants), improvement of energy management and indoor heat source management, development of green infrastructure, and urban planning.

CONTEXT

This statement is a compilation of published scientific literature and reports

EVIDENCE

Projected Impact

CATEGORY(S)

Energy Demand and Supply, built environments

REGION

Australia

DRIVER(S)

Temperature
Solar Radiation
Humidity

PRESSURE(S)

Pressure 1

The mean temperature for Australia has increased, and warming has accelerated in recent decades (IPCC, 2007). The linear trend in Australian mean temperatures from 1910 to 2006 was 0.09°C per decade while for 1970 to 2006 it is more than double the rate (0.19°C per decade).

The future temperatures of five Australian cities (Sydney, Melbourne, Alice Springs, Darwin, Hobart) with different regional climates varying from cold to hot humid were projected using nine climate models. All show the warming will continue in all five cities under three carbon emission scenarios (A1FI, A1B, and the scenarios of CO_2 stabilisation at 550 ppm). The minimum change in temperature by 2100 among the five cities is almost 2°C compared to the temperature in 1990. The largest change, nearly 6°C by 2100, was in Alice Springs under the A1FI scenario,

Pressure 2

Under the three scenarios, the projected mean trend from nine climate models indicates that solar radiation will likely increase, and the projected humidity will likely decrease.

Pressure 3

Meanwhile, Australia has already experienced five of its hottest years in the last decade. As our climate warms in step with the global climate, average local temperatures will also increase across the continent, raising the likelihood of more hot days (CSIRO 2007).

Pressure 4

Population growth and subsequent urbanisation drives urban heat island (UHI; consistently higher temperature in built environments compared to surrounding rural areas) (Fujibe, 2010). Observations in Melbourne indicate an average UHI value of 1.13°C annually, and 1.29°C in summer which can go up to 4°C, and also shows an increase of approximately 0.2°C per decade (Coutts et al. 2010). Urban heat island may exacerbate the impact of warming temperature as a result of climate change (Shimoda 2003). The urban effect may lead to significant increase in hot nights in urban areas in comparison with rural areas.

STATE(S)

In Australia, 77% of all householders occupy separate houses (ABS 2008). Brick, timber and fibro cement are the most common materials for outside walls. Dwellings that have insulation increased from 52% in 1994 to 61% in 2008. 67% of householders use either air-conditioner or evaporative cooler. Currently, most Australian states and territories require a minimum of 4 to 5 star energy efficiency rating for new house designs with this requirement with recent increases to 6 stars for some regions (Carmichael 2009).

In general, energy efficiency is rated at average 2 stars for existing Australian houses (AGO 2000), and 5 stars for standard newly constructed houses. Newly constructed high energy efficient houses can be 7 stars or higher. The heating and cooling energy requirement of a residential house at a given star rating also depends on its location. For example, in Sydney, the energy requirement for a 7-star house is less than 29MJ/m^2 annually, 49MJ/m^2 for a 5-star house, and 144MJ/m^2 for a 2-star house. For the similar houses in Darwin (a cooling dominated region), a 7-star house requires around 277MJ/m^2, 400MJ/m^2 for a 5-star house, and 628MJ/m^2 for a 2-star house. Increasing the energy efficiency of residential buildings has been advocated as a cost-effective means to reduce energy consumption (CIE 2009).

Meanwhile, building energy demand also contributes considerably to electricity peak demand, especially on very hot or cold days. The capacity for extra electricity to meet these demands has to be maintained, resulting inefficient production. For example, in NSW 10% of generating capacity is required for only 1% of peak demand time in a year (Frew 2006). It is even worse in SA.

The state of building energy consumption is closely driven by the local climate condition, especially 'dry bulb' temperature (air temperature shielded from radiation and moisture), 'wet bulb' temperature (air temperature taking into account moisture in the air) and solar radiation which is modified slightly from clearness index (atmospheric and cloud conditions) and wind speed (Wan et al. 2011, Lam et al. 2010). Any change in the local climate will modify building energy consumption including peak demand.

IMPACT(S)

Impact 1 (see example in Background section)

Increasing temperature in conjunction with increasing solar radiation and decreasing humidity has significant impacts on residential electricity consumption. An early simulation study by BRANZ (2007) indicated that cooling load increased significantly with a tripling of nation-wide average demand by 2070. There is noticeable decrease in heating load in cooler climate zones. Requirements for home air conditioning increases by an average of 76% across the country.

A building impact assessment was undertaken recently based on the Australian house energy rating software, AccuRate. It was found that buildings with existing energy efficiency from low to high will all be impacted by climate change at different scales. The sensitivity of the total heating and cooling (H/C) energy requirement of houses to global warming differs depending upon the star rating or the energy efficiency. The energy requirement of the houses with a lower energy rating of 2 stars, which represents the average energy efficiency of the existing housing stock, appears to be more sensitive to global warming in terms of the absolute changes in the energy requirements.

The impacts of climate change on residential building H/C energy requirements are quite different in different regions (Wang et al. 2010). The locations at a cooling dominated warm or H/C balanced temperature regional climate (Sydney, Alice Springs, Darwin) have the highest risk of inadequate of electricity supply. In Sydney, Alice Springs, and Darwin, the total H/C energy requirement consistently increases over time. The increase is highest for a hot humid climate (Darwin), followed by the hot and dry summer climate (Alice Springs), and lowest for H/C balanced temperate climate (Sydney). The H/C energy requirement level of Melbourne and Hobart will be lower than in 1990.

Impact 2

Global warming may have significant impact on building energy performance, carbon emission and related emission reduction policies (Wang et al. 2011). In hot/dry or humid cooling-dominated climate, the effectiveness of carbon emission reduction effort by increasing building energy efficiency would like be considerably compromised by global warming. For example, in Darwin, reductions of carbon emissions gained by increasing housing energy rating from 2 to 5-star (or retrofitting old houses to meet current standard) will likely be wiped out when global warming reaches 1.7℃.

Impact 3

By simulating building energy, it was found that global warming would likely affect the thermal and energy performance of office buildings in Australia (BRANZ, 2007). Assessing the energy consumption in all eight capital cities in Australia, it was found that the ground floor of office building would be most sensitive to the global warming. With the increase of external air temperature, the overheating hour may increase up to 53% in Darwin and 47% in Hobart (Guan 2009a). A 28-59% increase of cooling capacity is required for new office buildings to meet the warmer scenario projected 2070 (Guan 2009b).

Impact 4

Increases in the number of hot days and frequency of heatwaves will impact building energy consumption and exacerbate the peak demand during the summer, adding more pressure on power supply. A study in UK using the HadRM3 climate model, found that for each 1°C increase in external temperature, the peak cooling load increases by 10%, chiller power by 14% and fan power for air distribution by 30-50% (Watkins et al. 2011). Though there is no accurate quantification on how much the building energy consumption will affect peak demand under future climate change in Australia, simulations using CSIRO Mk3.5 climate model and downscaling by CSIRO's CCAM indicated that for an 1°C increase in the average temperature of Australian capital cities, peak regional demand changes by -2.1% in New South Wales, -0.1% in Victoria, +1.1% in Queensland and +4.6% in South Australia (Thatcher 2007). As the timing and duration of daily peak demand at any location varies between summer (for cooling) and winter (for heating), the projected demands take into account changes in energy use behaviour as well as projected changes in climate. The change in peak demand is much lower than the change in annual energy requirement estimated at individual residential house level (BRANZ 2007; Wang et al 2010).

Impact 5

Increased urban heat island will exacerbate the increase in local temperature and further increase the energy cooling demand in Australia.

RESPONSE(S)

Response 1: to I1 and I3

Increased stringency in building design can improve energy efficiency for climate change mitigation and may in turn enhance the adaptive capacity to climate change in the sense of maintaining current energy consumption or reduce use in the future. For example, the enhancement of thermal performance and thermal mass of buildings to reduce energy consumption (Duell et al. 2005). Passive design is often considered as an option with its energy performance depending on building orientation, shape, façade glazing and obstructions of surroundings. Modelling by BRANZ (2007) indicates that improvement of insulation will reduce the energy load.

Other studies in New Zealand also indicated that the energy consumption could be reduced by 40-70% from 2000 level by passive design, optimising wall and roof design (Su, 2009). Investigations of houses in Perth, by simulation using AccuRate indicated 83% of houses in a passive design are more likely to meet 5 star energy rating in comparison with 43% for the houses without considering passive designs (Peterkin 2009).

However, design adaptability should also be considered for a mass cost-effective and high-energy-performance building development (Morrissey 2011). Using AccuRate and representative residential housing in Victoria, Australia, it was found that the energy performance for smaller dwellings less than 250m^2 would not change too much, demonstrating that it has a less limitation for its adoption in building development without compromising energy performance. Meanwhile, it also indicated that higher energy performance or energy rating building designs would have more adaptability.

A more detailed study by Ren et al (2011) indicated that for existing houses in mild temperate regions (such as Melbourne and Mildura), improvement of building envelop energy efficiency from 2 to 5 stars may be required to achieve the adaptive capacity to fully counteract the effects of global warming up to 6°C. For new houses, the improvement of building envelop energy efficiency from 5 to 7 stars is required to achieve the capacity that is sufficient to counteract the effects of global warming up to 6°C in Melbourne and 4.5°C in Mildura.

To promote building energy efficiency, Australian Building Codes Board (ABCB) has increased the stringency of the Building Code of Australia (BCA) to ensure the industry adopts energy efficient measures, which is also essentially positive in response to climate change. For new house designs, the requirement is rising to 6 stars (Carmichael 2009).

Response 2: to I1 and I3

While renewable energy is considered as one of effective options to decarbonise the Australian housing sector (Newton et al. 2011), the adoption of local renewable energy generation can also enhance the adaptive capacity of housing to accommodate the impact of climate change. In cooling dominated climates such as Darwin and Alice Springs, and heating and cooling balanced regions such as Brisbane and Sydney, other alternative technologies may be required in addition to improve building energy performance and boost the adaptive capacity (Ren et al. 2011). These may include the use of high EE air-conditioning and appliances, and installation of on-site renewable energy such as solar PVs and solar hot water.

Response 3: to I4

The use of energy efficient appliances may also improve the adaptive capacity of buildings. Simulations using CSIRO Mk3.5 climate model and downscaling by CSIRO's CCAM indicated that by halving the energy demand of cooling appliances by increasing their energy efficiency, reduced the peak electricity demand by 2.2% in New South Wales, 2.9% in Victoria, 5.6% in Queensland and 12.3% in South Australia (Thatcher 2007).

Response 4: to I1 and I2

In addition to building energy efficiency and the use of renewable energy that may increase the climate adaptive capacity, 'consumer energy efficiency' was proposed which considers occupants' behaviour (Stephenson et al. 2010). In the context of a New Zealand case study, the energy culture framework is presented, linking and interconnecting the effects of technologies, activities and aspiration at the scales cross individuals, families, institutions, or entire economic sectors, examining the interaction amid cognitive norm (e.g. expected thermal comfort), material culture (e.g. heating devices) and energy practices (e.g. heating hours) in relation to energy consumption.

Response 5: to I1 and I4

Better energy management, on another hand, will improve the resilience of buildings in response to climate change. Better energy management should not only address the problem of escalating comfort needs, but should also not generate more expectation of comfort that would push up the demand, especially the peak demand (Strengers 2008). It could be driven by new regulations including pricing, and introduction of new technology. In addition, providing opportunity to control comfort in each room such as thermostats may improve occupants' satisfaction (Karjalainen 2009). The optimisation of thermosetting for cooling and heating setting may also significantly reduce energy consumption (Orosa et al. 2010; Moon et al. 2011).

Response 6: to I3

In addition, proper management heat sources inside buildings may also reduce energy consumption. For example, reduction of lighting and equipment loading can reduce the internal heat sources in office buildings. Reductions of 10W/m^2 will reduce internal temperature by about 1°C (BRANZ 2007), leading to the reduction of cooling loads.

Response 7: to I1 and I3

Application of technology will improve the climate adaptive capacity for buildings in response to climate change, such as use of cooling technology, for example, improvement of the coefficient of performance (COP) (Watkins et al. 2011). A study in UK found that mixed-mode building, which apply passive measures to minimise active cooling, can maintain adequate thermal comfort in UK in the future, and evaporative cooling may be considered an effective low-energy cooling technique with increased wet-bulb temperature depression, or the difference between dry and wet bulb temperature, in future warming climate (Smith et al. 2011), such as the arid areas in Australia.

Response 8: to I1, I3 and I5

Technology also includes development of 'cool colours', not necessarily white, that reflect heat by optimising the near infrared reflecting properties of pigments (Gurzu et al. 2010). The paint can be used for both roofs and roads, assisting in reduction of cooling loads and urban heat island effect, especially in summer.

Response 9: to I5

Developing green infrastructure will reduce the effect of urban heat island. A synthesis of data on the cooling effect of parks shows that, on average, a park was 0.94°C cooler than surrounding built environment in the day (Bowler et al. 2010). Green areas were identified to be one of most significant factors to influence urban thermal environment in addition to building forms (such as floor area ratio, building height and building density) (Zhao et al. 2011), and the aggregated amount of impervious surface area is considered as the primary drivers to urban heat island (Zhang et al. 2010). Therefore, green infrastructure is one of options to reduce the impact of urban heat island, moderate the climate change impact in urban areas, and subsequently reduce cooling energy consumptions. Proper urban planning can optimise the urban climates and reduce urban heat island (Coutts. 2010), and consequently reduce building energy consumption.

BACKGROUND

As an example (Wang et al. 2010), 5-star buildings generally represents the average energy efficiency of newly built residential buildings in Australia. In Darwin, compared to the energy requirement in 1990, cooling and heating energy requirement of an Australian house of 289.4m^2 gross floor area and 207.4 air-conditioned area is projected to increase 227 MJ/m^2 by 2050 and 540 MJ/m^2 by 2100 for the A1FI scenario. In Alice Springs, there is an increase of 80 MJ/m^2 by 2050 and 305 MJ/m^2 by 2100. In Sydney, there is a smaller increase of 49 MJ/m^2 by 2050 and 170 MJ/m^2 by 2100. In terms of the percentage changes in energy requirement, Sydney appears most sensitive to global warming due to the rapid increase in cooling requirement and the negligible reduction in heating requirement on a relatively small reference energy requirement in 1990, followed by Alice Springs and then Darwin. Consequently, global warming may potentially pose more pressures to the capacity of local energy supply in Sydney. Moreover, there appears to have been an acceleration in the cooling energy requirement beyond a global warming temperature of 2°C in Sydney.

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DURABILITY OF CONCRETE BUILDINGS AND INFRASTRUCTURE

SUMMARY

- Concrete is the main construction material used in Australian buildings and infrastructure. Its performance is vital to provide the nation's essential services and maintain economic activities. The key performance requirements for the design, construction and maintenance of concrete structures relate to safety, serviceability, and durability.

- The deterioration rate of concrete structures depends on the construction processes employed, the composition of the materials, and on the environment.

- Changes to climatic conditions will alter this environment, especially in the longer term, altering deterioration processes with implications for the safety, serviceability and durability of concrete infrastructure.

- In this regard, proper climate adaptations in design and maintenance have to be considered in response to climate change.

CONTEXT

This statement is based on a synthesis of peer-reviewed literature

EVIDENCE

Projected Impact

CATEGORY(S)

Urban buildings and infrastructure; Rural buildings and infrastructure; Atmospheric and land surface climate; Ocean climate and sea level

REGION

Australia

DRIVER(S)

Temperature
Atmospheric CO_2
Humidity
Sea level rise

PRESSURE(S)

Pressure 1

The Intergovernmental Panel on Climate Change Fourth Assessment Report indicated a significant increase of CO_2 concentration in the atmosphere from 280 ppm in 1750 to 380 ppm in 2005 with an increasing trend. In comparison with pre-industrial temperatures, the best estimation of the temperature increase from 1990 caused by increasing atmospheric CO_2 concentration can be 2.1 °C for 550ppm CO_2, 3.0 °C for 700 ppm, and 4.4 °C for 1000ppm CO_2 by 2100 (IPCC 2007).

Pressure 2

The mean temperature for Australia as a whole has been increasing, and warming has accelerated in recent decades (IPCC 2007). The linear trend in Australian mean temperatures from 1910 to 2006 is 0.09℃ per decade while that for 1970–2006 is more than double that rate (0.19℃/decade). Based on the average projections from nine GCMs considering A1B, A1FI and 550ppm stabilisation scenarios for ten capital cities, i.e. Adelaide, Alice Springs, Brisbane, Canberra, Darwin, Hobart, Melbourne, Perth, Sydney and Townsville, temperature trends increase, while trends of relative humidity decrease. It was also found that the increases in the air temperature in a hot/warm regional climate are higher than those in a cold climate (CSIRO 2007; Wang et al. 2010a; b).

Pressure 3

The estimated average relative sea level rise around Australia over the period 1920 to 2000 was 1.2 mm per year, a global-average rise of 18-59 cm by 2100 is projected with a possible additional contributing from ice sheets of 10-20cm (CSIRO 2007).

STATE(S)

State 1

Concrete construction is the predominant construction type for most critical infrastructure, and its performance is therefore vital to underpinning the nation's essential services and economic activities.

State 2

In general, the durability of concrete structures is considerably affected by the deterioration of concrete materials that are subject to physical factors (e.g. freeze–thaw cycles, thermal mismatch between cements and aggregates), mechanical factors (abrasion, impact and erosion) and chemical factors that occur both with and external to the concrete structure (Neville 2008).

Chloride-induced corrosion is the major threat to the durability of maritime and coastal concrete structures (Akiyama et al. 2010), while **carbonation** caused by penetration of CO_2 reduces the pH and expose steel reinforcement to corrosion (Ho et al. 1987; Ann et al. 2010). Corrosion products cause considerable expansion, generating internal stress and causing cracking flaking or delamination.

State 3

Existing standards in Australia address the need to take into account environmental exposure. They specify requirements for durability, which is defined as the capacity of structures to resist deterioration given expected and unexpected environmental attack.

Environmental exposure is classified on the basis of macroclimate (arid, temperate and tropical climatic zones), and microclimate represented by the proximity to the coast (Australian Standard 2009; Wang et al. 2010a; d). These are categorised into exposure classes A1, A2, B1, B2, C1 and C2 (or C in the previous version of the standard). Considering the non-industrial environment, inland concrete structures (or >50km from the coast) will be in one of three exposure classes: A1 in arid climatic zone, A2 in temperate climatic zone, and B1 in tropical climatic zone. Structures near the coast (or between 1km and 50km from coast) are classified as B1, while structures less than 1km from the coast are in B2. Structures with a periodical contact with water, known as spray zone and splash zone, are in classes C1 and C2. For each exposure, concrete structures are required to meet both strength and cover requirement in addition to water/cement ratio and cement content to meet minimum durability (Australian Standard 2008; 2009). Generally, concrete structures in low exposure classes (i.e. A1 and A2) have fewer requirements in cover and concrete strength grade, in contrast with those in high exposure (i.e. C1 and C2).

State 4

Considering no climate change, or CO_2 concentration, temperature and relative humidity by 2100 are maintained at the level same as in 2000 in Australia (Wang et. al, 2010b):

1. Carbonation depth of concrete by 2100 is in the range of 0 to 21mm;
2. Probability of corrosion initiation by 2100 falls in the range from 0 to 28 percentage points;
3. Probability of carbonation induced corrosion damage by 2100 is in the range of 0 to 25 percentage points.

State 5

The chloride penetration induced corrosion mostly occurs around coastal regions. Without consideration of climate change, the probability or likelihood of corrosion initiation and damage ranges from 0 in the south part of Australia to 34 percentage points in the north, mostly affected by regional temperature (Wang et al. 2010b). It is understood that chloride-induced corrosion will be affected by temperature and humidity (El Hassan 2010).

IMPACT(S)

Impact 1

Increases in atmospheric CO_2 levels will affect carbonation-induced corrosion damage and safety loss to reinforced concrete (RC) structures, and carbonation-induced safety loss to pre-stressed concrete (PSC) structures over the next 100 years considering (Stewart et al 2008). For RC and PSC structures, for the worst case emissions scenario, the mean proportion of corrosion damage is up to 540% higher than that predicted for the best CO_2

emission mitigation scenario. There is thus a significant likelihood of corrosion damage that will need costly and disruptive repairs during the service life of many concrete structures. For the worst case scenario, the probabilities of flexural and shear failure are about 6% and 18% higher than the best mitigation scenario, respectively.

A recent report released by CSIRO (Wang et al. 2010b) and a similar study (Stewart et al. 2011) assessed the impacts of climate change on carbonation-induced corrosion of concrete structures. Considering of climate change (medium estimation of temperature and relative humidity) at A1FI emission scenario projected by CSIRO Mk3.5 climate model and the definition of environment exposure defined in relation to the distance of concrete structures from the coast (Wang et al. 2010b, e; Stewart et al. 2011):

1. Carbonation depth change by 2100 falls in the range of 15 mm less to 8mm more than the baseline where climate change is not considered. Two areas will face higher carbonation. Around the border between New South Wales and Victoria, temperature increase pushes carbonation higher. In a small area in the west of Western Australia, the impact of a decrease in relative humidity is not sufficient to offset an increase in temperature, leading to an increase in carbonation.
2. Probability of carbonation-induced corrosion initiation changes from 22 percentage points less to 27 percentage points more than the baseline (presented in S1) by 2100, depending on the region. The probability is higher around the boundary between the arid climatic zone in central Australia and the temperate climatic zone in the west, south and east of Australia. This is mostly caused by a lower cover requirement in design for concrete structures in arid and temperate climatic zones, which are also away from coasts.
3. Probability of carbonation induced corrosion damage changes due to climate change in a range from 19 percentage points of decrease to 15 percentage points of increase than the baseline (presented in S1) by 2100. Its spatial patterns are similar to those of corrosion initiation.

Impact 2

Global warming influences the probability of corrosion initiation, and reduces reliability concrete structures. In some cases, the climate change will lead to lifetime reductions ranging from 2% to 18% for structures located in oceanic environment (Bastidas-Arteaga et al. 2010).

In Australia, climate change may have moderate impacts on chloride-induced corrosion (Wang et al. 2010b; Stewart et al. 2011).

1. In response to climate change, an increase in the probability of corrosion initiation and damage is generally more along the coast than other areas, with hotspots along the west coast of Western Australian and the east coast of New South Wales up to the border with Queensland. This is caused by the relatively higher increase in temperature to 2100 in those areas.
2. Due to climate change, the risk of chloride induced corrosion initiation increases in the range 0 to 3.5%, depending on the region. This lower change in risk profile may be due to the fact that under climate change there is likely to be less marked increases in temperature in coastal areas compared to inland areas. A corollary is that in inland areas, where chloride and moisture prove suitable for corrosion

initiation, the risk of corrosion is likely to increase more as temperature increases under climate change.

RESPONSE(S)

Response 1: to I1 and I2

Increase in concrete cover is one of the most straightforward adaptation options in the design of concrete infrastructure to maintain structural durability and serviceability under climate change, which can increase the time of carbonation and chloride ingress to reach concrete reinforcement and in turn delay carbonation- and chloride-induced corrosion (Wang et al. 2010b; 2011).

For exposure classes A1, A2 and B1 the current cover design requirement is a minimum of 20mm, 30mm and 40mm respectively. The cover is required to increase up to 10mm for exposure A1 and A2, and 8mm for exposure B1 to counteract the impact of climate change on carbonation-induced corrosion. This is an increase in cover up to 50% for exposure A1, 30% for exposure A2 and 20% for exposure B1.

Ignoring ocean acidification, the increase of concrete cover required to counteract chloride-induced corrosion is within a more moderate range of up to 5mm in high exposure classes C1 and C2. Increase of concrete cover required in Sydney is relatively greater than in other areas; projected temperature increase was greatest here among the nine urban cities studied. The concrete cover for structural design life to 2100 needs to increase up to 4mm for exposure class C1 and 5mm for C2. In comparison with the current cover requirement of 50mm for exposure class C1 and 65mm for exposure C2, this is about an 8% increase. Greenhouse emission reduction could reduce the requirement to increase cover.

Response 2: to I1 and I2

In addition to the option of increasing cover, a reduction of the diffusion coefficient is another effective way to increase the time of carbonation or chloride penetration to reach concrete reinforcement. The reduction of carbon dioxide diffusion coefficient to mitigate climate change impact on carbonation-induced corrosion is at least 15% for a design service life of concrete structures up to 2040. The reduction is 30% and 45% for a design service life up to 2070 and 2100, respectively. For chloride penetration, the diffusion coefficient has to be reduced at least 5-8% for structure designed to service by 2100 for exposure C1, and 5-7% for exposure C2.

In practice, selecting a high strength grade of concrete may reduce the diffusion coefficient and therefore enhance the adaptive capacity of concrete structures to counteract climate change impacts. For example, using the strength grade of concrete designed for exposure B1 will reduce carbonation-induced corrosion initiation of concrete structures at exposure A1 and A2 from 21% to 8.7% by 2040, from 45% to 24% by 2070, and from 71% to 44% by 2100. It is generally considered enough to use the strength grade for exposure B2 for concrete structures actually in exposures A1, A2 and B1 exposures.

To counteract the impact of changing climate on chloride-induced corrosion, a strength grade for exposure B2 should be selected for concrete structures designed for exposure B1, and a strength grade of C should be applied for concrete structures designed for exposure B2. For concrete structures at exposure C an even higher strength grade is required.

Response 3: to I1 and I2

For existing concrete structures under changing climate, adaptation can be enhanced by developing new technologies for maintenance to counter the impact of increasing corrosion risk under changing climate. On the other hand, there is a wide range of conventional maintenance and retrofitting options that can enhance the durability of concrete structures and these can be applied to reduce the adverse affects of climate change.

Creating a surface barrier by coating can reduce the exposure of concrete structures to external stimuli. Meanwhile, extraction and cathodic protection is more commonly used for structures with high corrosion risk to reduce the penetration of deleterious agents. Cover replacement is most effective, but also the most expensive option. This is followed by cathodic protection that also has a high operating cost and then realkanisation or chloride extraction. The surface coating is the cheapest option, but is also less effective.

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ELECTRICITY DEMAND, SUPPLY AND DISTRIBUTION INFRASTRUCTURE

SUMMARY

- Australia and New Zealand are facing challenges of warmer future, especially in those areas with warm or hot climates. The electricity demands are highly sensitive to temperature.

- The peak electricity demand in Queensland and South Australia are likely to increase by 1.1% and 4.6 %, respectively, and decrease by 2.1 %, and 0.1 % in New South Wales and Victoria, respectively.

- In Hamilton, New Zealand, supply capability could meet the demand in 2030 even with high population increase but the circuit rating may be impacted. Besides, increased electricity demand requires more fossil fuels to generate electricity leading thus increasesd greenhouse gas emissions.

- In term of reducing electricity demand and greenhouse gas emission, improvements in energy efficiency of cooling appliances and compressed air systems, use of renewable resources, and promotion in energy efficiency in building design have been demonstrated as effective.

- Consideration of climate change in design of electricity infrastructure is necessary to reduce the negative impacts of climate change on electricity transmission infrastructure, such as conductors.

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Energy Demand and Supply
Networked Infrastructure: Energy
Atmospheric and land surface climate

REGION

Australia
New Zealand

DRIVER(S)

Temperature
Extreme and variable weather patterns

PRESSURE(S)

Pressure 1

The mean temperature for Australia has been increasing, and the warming has accelerated in recent decades (IPCC, 2007). The linear trend in Australian mean temperatures from 1910 to 2006 is 0.09℃ per decade while that for 1970–2006 is more than double that rate (0.19℃/decade).

The temperature in four state capital cities under the IPCC A2 carbon emissions scenario projected by the CSIRO Mk 3 climate model, shows in increase in average maximum temperatures over the period 2001–2010 to 2051–2060 of 0.9°C for Sydney, 1.2°C for Melbourne, 1.2°C for Brisbane and 1.1°C for Adelaide. The average minimum temperatures are projected to increase by 1.1°C for Sydney, 1.0°C for Melbourne, 1.4°C for Brisbane and 0.9°C for Adelaide (Thatcher 2007).

Temperature in Hamilton, New Zealand was projected by the models developed by NIWA (Jollands, 2007). The models were based on the CSIRO and Hadley models (Houghton, Ding et al. 2001) for a total of four climate change projections (S1—CSIRO Low; S2—CSIRO High; S3— Hadley Low; S4—Hadley High) of temperature in Hamilton over the period between 2005 to 2030. The projections showed a progressive increase in temperature.

Pressure 2

In addition to higher temperatures that would drive up electricity demand and put more pressure on electricity infrastructure, the increasing likelihood of the occurrence of severe winds, bushfire as well as droughts in Australia (CSIRO, 2007) also necessitate more reliable electricity transmission infrastructure.

STATE(S)

State 1

In Australia, by June 2009, there was a principal installed electricity supply capacity by about 50.8GW sourced from coal, gas and renewables; there are approximately 781,000 circuit kilometers of overhead transmission lines and about 114,000 circuit kilometers of underground cables, with total 675,348 transformers. In 2008-09, there are about total 10 million end users who consumed 204,300GWh; including 59,881GWh by residential use and 143,175GWh by business (ESAA, 2010). In addition, infrastructure for electricity in Australia is rated as C^+ in Australian Infrastructure Reporting Card (2010), implying that major changes are required before it is fit for current and future purpose.

State 2

In New Zealand in 2007, there was 8.9GW electricity generation capacity and more than 40,000 GWh of electricity generated from various sources, including coal, oil and renewable. 33% consumed by residential use, 23.3% by commercial use and 43.7% industrial use (including agriculture). Hamilton City, New Zealand, for example, is supplied by three substations, each operating 3-phase transformers, totalling 118 MVA theoretical capacity. The network is capable of operating even if one of 23 MVA transformers fails. Thus, Hamilton City's capacity infrastructure is relatively robust. However, climate change impact on peak-load electricity consumption and conductor resistivity should be taken into account.

State 3

The electricity demand is sensitive to climate change in terms of its relationship with temperature. Increased variability in demand is an issue for all participants of the Australian National Electricity Market (NEM), and the problem is particularly important in South Australia where the daily peak demand during extreme hot days in summer can increase to twice the average daily summer peak demand (Thatcher 2007).

State 4

One of significant issues for electricity markets is the management of demand variability, which is managed through the Australian National Electricity Market (NEM) in Australia (AEMO, 2010). In addition to the concerns of stresses on the electricity transmission network for supply and its reliability and security, variability in electricity consumption is also important on the financial aspects of the systems from spot price to long-term investment decisions in base and peaking load plants.

IMPACT(S)

Impact 1

Weather, including temperature, determines a large proportion of the variability in electricity demand and long-term electricity demand will be impacted by climate change.

Models (intraday demand model) show that a temperature increase of 1°C by 2051-2060 , while change regional peak demands by -2.1% for New South Wales, -0.1% for Victoria, +1.1% for Queensland and +4.6% for South Australia, assuming no acclimatisation by the resident population (Thatcher 2007)

To enhance electricity transmission and distribution network to accommodate the increased use of air-conditioning in a warmer climate, especially during summer, could take 57% of total cost ($2.5bn) arising from climate change over the next five years (Parsons Brinkerhoff, 2009)

However, the degree of impact depends on geographic locations. In Hamilton City, New Zealand, despite the significance of climate variables in explaining the variation in monthly electricity consumption, population increase over the next 25 years could have a greater impact on electricity demand than the projected change in climate. Moreover, even in the high population scenario, the redundant design of power supply in Hamilton City ensures consumption in 2030 should be well below the supply constraint (Jollands, Ruth et al. 2007).

Nevertheless, as a result of climatic changes, electricity distribution infrastructure is likely to require upgrading earlier (but only by 1 or 2 years) than would otherwise have been the case (Jollands, Ruth et al. 2007).

Impact 2

Impacts on electricity distribution and transmission infrastructure are represented by increased risks of blackout when demand exceeds supply, damage to above ground assets, reduced network capacity and accelerated asset deterioration. (Maunsell Australia, 2008).

Warmer temperatures will increase the electricity demand/load as a result of increased use of air-conditioning. A preliminary study indicated (Nguyen et al, 2011) that when the energy demand increases by 20%, the energy loss will increase by 44%. During the 3-day hot spell in January 2009, the peak power demand in Victoria jumped by about 2000 MW, i.e. about 24% above the average maximum values for January/February. The electrical loss then would increase by 53%.

Although, in Hamilton City , New Zealand, supply cables are all underground and are designed with the considerations of ground temperature (25°C) and air temperature (28°C) with very limited climate change impacts, the climate change is likely to have an impact on the circuit rating. Climate change is likely to reduce the circuit rating (in MVA) by 0.25–1% in summer and autumn, 0.3–0.7% in winter and 0.29–0.6% in spring. While these are not considerable changes, they do add additional restrictions on the circuit (Jollands, Ruth et al. 2007).

Impact 3

The combustion of fossil fuels for global electricity generation accounted for approximately 22% of total global GHG emissions (10.5 Gt-CO_2) in 2002 (IPCC, 2005 and IPCC, 2007) and is rising.

Fossil-fuelled electricity generation accounts for a high proportion of total electricity generation system in Australia and New Zealand. Australia relies on fossil fuels for over 90% of domestic electricity generation, far more than the global value of 68% (Clifton and Boruff 2010; Kuwahata and Monroy 2011). In New Zealand, although electricity generation system is dominated by hydro generation at approximately 60% of installed capacity between 2005 and 2007, the fossil-fuelled generation represents approximately 32% (Mason, Page et al. 2010).

In the future, operation of electricity generation will be constrained by changes in emission regulations. Adaptation to the change to pursue 'carbon neutral' may incur a typical network business a cost of between $1.2m and $3.2m over a 5-year regulatory period (Parsons Brinkerhoff, 2009).

Impact 4

Reported by Parsons Brinkerhoff (2009), climate change is likely to increase exposure of the energy network to risks from extreme events such as bushfire, tropical cyclones and, to a lesser extent, floods in addition to increasing peak demand. Climate change is likely to have more impacts in tropical regions and those regions that would be affected by the southward shift of the cyclone belt.

RESPONSE(S)

Response 1: to I1 and I3

An effective way to accommodate climate change impact is to introduce measures to reduce demand, for example by improving the efficiency of electrical cooling appliances. Halving the average energy consumed by electrical cooling appliances had greatest benefits for Queensland and South Australia where peak demand was reduced by -5.6% and -12.3%, respectively. Under the same circumstances, the peak demand for New South Wales and Victoria was found to change by -2.9% and -2.2%, respectively (Thatcher 2007).

Response 2: to I1 and I3

To curb the demand, increased stringency in building design to improve energy efficiency is another effective method to maintain current energy consumption or use less in the future.

To promote building energy efficiency, Australian Building Codes Board (ABCB) has increased the stringency of the Building Code of Australia (BCA) to ensure the industry adopts energy efficient measures, which is also essentially a response to climate change. For new house designs, the requirement is to rise to 6 stars energy efficiency rating (Carmichael, 2009).

In New Zealand, space heating consumed an average 34% of total household energy use (Isaacs, Saville-Smith et al. 2010). Energy consumption for space heating can be reduced by optimizing wall and roof design. By analyzing the quantitative relationships between building design data and annual energy consumption data, it was shown that the optimization of wall and roof design could result in between 40 - 70% reductions in energy demand from 2000 levels (Su, 2009).

Response 3: to I1 and I3

Improvement of energy efficiency in industry is also effective to reduce energy demand. For example, compressed air is a commonly used utility across most manufacturing and processing industries. Considering more than 30% of the total annual energy (excluding transport) in New Zealand (MED 2006) (Ministry of Economic Development) was consumed by industry, improvement of compressed air system were identified as a significant opportunity by the Ministry of Economic Development New Zealand Energy Strategy of 2007 (MED 2007). In addition, initial industrial energy efficiency programmes sponsored by the newly created NZ Electricity Commission were also established (Neale and Kamp 2009). Early work conducted by the Energy Research Group at the University of Waikato demonstrated savings of 20–30% in food, plastics and wood processing industries (Neale, Walmsley et al. 2006).

Response 4: to I1 and I3

Several countries are considering using daylight saving time (DST) as a tool for energy conservation and reduction of greenhouse gas emissions. Although a quasi-experiment in parts of Australia which extended DST in 2000 to facilitate the Sydney Olympics, showed that the extended DST did not reduce overall electricity consumption. Rather, it caused an intraday shift in demand that follows activity patterns tied to the clock rather than sunrise and sunset (Kellogg and Wolff 2008).

Response 5: to I1 and I3

Use of renewable resources to generate electricity is a significant way to enhance supply capacity to meet increasing electricity demand while reducing GHG emissions. Policies and regulations are implemented by the governments in Australia and New Zealand to encourage emission reduction. Australian Government introduced two major initiatives, one the implementation of a national emissions trading scheme titled the Carbon Pollution Reduction Scheme (CPRS) (though it was suspended while currently debating on the introduction of carbon tax) and the other to extend the Mandatory Renewable Energy Target Scheme (MRETS) by increasing the target for 2020 from 9500 GWh to 45,000 GWh. Additional support is provided for renewable energy in the form of the AU$500 million Renewable Energy Fund which will develop, commercialize and deploy renewable energy technologies, the AU$150 million for solar and clean energy research, and more than AU$500 million for the Solar Cities, National Solar Schools, and Green Precincts initiatives (Kuwahata and Monroy 2011). The New Zealand Government legislated against any new fossil-fuel based thermal generation for a 10 year interval from 2008 by making an amendment to the Electricity Act 1992 (Atkins, Morrison et al. 2010).

Response 6: to I1 and I3

Design of electricity infrastructure should consider effects of potential climate change in the future to reduce its adverse impacts on functionality and reliability of parts of infrastructure such as conductors (Jollands, Ruth et al. 2007).

BACKGROUND

Note 1: There is some questions regarding the effectiveness of promoting building energy efficiency. However, a recent investigation of five case study houses recognized in awards from the Australian Institute of Architects suggests that the assessment processes underpinning the regulations do not correlate well with measured environmental performance, the perceptions of occupiers, and how these houses are actually designed and operated. The regulatory concept of 'meeting generic needs' fails to account for the diversity of socio-cultural understandings, the inhabitants' expectations and their behaviors. In particular, standards and regulations failed to predict adaptive comfort as well as the low-energy consumption in the five case study houses (Williamson, Soebarto et al. 2010).

In addition, projections of gains from increased energy efficiency in buildings can be frustrated by the complexity of human behavior, including ‘take-back’ or ‘rebound.’ For example, when houses are made more energy efficient, people can take advantage of the better thermal properties of the building, which reduce the marginal cost of warmth, and use their heaters more (Stern, Aronson et al. 1987; Milne and Boardman 2000). Howden-Chapman et al (2009) describes findings on the rebound effect or 'take-back'-the extent to which households take the gains from insulation and heating improvements as comfort (higher temperatures) rather than energy savings.

Note 2: Studies provided suggestions on how to make policies and regulations most effective in dealing with rising proportion of electricity generation from renewable resources.

Lambie (Lambie 2010) studied which factors of CPRS have effects on a generator's decisions to invest in low emissions plant and retire high emissions plant. Under the context of CPRS, it's concluded that design features such as the method of allocating permits, the stringency of the emissions cap along with permit price uncertainty, provisions for banking, borrowing and internationally trading permits, and the credibility of emissions caps and policy uncertainty may all significantly impact on the investment and retirement behaviour of generators. In addition to the Carbon Pollution Reduction Scheme (CPRS) and an extension to the Mandatory Renewable Energy Target Scheme (MRETS) proposed by the federal government, the Council of Australian Governments (CoAG) must work to streamline policies between the federal and state governments and the latter must apply policies unique to their region for what technology is prevalent(Kuwahata and Monroy 2011).

Kelly (2007) compared the renewable energy development strategies of three countries (UK, Australia, and New Zealand) all using a variant of the quota/certificate approach as the central instrument in their programs, and then found the regulatory frameworks defining the application of the certificate systems differ notably. Likely differing outcomes suggest that these regulatory settings may be at least as important as the selection of the basic policy instrument, in determining the overall success of programs of this nature. That in turn suggests that development of effective policy instruments depends not only on the selection of basic policy instruments, but at least as strongly on the regulations or policy settings governing the application of the instruments.
Note 3: There are many factors determining if renewable resources could replace fossil fuels to generate electricity, including resource availability, technology availability, and economic availability.

Resource availability: Studies have demonstrated that there are sufficient quantities of renewable resources that could be used in Australia and New Zealand. In New Zealand, it's sufficient to achieve 100% renewable electricity generation system by replacing the 32% of fossil-fuelled thermal generation with wind power, geothermal power and other renewable power. As modeled by Mason et al (2010), renewable generation mixes comprise 53-60% hydro, 22-25% wind, 12-14% geothermal, 1% biomass and 0-12% additional peaking generation. Atkins et al (2010) also proved that a 90% renewable energy target for the electricity sector could be met by 2025 with careful planning using the technology of Carbon Emissions Pinch Analysis. Australia has plenty of renewable resources. Studies indicated that currently in Australia there are hydro, wind, bioenergy, solar, geothermal and ocean technologies being used to produce renewable power, and of these all except hydro power, has large amounts of potential as resources (Kuwahata and Monroy 2011). Clifton and Boruff (2010) proved that solar resource is plentiful in Australia, and CSP facilities could be sited over large areas of the Wheatbelt region of Western Australia which can be tailored to local patterns of supply and demand.

Technology availability: Availability of technology is also a key factor determining the use of renewable resources, such as hydro, wind, bioenergy, solar, geothermal and ocean technologies, for electricity generation. The technology is mature enough to be immediately deployed in large-scale for wind, bioenergy, solar, and geothermal, (Kuwahata and Monroy 2011). For some specific contexts, renewable energy supply is technically feasible, such as small to medium-sized tourist accommodations and a large hotel (Dalton, Lockington et al. 2008; Dalton, Lockington et al. 2009; Dalton, Lockington et al. 2009).

In addition, technological advances in renewable resource generation can improve the efficiency of renewable resource use. For example, incorporating a water-augmented air-cooled system in plants could improve the efficiency of geothermal power generation.

Models show this could increase maximum generation on the hottest day by 6.8%, with an average gain in power over the summer of 1.5%, and the average gain for the whole year of 1% (Sohel, Sellier et al. 2009). Another example is the integration of solar thermal for improved energy efficiency in low-temperature-pinch industrial processes. A systematic operating strategy for the solar collector system was developed by combining a thorough site pinch analysis study with appropriate solar information. This strategy could overcome the non-continuous nature of the solar thermal supply, which has been applied to a New Zealand milk powder plant(Atkins, Walmsley et al. 2010).

However, barriers for renewable resources use do still exist. One significant issue of these barriers is how to maintain continuity of supply in the event of possible disturbances to power production. For example, in the case of wind energy, such disturbances can result from extreme weather events due to frontal systems or rapidly evolving low pressure systems. Thus wind farm sites need accurate, local scale, wind-focused forecasts. A case study focusing on the Woolnorth wind farm on the northwest tip of Tasmania highlights some of the key challenges that will be involved in developing such forecasts(Kay, Cutler et al. 2009).

Economic availability: Return from investment in electricity generation from renewable resources is a core issue which determines investors' commitment. Although there are large amounts of potentially useful renewable resources in Australia, the costs and return on investments are proven to be viable in the current market only for cases of wind and bioenergy. Within the current electricity market, it's very difficult for renewable resources to compete with fossil-fuel based power, given the ample supply of coal available in Australia and the heavy subsidies it receives. To become more competitive with electricity generated from coal-fired power plants, a feed-in tariff scheme could be implemented, and subsidies to the coal industry should be reduced if not removed. In addition, direct subsidies or tax exemptions, or aiding with easier access of finance options should be applied to address high capital cost of renewable power technologies. For technologies that require further technical development, funding towards research and development or pilot projects, and support for international collaboration projects would accelerate their path to deployment. All these supports should be given by the governments (Kuwahata and Monroy 2011). Other studies have proved the economically viable of renewable energy supply for specific contexts, such as small to medium-sized tourist accommodations and a large hotel (Dalton, Lockington et al. 2008; Dalton, Lockington et al. 2009; Dalton, Lockington et al. 2009)

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TRANSPORT INFRASTRUCTURE

SUMMARY

- Current transport infrastructures were designed without taking into account effects of climate change. Transport infrastructures are likely to face potential threats as a result of climate change including long-term effects, such as structural deterioration, and short-term extreme events, such as structural safety during cyclones.

- Enhanced design, planning and maintenance have to be developed to mitigate threats. It becomes more important when practitioners may not recognize the threats of climate change. In this regard, research communities should assist practitioners in recognising climate change impacts.

CONTEXT

This statement is a synthesis of published scientific literature and reports

EVIDENCE

Projected Impact

CATEGORY(S)

Networked infrastructure: Transport

REGION

Australia
New Zealand

DRIVER(S)

Temperature
Precipitation
Humidity
Sea level rise

PRESSURE(S)

Pressure 1

The mean temperature across Australia has increased by 0.9°C since 1950. Over the 50 year period the number of hot days have increased and number of cold days have decreased. 2000-09 is Australia's hottest decade on record (CSIRO, 2007; 2010).

By 2030, average temperatures are projected to increase by 0.6 - 1.5°C above the 1990 level (CSIRO, 2007). Climate models also project decreases in cold days and nights, decreases in frost days and cold spells, and increases in extremely warm nights. This corresponds to an increase in the frequency and length of drought periods, especially over southern Australia (Taylor and Philp 2010).

Pressure 2

Over the last 50 years, rainfall patterns have changed over Australia as a result of climate change. In northern and central Australia, rainfall tended increase, whereas in southern and eastern Australia the tendency is for decreases in rainfall (CSIRO, 2007; 2010). The number of days with no precipitation is expected to increase in the future, corresponding to a decrease in mean rainfall across Australia. However, intense rainfall events in many areas are projected to increase. In addition, decreased snow cover, shorter snow season lengths, decreased peak snow depths and changes in the timing of snow seasons are projected (Taylor and Philp 2010).

In New Zealand, many cities will face an increased rainfall in the future. For example, monthly rainfall is projected to increase in Hamilton over the 2005–2030 period (Ruth, Bernier et al. 2007). Three other New Zealand sites, Auckland, Wellington and Invercargill will also face increased rainfall, brought about largely by an increased frequency of rainfall events rather than an increase in rainfall intensity (Sansom and Renwick 2007).

Pressure 3

Sea level around Australia increased by around 10cm from 1920 to 2000. More recently, over 1993 to 2009, sea levels rose by 1.5 to 3mm per year in southern and eastern Australia compared to 7 to 10mm in northern and western Australia (CSIRO, 2007; 2010). The global average sea level is projected to rise by 18 to 59cm by 2100. Melting of ice sheets could potentially contribute a further 10 to 20cm rise (Taylor and Philp 2010).

Pressure 4

Additional consequences of changing climate conditions include increases in evaporation, declines in soil moisture over southern Australia caused by reduced precipitation, increases in wind loading due to changes in wind speeds along the most coastal areas, moderate increases in solar radiation in southern Australia especially in winter and spring, and increases in frequency of bushfires (Taylor and Philp 2010).

STATE(S)

State 1

Of the Australian transport infrastructure, major changes are required to enable road infrastructure to be fit for current and future purposes (overall rating C; Engineers Australia, 2010). In particular, local roads that are currently in poor condition will require a critical change to meet current and future purposes. Rails in Australia are also rated as poor condition, though airports and sea ports are generally considered in good condition (Engineers Australia, 2010).

State 2

Existing transport infrastructure has little consideration of climate change during design stage; the potential impacts cannot be neglected. Transport infrastructure is likely to be affected by sea level rise exacerbated coastal inundation and erosion, as well as the intensity and frequency of storm surges. Higher temperatures will increase the likelihood of structural deterioration and structural failure such as rail buckling and road fatigue (Engineers Australia, 2010). Therefore, new transport infrastructures designed without consideration of climate change and existing infrastructure without implementation of proper adaptations may not be able to provide designed services in future (Taylor and Philp 2010).

IMPACT(S)

Impact 1

Concrete is widely used in transport infrastructures, such as bridges and seaports. A concern is the deterioration of concrete through chloride-penetration and carbonation-induced corrosion. Studies by (Wang et al. 2010; Stewart et al, 2011) projected the probability of chloride-induced corrosion and carbonation-induced corrosion of concrete bridge structures and port structures due to changes in CO_2 concentration, temperature and humidity in Australia. The studies showed that climate change could considerably accelerate concrete deterioration, especially for 'legacy' structures which were the most vulnerable to increase in CO_2 concentration and climate change.

Impact 2

Extreme temperatures may signifcantly increase the internal stresses and movements of steel bridges and rail tracks, and also cause the expansion of concrete joints, protective cladding, coatings and sealants on bridges and seaports. For example, an increase in the frequency of heatwaves would exacerbate the degradation of rail track performance, especially those already in relatively poor condition. This would increase the likelihood of railway buckling, as happened during the 2009 heatwave in Melbourne (Nguyen et al, 2011). Increased precipitation, higher temperatures combined with increased solar radiation as well as evapotranspiration may reduce the life of road pavements (Austroads, 2004). Embrittlement may cause surface cracks that allow water to infiltrate the road pavements resulting in potholes and rapid loss of pavement and high temperatures can cause asphalt pavement softening and lead to traffic related rutting. Pavements can buckle under extreme temperatures. Extreme temperatures, as well as warming, may increase heat stress conditions for workers and so limit the undertaking of maintenance and construction activities (Taylor and Philp 2010). The impact of climate change on port structures is often related to the increased number of extreme events such as cyclones, hot days and changing wind intensity. The impact risks were mostly considered as high or above by 2100 in all States except South Australia and Tasmania assuming A1FI emission scenario; Queensland is most vulnerable, especially assuming hot and wet/dry A1FI emission scenario (Maunsell Australia, 2008).

Impact 3

Changes in precipitation can affect ground movement, watertable and associated salinity of soils. This could accelerate the deterioration of materials and structures for transport infrastructure, reduce their service life, increase maintenance costs, and may eventually contribute to structural failure under extreme events. However, on the basis of simulation with HDM4 software (Austroads, 2004), the major impact would likely come from increasing population and traffics in the future. The impact of climate change may be minor though it will exacerbate other impacts.

Impact 4

Increases in the frequency and intensity of extreme rainfall events could result in increased flood damage to road, rail, bridge and tunnel infrastructure, therefore design and planning of land-based transport infrastructure should take into these factors into account (Taylor and Philp 2010). For example, failure of slopes is a common damage caused by intense rainfall in UK (Hughes, Glendirrning et al. 2008). In Hamilton, New Zealand, the costs for road repairs may increase by 9% by 2030 as a result of increases in rainfall (Jollands, Ruth et al. 2007).

Impact 5

Sea level rise and the increased risk of storm surges may affect coastal transport infrastructure. For example, tunnels and culverts are vunerable to increased tidal and salt gradients, ground water pressure and corrosion of materials (Taylor and Philp 2010).

Impact 6

The impacts of hot and dry conditions on unsealed road surfaces are likely to increase; when combined with increased wind intensity this will lead to more dust storms and decreased usability of the road. Downstream impacts include smothering of vegetation, and social impacts due to dust infiltration into residential properties (Taylor and Philp 2010).

RESPONSE(S)

Response 1: to Impact 1

For existing concrete transport infrastructures, enhancing current maintenance procedure such as creating a surface barrier by coating can reduce the exposure of concrete structures to external stimuli. In addition, extraction and cathodic protection is also more commonly used for structures with high corrosion risk to reduce the penetration of deleterious agents (Wang et al., 2010).

Response 2: to Impact 1

Increasing the thickness of concrete covering to lengthen the time it takes carbonation and chloride ingress to reach concrete reinforcement, is one of the most straightforward adaptation options in the design of new concrete infrastructure. Reducing the diffusion coefficient is another effective way to increase the time it takes carbonation or chloride penetration to reach concrete reinforcement. In practice, selecting a high strength grade of concrete may reduce the diffusion coefficient and therefore enhance the adaptive capacity of concrete structures to counteract climate change impacts. Finally, surface coatings, such as polyurethane, silane and polymer modified cementitious coatings are effective in reducing the impact of climate change as long as their performance can be maintained over the period similar to the designed structural service life (Wang et al., 2010).

Response 3: to Impact 2

Increases in the number of hot days should have limited impact on pavement or structural design in the short term (30 to 40 years) however, in the long term (100 years), there will be a likely impact on pavement and structural design. Substitution of materials and a higher level of maintenance service may be required (Taylor and Philp 2010).

Response 4: to Impact 3

In response to the changes in precipitation, pavement and drainage design, should fully consider future floods along with development of targeted maintenance schemes, for examples changes in culvert design and material specifications of road subgrade (Taylor and Philp 2010).

Response 5: to Impact 4

Knowledge of the impacts of climate and vegetation on embankment and cut slope stability needs to be improved (Hughes, Glendinning et al. 2008; Hughes, Glendirrning et al. 2008; Toll, Mendes et al. 2008). For example, Hughes et al (2008) developed a model to predict long-term behaviour of embankments subjected to a changing climate and identify embankments at risk.

Response 6: to Impact 5

Transport infrastructure such as bridges should take into account the effect of sea level rise and severer storm surges; more rigorous design standards should be developed for constructions in saturated soils and flood-prone areas; changes in materials specifications to cope with the corrosive nature of the coastal environment is also useful (Taylor and Philp 2010).

Response 7: to Impact 6

Increase in coastal wind requires the update of design factors for transport infrastructure; materials for bridge construction may need to be substituted by those with greater strength (Taylor and Philp 2010).

Response 8: to Impact 1-6

Perceptions may considerably affect the decision-making in develop climate adaptation. For example, a survey showed that practitioners perceived sea-level rise not a risk to most ports this century (Becker, Inoue et al. 2011). In this regard, it is important for research community to assist practitioners in recognising climate change impacts.

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WATER SUPPLY AND DEMAND

SUMMARY

- Australia and New Zealand have been facing challenges with water shortages. Rainfall and snow cover decreased significantly in some parts of Australia during the past several decades, and the decreasing trend in Australia is likely to continue.

- Many cities in Australia experienced shortages of water supply and had to impose water restrictions during the recent prolonged draught. In contrast to shortage of water supply, water demand has been consistently increasing, which could be caused by drier and warmer climates and increasing population.

- Increasing temperature and population as well as reoccurrence of drought in the future will increasingly expose Australia and New Zealand to the risks of severe water shortage

- To mitigate the severe water shortage, adaptation measures could be developed at different levels, including use of rainwater and recycled water, developing effective water-saving behaviour, sustainable irrigation, increasing investment in water infrastructure, and building desalination plants

CONTEXT

This statement is a compilation of published scientific literature and reports

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Water Demand and Supply

REGION

Australia
New Zealand

DRIVER(S)

Temperature
Precipitation
Soil moisture

PRESSURE(S)

Pressure 1

Increased mean maximum and minimum temperature, and subsequent increase in the number of hot days and warm nights and a decrease in the number of cool days and cold nights, have been observed in Australia and New Zealand over three periods during the past century (1931-2005, 1946-2005 and 1961-2005)(Chambers and Griffiths 2008). In southeast Australia, the trends in average maximum temperature have been increasing in all seasons since 1950 (Murphy and Timbal 2008). The temperatures recorded in New Zealand during the 20th century have also risen about 0.7°C (Wratt, Mullan et al. 2003).

Recent studies (CSIRO 2006; 2007a; 2007b) project a local warming for eastern New South Wales of between 0.2°C and 2.1°C by 2030 and between 0.7°C and 6.4°C by 2070. New Zealand is estimated to warm by 0.7°C for every degree of global warming between 1990 and 2100. Temperatures across the North Island could warm by 3°C over the next 70–100 years, and temperatures in the South Island could increase 2.5°C (cited in Ruth, Bernier et al. 2007). In Hamilton, changes in temperature between 1990 and 2030 projected by CSIRO and UK Hadley climate models under high and low greenhouse gas emission scenarios show warming in all seasons (Ruth, Bernier et al. 2007).

Pressure 2

A relationship exists between soil moisture and temperature, particularly in spring and summer. Annually, a rise of 1°C leads to a 9% reduction in soil moisture over the southern Murray Darling Basin (MDB). Since 1950, rising temperature has contributed up to 45% of the total soil moisture reduction. A warming climate can also led to an inflow reduction. The reduced water availability can only be mitigated by increased rainfall (Cai, Cowan et al. 2009).

Many studies have showed that rainfall decreased significantly in some parts of Australia during the past several decades (Timbal, Arblaster et al. 2006; Meneghini, Simmonds et al. 2007; Bates, Hope et al. 2008; Cai and Cowan 2008; Murphy and Timbal 2008; Shi, Ribbe et al. 2008; Shrestha, Riley et al. 2009). For example, in Sydney, statistical analysis of available rainfall data in the Warragamba catchment area that supplies about 80% of Greater Sydney's drinking water, indicates a trend of decreasing rainfall of 2.52mm/year between the period of 1945 and 1998 (whereas between 1890 and 2003, a linear increasing trend of 0.32mm/year was observed) (Shrestha, Riley et al. 2009). A similar situation also occurred in Perth, Western Australia, where annual rainfall has declined by 15-20% in the past 40 years (Bates, Hope et al. 2008).

The decreasing trends of rainfall in Australia are likely to continue in the future. By applying five climate models to project the average rainfall in southeast Australia, it is projected that the average rainfall in the region is likely to decline further, with the greatest seasonal decline occurring during the first half of winter (Timbal and Jones 2008). For the Sydney region, current estimates (CSIRO, 2006; 2007a; 2007b) vary from +7% to -13% by 2030 and from +20% to -40% for 2070, with greater likelihood of rainfall reductions than increases. For a 'business-as-usual' scenario, by using NCAR CSM 1.4 climate model was used to investigate the effect of global warming on rainfall in central Australia, the results indicate that there will be a decrease of rainfall in central Australia of about 10% to 20% for the period between 2051-2080 compared to 1951-1980 (Taminiau and Haarsma 2007). However, in Hamilton, New Zealand, the range of monthly precipitation range is likely to increase over 2005–2030 (Ruth, Bernier et al. 2007). The same trend also projected in three other New Zealand sites, Auckland, Wellington and Invercargill (Sansom and Renwick 2007).

Pressure 3

Snow is another important water resource. According to the data collected at Spencers Creek, NSW, snow course from 1954–2007, there was a significant decrease in snow. Snow cover declined on average by 15 m-days per decade, from an average of 213 in the first 10 years of measuring to only 146 m in the last 10 years (Green and Pickering 2009)

STATE(S)

State 1

Because of the recent rainfall reductions, many cities experienced a decline in water storage in reservoirs. In Sydney, flows into the Sydney water-supply reservoirs were reduced to about a quarter of that received in 1949–1990, and became more severe in May 2007 when reservoirs were less than 40% full (or less than 500 days of supply) (Shrestha, Riley et al. 2009; Warner 2009). The same situation is also happening in southwest Western Australia (SWWA) (Wallace, Li et al. 2009; Bates, Chandler et al. 2010). At the time, the metropolitan drinking water catchments in Perth could only supply less than 40% of water demand despite of the construction of a new dam. Overall, runoff from Perth’s drinking water catchments has declined up to 70% in the past 40 years (Petrone, Hughes et al. 2010). For the past several years, Melbourne also experienced low rainfall conditions and consequent low water storage that went down to 25.5% in June 2009, and water authorities were forced to impose water restrictions after 20 years of unrestricted supply (Gato, Jayasuriya et al. 2007).

State 1

Water demand has increased while inflows declined. In Perth, the water demand rose from 125GL in 1970s to 250GL recently (Petrone, Hughes et al. 2010). For Sydney, mean inflows to the dams were over 2000 Gla-1 or at least three to four times the urban needs from 1949 to 1990. During 1991–2007, the average inflow however dropped to 570 Gla-1, less than the 2003 demands of over 600 Gla-1 prior to water restrictions (Warner 2009). Total water demand increase is the consequence of increasing population and drier climates (Gato, Jayasuriya et al. 2007). In Sydney, individual consumption is about 233 ld^{-1}, while the level 5 restrictions in Brisbane limited consumption to between 120 and 140 ld^{-1} per person (Warner 2009). In Hamilton, New Zealand, water consumption generally ranges from 10,000 litres per person per month (~333 ld^{-1}) during the winter to around 16,000 litres per person per month (~533 ld^{-1}) during the summer. However, during summer in 1998 – 2000, consumptions were well above normal due to the historical warm conditions (Ruth, Bernier et al. 2007).

IMPACT(S)

Impact 1

Studies of daily water-demand data from 1991 to 1999 in East Doncaster of Melbourne indicated that water consumption was weather sensitive and dependent on temperature and rainfall (Gato, Jayasuriya et al. 2007). Melbourne is likely to face severe water shortage, considering that the percentage reductions in water resources is approximately twice as large as corresponding changes in rainfall (Timbal and Jones 2008). Water demand in Perth is also likely to increase, by more than 3% per year in the future (Petrone, Hughes et al. 2010).

As population increases, the effect of climate variables on per capita consumption is multiplied. For example, in Hamilton, New Zealand, a temperature difference (20℃ to 30℃) that results in a 8ML increase in consumption today translates into a 14ML increase in 2030 under a high population scenario (180,000 people in 2030) (Ruth, Bernier et al. 2007). Currently, Hamilton is able to supply 85 ML a day and has a reserve storage capacity of just over 90 ML. Under a high population scenario, in the circumstance of six days in a row without rain and with temperatures above 30℃, there would be a deficit between demand and supply of 15 ML on the seventh day. Under a medium population scenario (164,500 people in 2030), this could happen after twelve days of hot, dry weather (Ruth, Bernier et al. 2007). Models indicate that there could be a 40% chance that Hamilton City would experience water shortage in a seven-day period in any given year after 2030 (Ruth, Bernier et al. 2007)

RESPONSE(S)

Response 1: to I1

Rainwater is considered as a useful substitute for freshwater to address growing water shortages. Rainwater tanks are effective in capturing runoff from roofs, with the maximum stormwater reduction 48.1% or 68.3 m(3)/lot/year (Zhang, Grant et al. 2010).

The performance of stormwater harvesting shows variable levels of potable water savings, with collection recording from 20% to up to 100% of the mean annual rainfall (Fletcher, Deletic et al. 2008). In densely settled suburbs like Enmore in Sydney, roofs were estimated to cover about 70–80% of the total area. In contrast, in the North Shore suburbs like East Gordon in Sydney, block sizes are up to 2000 m^2 and the roof areas do not exceed 20% of the total area. However, even if water harvesting was collected by roofs from only 20% of the total area, this would be sufficient for 1800 people in one km^2 per year (Warner 2009).

In Australia, some schemes have been implemented to encourage stormwater collections. For example, on the Northern Adelaide Plains, South Australia, a Parafield stormwater Aquifer Storage and Recovery (ASR) scheme successfully harvested 1.1 Mm^3/yr urban stormwater to supply a wool scouring plant, especially with water of lower salinity than the mains water supply (Rinck-Pfeiffer, David et al. 2008). Parafield ASR scheme late aimed at producing drinking water supplies from the some source of treated stormwater through an Aquifer Storage Transfer and Recovery (ASTR) scheme (Rinck-Pfeiffer, David et al. 2008).

See Background box for further information in rainwater reuse

Response 2: to I1

Recycling is potentially effective in distant and drier areas (Attwater, Aiken et al. 2006; Naji and Lustig 2006; Radcliffe 2010). A study analysing the water-saving performance of both roofwater and greywater in the rural township of Cranbrook, Western Australia (Zhang et al, 2010), showed that greywater usage (maximum reduction 32.5%) significantly reduced main water supply more than rainwater harvesting (maximum reduction 25.1%), and had considerable effects on drainage system by reduction approximately 54.1% or 88.1 m3/lot/year.

In fact, rainwater and recycling water are often utilised at the same time to address water shortage and meet water-self-sufficiency. For example, in the city of Adelaide, the level of water-self-sufficiency that may be achieved by applying both rainwater and recycling water was estimated to be around 60% (Barton and Argue 2009).

The wastewater from industry could be reused. Although 12% of water used in industry cannot be recycled for food and beverage enterprises, it could be used for other purposes to reduce fresh water consumption. In the case of Blue Scope Steel in the Illawarra, for example, recycled water from the Wollongong sewage treatment plant was used thereby saving 7.3 Gl per year from the Avon Dam (Hird 2006). Sydney's sewage treatment plants used 10 Gl per year of recycled water in their operations, or about 85% of their requirements (SydneyWater 2006).

Response 3: to I1

The use of wastewater is being promoted through policy in many parts of the world with the aim of achieving sustainable water management. However there are some major barriers to the success of wastewater use policies and their instruments. One of these barriers can be a lack of community support (Hurlimann, Hemphill et al. 2008).

A significant barrier to use wastewater is a lack of community support, for example, in Toowoomba which has population of approximately 95,000 (Hurlimann and Dolnicar 2010). In 2006, the residents of Toowoomba were invited to vote in a referendum concerning whether or not an indirect potable wastewater reuse scheme should be constructed to supply additional water to the area at a time when the dam level in Toowoomba was at approximately 20% of capacity. Toowoomba residents, after intense campaigning on both sides of the referendum debate, however voted against the proposal.

The lack of community support is due to competing environmental, scientific, and cultural discourses about the use of wastewater emerging from community, government, and industry responses. A study was carried out to investigate a case about treated wastewater use to increase domestic water storages in a local government in Australia in 2007 (Mankad and Tapsuwan 2011). A 3-month community consultation was conducted, including health and environmental assessments. Despite apparently favorable recommendations, the proposal was not considered suitable as an immediate response to securing the region's water supply. Based on this case, the study concluded that the use of wastewater could not be successful if the community was not engaged.

On the other hand, there was a successful case in Queensland which addressed water shortages by using recycling water (Freeman, Bates et al. 2008). Effective public communications led to public support, which was a key to success. Survey results for 2007 showed that 71% of residents supported recycled water use and significantly conserved water with a per-capita residential use of only 123 L per day.

See Background box for further discussion of community acceptance of wastewater

Response 4: to I1

In addition to increasing the capacity of water supply by using rainwater and recycling water to meet water demand, strategies to change effective water-saving behaviour is also potentially an effective way to reduce water demand (Chanan, Kandasamy et al. 2009).

Pricing is considered a common and effective policy to curb water demand. It was predicted that Sydney would face the possibility of critical water shortages in the short- to medium-term without a fundamental change in water policy, such as pricing, if low rainfall events had continued (Grafton and Kompas 2007). However, some studies indicated that water demand is price inelastic, for example, a study (Hoffmann, Worthington et al. 2006) that used suburb-level quarterly data in Brisbane from 1998 to 2003.

Initiatives for retrofitting of water efficient devices and technical improvement to household water infrastructures were also considered to be important measures to save water (Lawrence and McManus 2008). In Toowoomba of Queensland, rebates for water efficient devices were provided by both the State Government and Toowoomba Regional Council (Mead and Aravinthan 2009). However, education was also considered a significant part of demand management programs and likely to save the most water by changing consumer behaviour (Mead and Aravinthan 2009).

See Background box for further information on factors influencing water-use behaviours

Response 5: to I1

Sustainable irrigation plays an important role to achieve the reduction of water demand. In 2003, Northern Australia Irrigation Futures (NAIF) was established under a collaboration of four government bodies responsible for NA, research organisations and industry, to develop new knowledge, tools and processes to support debate and decision-making about the future of irrigation in Northern Australia (Camkin, Bristow et al. 2008).

To increase the amount of water available, Australian governments undertake a series of water reforms to increase irrigation efficiency. However, increasing irrigation efficiency may be not cost effective. Therefore, policy should consider impacts on irrigation efficiency and other objectives. Qureshi et al (2011) used the Murray-Darling Basin as a case study to present the differences amid irrigation and water-use efficiency, basin efficiency and economic efficiency, and explored the implications for water reform and the efficacy of market based approaches to addressing the water scarcity issues and environmental flow needs.

Upgrading irrigation infrastructure is considered an effective measure to increase irrigation efficiency. White et al (2006) developed a model to explore the potential for achieving further on-farm savings within the Murray-Darling Basin through increased adoption of the best management practices. It was found that savings in excess of 900 GL per annum could be achieved on irrigated farms in the Basin, under reasonable time frames, and plausible scenarios for farm investment and the adoption of new technologies. Greater savings could potentially achieved through investing significantly in new irrigation technologies, increasing adoption rates, and reducing current losses incurred in bringing water from storages and river systems to the farm gate.

Upgrading of irrigation infrastructure has been used in some regions, and the results of implementation of new irrigation technologies have demonstrated the effectiveness. A study reports the improvement in performance of irrigators in the lower Murray Darling region of New South Wales in the last 10 years through upgrading of irrigation infrastructure, both on and off farm. Metered readings from water supply authorities from three irrigation districts have found that the volume of water diverted has dropped 30-60% due to supply infrastructure upgrades(Giddings 2008). Another study (Mosley and Fleming 2009) also proved the benefits by upgrading irrigation infrastructure.

Considerable improvement in water use efficiency is also gained by installation of water re-use systems. In Mosley's study (Mosley and Fleming 2009), they investigated the effectiveness of full rehabilitation, which consisted of improved inlet structures, flow metering, elimination of water leaks, laser leveling of paddocks, and construction of re-use systems to recycle excess surface irrigation runoff.

However, the use of recycled water inevitably led to a range of complex issues that had to be addressed, including costs and benefits of supplying an additional source of water to current or new cropping systems; optimum irrigation design and management, particularly where there are multiple sources of irrigation water; management of overflow from on-farm water storages; and environmental implications with regard to salinity, runoff, drainage, nitrate leaching, and environmental flows. For these issues, Brennan et al(Brennan, Lisson et al. 2008) introduced an approach that couples agricultural production system and economic models that enabled the analysis of the likely benefits and risks of investing in recycled water.

Response 6: to I1

Investment in new water infrastructure, such as new dams, is another means to increase water supply or water storage. For example, Hamilton City Council considered expanding the water treatment facility to be able to handle 100ML per day of drinking water production. Even under the high population scenarios, the increased capacity would be able to withstand all but the driest and warmest conditions projected (Ruth, Bernier et al. 2007).

However, many economic and environmental factors influence investment in new water infrastructure. With the advent of COAG reforms in the late 1990s requiring full commercial return from 'public infrastructure', and the tightening regulatory compliance for any project that involves the development or modification of any natural resource, it has become increasingly difficult for the private sector to invest in new large-scale water supply infrastructure. Noonan et al (2006) emphasize that water utility corporations that are government owned were well-suited to fulfilling the demand for new water infrastructure. In addition, a decision support tool to facilitate irrigators to make long- and short-term irrigation infrastructure investment decisions at the farm level is developed, which was tested, validated and accepted by the irrigation community and researchers in New South Wales (Khan, Mushtaq et al. 2010).

Response 6: to I1

Desalination is often considered as an option to solve the water-supply problem. The desalination capacity in Australia is around 1% of the total world's desalination capacity. All capital cities except Darwin considered building at least one desalination plant as a means to provide water security after the prolonged drought that significantly reduced dam storage (El Saliby, Okour et al. 2009). Perth was the first capital city to use desalinated water for drinking water supply. A desalination plant in Sydney was eventually operational in early 2010, with a capacity of 91 Gla^{-1} providing 15% of current needs in Sydney. However, some people claimed that desalination, whilst possible and even necessary for a city like Perth, with groundwater problems and no extensive water-receiving catchments, was a costly option for Sydney (Warner 2009) and Melbourne.

BACKGROUND

Some factors influencing rainwater reuse:

There are social, institutional, and economic factors influencing sustainable rainwater management in Australia (Fletcher, Deletic et al. 2008; Brown, Farrelly et al. 2009; Brown and Farrelly 2009; Gardner and Vieritz 2010; Rozos, Makropoulos et al. 2010; Mankad and Tapsuwan 2011).

For example, a study to understand what drives and limits treatment technology adoption for stormwater management by having an online questionnaire survey over 800 urban water professionals in three Australian capital cities, Brisbane, Melbourne and Perth, in November 2006 revealed that the professional community was highly aware of the importance of improving stormwater quality for receiving waterway health, yet they did not consider that politicians share this perspective placing a substantially lower level of importance on stormwater quality management. There are also significant acquisition barriers within each city, including institutional arrangements, costs, responsibilities, and regulations and approvals processes for more sustainable practices (Brown and Farrelly 2009).

Water quality is a key factor in the use of rainwater tank to collect rainwater. Risk assessment research suggested that zoonotic pathogens could occur at concentrations that would adversely impact on public health if rainwater was ingested without disinfection. A study (Rodrigo, Sinclair et al. 2010) to look into the characteristics and maintenance of rainwater tanks in urban areas of South Australia indicated that rainwater quality would be affected by roofs and tank material, overhanging vegetation, and maintenance. Another study (Kus, Kandasamy et al. 2010) to compare water quality of rainwater in tanks in Sydney and Wollongong against the Australian Drinking Water Guidelines (ADWG) and determine its suitability as a potable water supply, found that the rainwater tested complied to most of the parameters specified in the ADWG. Gardner et al (2010) reached a similar conclusion that the quality of rainwater in Australian cities was likely to meet ADWG (2004) on all chemical criteria unless exposed lead flashing on the roof contaminated the collected rainfall. However, a pilot scale study and a full-scale field investigation found that heavy metal concentrations in water samples taken from the tank's supply point could, in some cases, exceed levels recommended by guidelines (Magyar, Mitchell et al. 2007). In addition, the studies suggested that improved tank design is a potential approach to reduce sediment resuspension and mitigate impacts on water quality (Magyar, Mitchell et al. 2007).

Further discussion regarding the factors influencing community accept of wastewater

In order gain community support for wastewater use, it’s necessary to understand the factors that affect user perceptions. A study surveyed 162 residents in Mawson Lakes in South Australia about their perceptions to use recycled water for non-potable purposes through a dual water supply system (Hurlimann, Hemphill et al. 2008). The results indicated that the satisfaction with recycled water use depended an individual's positive perception related to the Water Authority's communication, trust in the Water Authority, fairness in the recycled water system's implementation, quality of the recycled water, financial value of the recycled water system, and risk associated with recycled water use.

(Dolnicar and Hurlimann 2009) explored all three antecedents to the behaviour of drinking recycled water and desalinated water by the Theory of Planned Behaviour, including attitudes, social norms and factors of perceived behavioural control. It indicated that people felt a lack of knowledge. They stated that information from scientists would have most influence on their decision to drink recycled and desalinated water while friends and relatives are most influential in preventing people from drinking recycled water. However, nearly all of them would be willing to drink it if there was a water crisis although people hold both positive and negative beliefs (mostly related to cost, health and environmental concerns) about water from alternative sources (Dolnicar and Hurlimann 2009).

Some other studies explored public’s attitude to the water from different perspectives. For example, Hurlimann and Dolnicar (2010) analysed people’s intention to relocate as a result of four different water sources. It indicated that there was the highest likelihood to relocate when there was insufficient water to meet their needs, followed by when recycled water was introduced into their supply, then the introduction of desalinated water. The scenario where residents had to rely on self-purified rain water from a tank had the lowest level of relocation intention. This also indicated that the use of rainwater tanks may currently be the most publically acceptable water alternative.

Hurlimann (2009) studied willingness to pay for recycled water in regional Victoria-Bendigo. The study found that participants under the study were willing to pay on average A7.66/kL for recycled water delivered to their homes, significantly greater than the A1.33/kL charged to Bendigo residents for the delivery of potable mains water which was however subject to water use restrictions. The results of this study indicated that individuals facing prolonged restrictions to use water may be willing to pay a higher price for recycled water.

Further discussion of factors influencing water-use behaviours

Graymore et al (2010) investigated the water-use behaviours and attitudes of rural and regional urban water users in southwest Victoria. It was found that the factors affecting water-use behaviours included the source of water supply (groundwater versus surface water), previous experience with water shortages and trust in the water authority and government. There is also a difference in the drivers for water saving, with farmers wanting to be 'water efficient' to keep their business viable and productive, while hobby farmers and residential users were 'saving water' for more altruistic reasons.

Another study proved the relationship between water consumption and household size and household income (Barrett and Wallace 2009). Large households may achieve economies by sharing water consuming resources, while wealthy individuals may consume more water per capita. As a result, considering projections of shrinking household size, the decline in household water efficiency may drive up the demand for water, unless offset by proper demand management through policies and water efficiency of houses and appliances.

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AGRICULTURE – WATER RESOURCES

SUMMARY

- Australian agriculture faces significant challenges in adapting to rapidly changing water supply and use.
- Agricultural water supply, including water for livestock and irrigation, accounted for 50% of total Australian water consumption in 2008-09. Some of the main uses were cotton growing (12%), cereal crops for grain or seed growing (11%), dairy cattle grazing (10%) and sugar cane (10%) (ABS 2010).
- Changes in annual rainfall and streamflow have not always been gradual. Step decreases were observed in south-western Australia in the mid 1970s and in southern and eastern Australia in 1997, shifting many water systems beyond their historical operating limits (Jones 2010, Risbey 2011).
- The use of historical climate to construct the likely range of operating conditions for water resource management is no longer sufficient. Combining past and recent climate with model projections of future change is necessary (Jones 2010, Milly *et al.* 2008).
- While great variability will remain a characteristic of Australian rainfall conditions, rainfall over southern Australia is projected as very likely to decrease in future. Changes in other regions are less clear (Jones 2010).
- Agriculture, particularly in the Murray-Darling Basin, is involved in a water reform process that is aiming to improve environmental health and ensure sustainable irrigation (Jones 2010). The Murray-Darling Basin Authority will release a Basin Plan in 'mid 2011'. The Guide to the Basin Plan (Murray–Darling Basin Authority 2010) considered scenarios providing additional amounts of 3,000, 3,500 and 4,000 GL/y of water for the environment (a gigalitre is one billion litres). To provide more water for the environment the Standing Committee on Regional Australia (2011) recommended that the government focus greater investment into water saving projects rather than solely relying on purchasing water entitlements.
- The challenge for agriculture will be to increase water use efficiency in the face of both climate change and water reform policies (Jones 2010).
- The Australian Government has commissioned the CSIRO to undertake assessments to provide robust estimates of current and future water yield in several major water systems across the country to help underpin the sustainable planning and management of water resources (see for example, CSIRO 2008 and CSIRO 2009a,b,c).

CONTEXT

The main source of information was the chapter by Jones (2010), a review including more than 75 references. Other information was taken mainly from reports available on the internet (e.g. ABS 2010, Climate Commission 2011 and CSIRO 2008, 2009 a,b,c) and recent journal papers (e.g. Risbey 2011 and Vaze *et al.* 2011).

EVIDENCE

Observed Impact: Given the high degree of natural variability of Australia's rainfall, it is difficult to attribute observed changes to climate change. However, observations since 1970 show a drying trend in most of eastern Australia and in southwest Western Australia, but a wetting trend for much of the western half of the continent (Climate Commission 2011). See 'State' section for summary of research of the South Eastern Australian Climate Initiative (SEACI) and Indian Ocean Climate Initiative (IOCI).
Projected Impact: See statements for individual agricultural systems, including cotton, dairy and sugarcane.

CATEGORY(S)

Production systems: Food
Production systems: Fibre

REGION

Queensland
Victoria
New South Wales
South Australia
Tasmania
Western Australia
Northern Territory
ACT

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Solar Radiation
Extreme and variable weather patterns
Soil moisture

PRESSURE(S)

The consensus on projected changes in rainfall for the end of this century is (i) high agreement for southwest Western Australia, where almost all models project continuing dry conditions; (ii) moderate for southeast and eastern Australia, where a majority of models project a reduction; and (iii) low across northern Australia. There is a high degree of uncertainty in the projections in (ii) and (iii), however) (Climate Commission 2011).

The difficulties of projecting changes in rainfall are well illustrated by a recent assessment of how effectively 15 global climate models simulate annual and seasonal rainfall across south-east Australia (Vaze *et al.* 2011). The study showed that they generally reproduce the spatial patterns of mean seasonal and annual rainfalls reasonably well, but none simulated the actual annual rainfall time series or the trend in the annual rainfall very effectively.

STATE(S)

The South Eastern Australian Climate Initiative (CSIRO 2010) found that the 13-year drought in the southern Murray-Darling Basin (MDB) and Victoria that ended in 2010-11 was unprecedented compared with other recorded droughts since 1900. There was a 13 per cent reduction in rainfall in the southern MDB over the period 1997-2006 compared with long-term averages, which led to an extreme decline in modelled annual streamflow of 44 per cent relative to the long-term average (1895 to 2006). The Initiative concluded that it is prudent to plan for conditions that are likely to be drier than the long-term historical average conditions because the recent drought appears to be at least partly linked to climate change and climate model projections of a drier future across the south-east.

The Indian Ocean Climate Initiative (IOCI 2009) has found a step decrease in total annual rainfall averaged across south west Western Australia of almost 10% since the mid-1970s. Results from IOCI research indicate that relative to 1960-1990 annual rainfall in south-west WA will decrease by between 2-20 per cent by 2030 and by between 5 to 60 per cent by 2070 (Bates *et al*. 2008).

In 2007 and 2008, CSIRO undertook the world's first water resource assessment of its scale for the groundwater and surface waters of the Murray-Darling Basin, reporting on current and future climate scenarios and possible land management changes (CSIRO 2008). This assessment has been expanded to include all major water systems across the country to allow a consistent analytical framework for water policy decisions across the nation. Regions most recently studied are northern Australia (CSIRO 2009a), south-west Western Australia (CSIRO 2009b) and Tasmania (CSIRO 2009c). A water resource assessment of the Great Artesian Basin, a major groundwater resource which underlies parts of Queensland, New South Wales, South Australia and the Northern Territory, commenced in July 2010.

IMPACTS)

The impacts of climate change on water intensive agricultural enterprises, including cotton, dairy and sugarcane, have been described in separate statements.

Two considerations have the potential to increase the impacts of changes in water availability on agriculture. Firstly, it has been assumed in the past that though rainfall is highly variable, long term averages tend to be stable over time. Secondly, many water allocations for agriculture were made during the latter half of the 20th century, a period of generally favourable rainfall (Jones 2010). We now face the likelihood of climate change causing reductions in rainfall particularly in southern Australia, as well as the need to reduce water allocations for agriculture so that river environments can be protected and restored.

RESPONSE(S)

Jones (2010) reviewed options for dealing with climatic variability. As most of Australia's agricultural water use is for irrigation, improving irrigation efficiency is an obvious response. Limiting seepage from existing irrigation channels or adopting more efficient trickle/drip systems are two options. Using timers and sensors to schedule watering according to plant needs can also save about 10-15% of water use. Water management could be improved on a season-to-season basis if system-wide allocations were forecast earlier. More reliable forecasts of water availability could also allow more effective opportunistic cropping and grazing management.

Jones (2010) also reviewed the following options for dealing with projected climate change including: 1) Strategic planning of irrigation futures between stakeholders and research institutions, which has the potential to provide better security for the industry, improve environmental outcomes and identify future knowledge needs, 2) Improved seasonal prediction systems that will allow better forward planning for crop selection and areas planted, irrigation scheduling and minimise price risk if supplementary water is needed, and 3) Improved risk management that takes a longer outlook and combines observations with climate projections.

Climate change adaptation has many similarities to coping with current climatic variability. For example, CSIRO's Sustainable Agriculture Flagship is working to improve the water use efficiency of various farming systems. This includes the use of models such as APSIM^{TM} and Yield Prophet^{TM} (see, for instance, Carberry *et al*. 2009, Hochman *et al*. 2009).

BACKGROUND

See statements for particular agricultural enterprises, especially cotton, dairy and sugarcane, that are major users of water.

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AQUACULTURE: EDIBLE OYSTERS

SUMMARY

- Edible oyster production is a valuable industry in New South Wales, Tasmania and South Australia.

- Climate change impacts in conjunction with declining water quality driven by growing coastal populations poses risks to the industry

- Potential for adaptation in the industry includes development of industry-government relations, on-going monitoring and selective breeding programmes.

CONTEXT

This statement is based primarily on the report Climate Change Adaptation in the Australian Edible Oyster Industry (Leith and Haward 2010).

EVIDENCE

Projected Impact

CATEGORY(S)

Ocean biodiversity; Aquaculture

REGION

South-east Marine

DRIVER(S)

Temperature
Precipitation
Water CO_2
Wave climate
Ocean currents
Extreme and variable weather patterns
Sea level rise
Salinity

PRESSURE(S)

Pressure 1

Long-term monitoring of oceanographic data from the Maria Island Station (east Tasmania 42.6°S, 148.23°E) shows that the southward penetration of the East Australian Current has increased since monitoring commenced in 1944 (Hill et al. 2008). Model simulations also show this intensification of the East Australian Current, with a weakening in the north and a strengthening in the south, and predict a strengthening of 9 Sv* south of 30°S from 1978-2002 (Cai 2006).

The averaged results of an ensemble of four climate change experiments with the CSIRO Mark 3 model (2 x scenario A2, 1 x A1B, 1 x B1) for the period 2055-2085, project an annual mean increase of 20%, or about 10 Sv*, in the mean flow of the East Australian Current passing through the Tasman Sea at 36°S (Cai et al. 2005, Cai 2006). The intensified East Australian Current generates a warming rate in the Tasman Sea that is the greatest in the Southern Hemisphere with significant implications for sea level rise.

* 1 Sv = 10^6 m^{-3} s^{-3}

Pressure 2

Oyster production is affected by decline in rainfall or prolonged freshwater events. (White 2002).

Pressure 3:

Pressures on coastal and estuarine environments arising from increasing human populations and changing land use lead to declines in water quality and regulation of freshwater flows that can severely affect oyster production (O'Connor and Dove 2009).

STATE(S)

Climate change may lower production of oysters in some areas, as disease risk and summer kill threat increases, although sensitivity will vary regionally.

IMPACT(S)

Potential impacts include:

- Changes in the timing of spawning (hence market availability) and alteration of growth rates,
- Higher mortalities due to projected increase in air temperatures increasing the risk of summer kills, particularly in northern New South Wales and Queensland
- Potential for increased occurrences of harmful algal blooms and blooms of novel toxic species.
- Alteration in distribution and frequency of oyster diseases.
- Reduction of growth rates due to ocean acidification and lower viability and supply of wild caught spat.
- Projected sea-level rise and increased storm intensity will necessitate modification and upgrade of lease infrastructure.

RESPONSE(S)

Response 1

Key recommendations from Leith and Haward (2010) arising from a series of workshops held with the industry and across relevant scientific literature include specific cross-jurisdictional and regional priorities for building adaptive capacity and resilience such as

- Investigation and development of improvements in coastal and estuarine monitoring programmes and other monitoring and utilize a central repository for data
- Ongoing improvement and, where possible, streamlining of processes for regulatory compliance and assessment of development and planning applications for oyster aquaculture
- Continued efforts between growers, industry, banks and state government to ensure that growers are able to borrow against lease entitlements
- Continued development of knowledge-action networks that include growers, industry bodies, scientists, regional Natural Resource Management (NRM) organizations, and representatives of state and local government; and
- Ongoing development of industry-government relations through effective communication of clear and concise information that allows reciprocal understanding of the process of oyster farming and the needs of growers, on the one hand, and of government regulatory and approvals processes on the other.

Response 2:

Selective breeding programs may provide adaptation to ocean acidification risks (Parker et al. 2011). Experiments have shown that lines of Sydney rock oyster selectively-bred to enhance growth and disease resistance are more resilient to ocean acidification than wild populations (Parker 2011). Future studies need to investigate the physiological and genetic characteristics of the selectively-bred oysters that infer resilience to elevated pCO_2.

BACKGROUND

Oyster farming is one of the oldest aquaculture industries in Australia, dating back some 130 yrs in New South Wales (O'Connor and Dove 2009). In 2007-08, edible oyster production was valued around $37.9 million in New South Wales, $17.4 million in Tasmania, $21.2 million South Australia and $0.7 million in Queensland (ABARE 2009).

In New South Wales, the major edible oyster species is the native Sydney rock oyster *Saccostrea glomerata.* Production takes place in the intertidal zone of estuaries so the oyster are exposed to terrestrial impacts from upstream processes such water extraction (Leith and Haward 2010). It is not uncommon for large-scale kills to occur following heatwaves, particularly in northern NSW, towards the northern boundary of its farmed distribution (~Hervey Bay, Queensland) (see Nell 2005 for distribution). Since 1990, selective breeding programmes have reduced the time to market from 3 to 2 years. Sydney rock oysters have been relatively successfully bred for resistance to their two major protozoan diseases, QX and winter mortality, following support for breeding programmes after QX outbreaks which destroyed the industry in two important estuaries in central New South Wales. However, seed supply is still derived largely from natural catch although hatcheries are increasingly supplying demand (O'Connor and Dove 2009). New South Wales is diversifying into production of the exotic Pacific oyster *Crassostrea gigas*, cultivating diploid and triploid Pacific oysters (O'Connor and Dove 2009).

The exotic Pacific oyster *Crassostrea gigas* dominates the product in South Australia and Tasmania (Leith and Haward 2010). Production is wholly dependent on hatchery reared spat from mostly Tasmanian hatcheries (Leith and Haward 2010). In Tasmania, the oysters are farmed in shallow waters in estuaries so are exposed to terrestrial impacts but in South Australia they are farmed offshore in oceanic conditions (Leith and Haward 2010).

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AQUACULTURE: SALMONIDS

SUMMARY

- Salmon *Salmo salar* in Tasmania are farmed towards their upper thermal limit so growth is fast resulting in a production advantage compared to many northern hemisphere regions. However, current warm water temperatures during the summer months of some years lead to thermal stress and increased disease risk for salmon in sea cages.

- There is concern that ocean warming will result in the thermal limit being exceeded during hotter months every year in some Tasmanian regions, even though warming temperatures could improve production during the rest of the year.

- Additional impacts of climate change, such as availability of freshwater, extreme storm events and increases in harmful blooms, may also have consequences for the salmon industry.

- In the short term, outbreaks of most current diseases including Amoebic Gill Disease (AGD), Rickettsia-like Organism (RLO) infections, and Marine Flexibacteriosis are likely to intensify. A vaccine is being trialed for AGD.

- Selective breeding for increased tolerance to higher water temperatures, as well as to enhance disease resistance and productivity, is now possible following the establishment of an industry-partnered breeding program to improve fish health and production

- Some native species have potential as new candidates to supplement Tasmanian salmonid aquaculture; the most promising being considered are striped trumpeter; southern blue fin tuna; and yellowtail kingfish.

- Climate forecasts will allow planning and response measures to be in place for warmer months. Methods for providing seasonal forecasts of up to four mnoths of local temperatures at salmon farm sites and accuracy of forecasts are currently being evaluated.

CONTEXT

This statement is based on the report *Scoping Study into Adaptation of the Tasmanian Salmonid Aquaculture Industry to Potential Impacts of Climate Change* by S. Battaglene et al. (2008) which contains >100 references. Section 8.2-3 in the report gives précis of published papers on the effects of high temperatures on immune response of fish, on vaccine efficacy, and on pathogens; effects of global warming in populations and emerging diseases; general on climate change; and growth and population models.

EVIDENCE

Projected Impact

CATEGORY(S)

Ocean biodiversity; Aquaculture;

REGION

South-east marine

DRIVER(S)

Temperature
Ocean currents
Ocean climate and sea level

PRESSURE(S)

Pressure 1

Long-term monitoring of oceanographic data from the Maria Island Station (east Tasmania 42.6°S, 148.23°E) shows that the southward penetration of the East Australian Current has increased since monitoring commenced in 1944 (Hill et al. 2008). Model simulations also show this intensification of the East Australian Current, with a weakening in the north and a strengthening in the south, and predict a strengthening of 9 Sv* south of 30°S from 1978-2002 (Cai 2006).

The averaged results of an ensemble of four climate change experiments with the CSIRO Mark 3 model (2 x scenario A2, 1 x A1B, 1 x B1) for the period 2055-2085, project an annual mean increase of 20%, or about 10 Sv*, in the mean flow of the East Australian Current passing through the Tasman Sea at 36°S (Cai et al. 2005, Cai 2006). The intensified East Australian Current generates a warming rate in the Tasman Sea that is the greatest in the Southern Hemisphere with significant implications for sea level rise. Over 1944-2002, the waters off eastern Tasmania have become warmer, with mean trend of 2.28°C/century, and saltier, with mean trend of 0.36 psu/century (Hill et al. 2008). Trends are greater in the summer, when the greatest East Australian Current flow occurs seasonally. The changes correspond to a southwards shift in sea surface climatology of around three degrees latitude or 350 km over 1944-2002 (Ridgway and Hill 2009).

* $1 \text{ Sv} = 10^6 \text{ m}^{-3} \text{ s}^{-3}$

STATE(S)

State 1

Salmon *Salmo salar* in Tasmania are farmed towards their upper thermal limit so growth is fast resulting in a production advantage (production cycles of around 30 months) compared to many northern hemisphere regions (up to 36 months). The upper critical temperature range for salmonids is considered to be >22°C. Water temperatures than this currently occur during the summer months of some years leading to thermal stress and increased disease risk for salmon in sea cages.

IMPACT(S)

Warming will impact salmon in sea cage grow-out facilities as all Tasmanian hatcheries will soon be temperature-regulated due to the introduction of water recirculation and temperature control. There is concern that ocean warming will result in the thermal limit being exceeded during hotter months every year in some Tasmanian regions, even though warming temperatures could improve production during the rest of the year.

In the short term, outbreaks of most current diseases including Amoebic Gill Disease (AGD), Rickettsia-like Organism (RLO) infections, and Marine Flexibacteriosis are likely to intensify. In particular, AGD could be an increasing problem, not only because of the immune suppression and environmental conditions favouring the disease, but also due to reduced fresh water availability for treatment. Managing AGD is estimated to cost the industry A$15 million a year in treatment and lost productivity as it affects fish growth and frequent freshwater bathing is required to detach the parasitic amoeba (see http://www.csiro.au/science/ps3b6.html). The freshwater is in limited supply, and bathing is labour-intensive.

Additional impacts of climate change, such as availability of freshwater, extreme storm events and increases in harmful blooms, may also have consequences for the salmon industry. For example, increases in extreme weather frequency and intensity will require stronger cages and anchoring systems to reduce escapement of fish during storms. Blooms of the red dinoflagellate *Noctiluca scintillans* are reported from Tasmania since 1994 which may represent a novel, significant threat to the salmonid aquaculture industry (Hallegraeff 2010).

RESPONSE(S)

The general lack of knowledge about effects of higher water temperatures and other environmental changes related to climate change on farmed Atlantic salmon in Tasmania, especially larger fish in sea cages. Most of our knowledge of the effects of temperature on salmon health is based on information from cooler waters in the Northern Hemisphere, and often for different species of salmonids. Australia will need a sustained research effort to address this knowledge gap for the salmonid industry.

Development of a vaccine against amoebic gill disease (AGD) and selective breeding for AGD resistant stock are longer term solutions currently being tested under commercial conditions (see A vaccine for gill disease in Atlantic salmon http://www.csiro.au/science/ps3b6.html). Research is also required to determine the performance of currently used vaccines at higher temperatures and the development of new vaccines which will support immunity at increased temperatures.

Selective breeding for increased tolerance to higher water temperatures is now possible following the establishment of an industry-partnered breeding program to improve fish health and production (see Breeding Better Salmon http://www.csiro.au/science/ps20x.html).

The relocation of existing growout facilities to areas with significantly cooler temperatures would involve open-ocean offshore operation but operating costs are currently prohibitive and new technology would be required.

Culturing alternative species will only ever supplement, not replace, salmonid farming. Some native species have potential as new candidates for Tasmanian sea cage culture, the most promising being considered are striped trumpeter; southern blue fin tuna; and yellowtail kingfish. Sea cage trials using cultured striped trumpeter have been undertaken (see Striped Trumpeter Aquaculture http://fcms.its.utas.edu.au/scieng/mrl/researchareasdetails.asp?lSchoolResearchAreaID=518). Diversifying into alternative species will require establishment of a commercial marine fin-fish hatchery, zoning of new water for marine farming and overcoming new health, wild fish interactions and marketing challenges.

Climate variability, operationally defined as interannual change in the environmental conditions, has always been a factor for many Australian aquaculture businesses. Climate predictions allow appropriate business decisions to be made. Predictions involve risk, and as in all future business decisions, assessment of the risk and certainty of the prediction is required before deciding to take a particular business decision. Methods for providing seasonal forecasts of up to four mnoths of local temperatures at salmon farm sites and accuracy of forecasts are currently being evaluated. Forecasts will allow planning and response measures to be in place for warmer months (see Forecasting ocean temperatures for salmon at the farm site http://www.cmar.csiro.au/climateimpacts/projects.htm#proj1).

BACKGROUND

In 2007-2008, farmed salmonids (salmon and trout species) have emerged as a key production species in terms of value (~$299 million), surpassing tuna as Australia's most valuable finfish species group (ABARE 2009). >95% of salmonids are cultured in Tasmania. Salmonids are mostly supplied to a growing domestic market cultivated through strong marketing. Another factor behind the sector's strong growth is the role of research and development, which has allowed the sector to adopt improved feeding techniques and apply better disease control measures (ABARE 2009). However, the rapid expansion of the industry is potentially restricted by control and management of disease, competition from overseas producers, availability of water in which to farm and environmental changes (Battaglene et al. 2008).

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ASSISTED COLONISATION

SUMMARY

- Climate induced changes to ecosystems, is resulting in the geographic range of species to shift towards the poles or to higher elevations. The speed of these changes may exceed species' ability to adapt or disperse, leaving many species without suitable places to live and thus at an increased risk of extinction (Hoegh-Guldberg et al. 2008).

- For at risk species, assisted colonisation has been proposed as an adaptation strategy and involves physical movement of plants or animals from an area that has or will become unsuitable due to climate change to locations where the climate is predicted to be suitable, but where the plants or animals have never occurred before.

- While the merits of this adaptation option are hotly debated (Ricciardi and Simberloff 2009), species are already being moved as a result threats posed by climate change. In response, researchers have developed a decision tool for informing the timing of such moves (McDonald-Madden et al. 2011).

- To facilitate assisted colonisation in Australia, researchers have examined the policy and regulatory changes needed (Burbidge et al. 2011).

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Projected Impact

CATEGORY(S)

Natural & Managed Ecosystems; All Ecosystems; Biodiversity

REGION

Australia; Global

DRIVER(S)

Temperature
Rainfall
Soil Moisture
Ocean climate and sea level rise

PRESSURE(S)

Pressure 1

Air temperature is expected to increase across Australia by approximately 1^{o}C on average by 2030, with inland regions are expected to experience more significant rises in temperature (CSIRO and BOM 2007). Temperature increases of around 0.7-0.9^{o}C are expected in coastal areas and 1-1.2^{o}C inland. Warming is slightly lower in winter, down to 0.5^{o}C in southern parts of the country, there will be fewer days with frost, and the number of hot nights and days per year will increase in summer. Even accounting for uncertainty in emission scenarios, warming is at least 0.4^{o}C in all regions, and may be as large as 1.8^{o}C in some regions by 2030, and ranges from 1.0^{o}C to 2.5^{o}C by 2070 (CSIRO and BOM 2007).

Pressure 2

Changes in rainfall are expected to be variable across Australia, with an overall decrease in precipitation (CSIRO and BOM 2007). Best estimates by 2030 are -2 to -5% decreases in precipitation, though little of these changes will occur in the northern part of Australia. By 2050 these changes will be more extreme, from decreases of -5% to -20% across the country. A future warmer atmosphere under climate change has the ability to hold more water vapour, leading to increases in intensification of rainfall events. The number of dry days and the number of rain-per-wet day will both increase. Drought is expected to be more widespread in Australia, particularly in the south-eastern regions (CSIRO and BOM 2007).

Pressure 3

A warming air temperature has the effect of warming the ocean, causing a thermal expansion of the upper ocean. As a result, sea levels are rising: in Australia the overall sea level rise between 1993 and 2003 was 3mm, which is an order of magnitude faster than background rates of rise in the past few thousands of years (CSIRO and BOM 2007). Global sea levels are predicted to rise 18-59 cm by 2100, with changes in many parts of Australia, including the east coast, being higher than the global average (CSIRO and BOM 2007). Further unknown increases in sea level may occur due to the melting of ice sheets.

STATE(S)

As a result of climate induced changes to ecosystems, the geographic range of species is shifting towards the poles or to higher elevations. The speed of these changes may exceed species' ability to adapt or disperse, leaving many species without suitable places to live and thus at an increased risk of extinction (Hoegh-Guldberg et al. 2008). Indeed, some of our most species-rich areas of the globe and most valued ecosystems, such as coral reefs and mountain rainforests, may cease to exist in their current form as a result of climatic changes. In these cases standard conservation actions such as creating conservation reserves may offer insufficient protection. Instead, species persistence may require the radical action of assisted colonisation.

IMPACT(S)

Assisted colonisation is also known as managed relocation assisted translocation, or assisted migration. It involves physical movement of plants or animals from an area that has or will become unsuitable due to climate change to locations where the climate is predicted to be suitable, but where the plants or animals have never occurred before. If the relocation is successful, persistence of the population, species or ecosystem may be ensured. For example, relocation of low-latitude staghorn coral species, known to have a higher temperature range tolerance, to higher latitudes may be one way of preserving this species as the climate changes; relocating a sub-population of the high elevation wet tropics Golden bowerbird to lower latitude high elevation rainforest may prolong the persistence of this species. Managed relocation flies in the face of traditional conservation strategies. In fact there is an entire discipline, invasion ecology, devoted to managing the negative consequences of moving species into new regions around the globe. For this reason the merits of this adaptation option is hotly debated (Hoegh-Guldberg et al. 2008; Hunter 2007; Ricciardi and Simberloff 2009; Richardson et al. 2009). While debate continues species are already being moved under the guide of climate change (Willis et al. 2009).

RESPONSE(S)

Response 1.

Decision Frameworks

If assisted colonisation is deemed an acceptable adaption strategy (Hoegh-Guldberg et al. 2008) the question becomes one of optimal timing of implementing this action. McDonald-Madden et al. (2011) present a decision tool for deciding when, if ever, to implement assisted colonisation. This decision-making framework shows that the best timing for moving species depends on many factors such as: the size of the population, the expected losses in the population through relocation, and the expected numbers that the new location could be expected to support. The framework enables managers to trade-off the value of learning and reducing critical uncertainty versus the risk of species extinction by doing nothing or making a poor decision.

Response 2.

Low-risk assisted colonisation

Managers are likely to seek out low-risk scenarios for assisted colonisation. Using an analysis of temperate grassy woodlands from Australia, McIntyre (2011) identified relevant ecosystem attributes which make assisted colonisation a sensible strategy, and that may characterize other favorable situations globally. The contributing elements include: a biota adapted to resource conservatism, a naturally connected landscape with component species having wide distributions over a large climatic gradient, current land use unrelated to endogenous disturbance regimes resulting in extensive replacement and modification of the ecosystem over its entire range (McIntyre 2011).

Response 3.

Policy and regulatory advice

In another paper researchers have examined the policy and regulatory changes needed to facilitate assisted colonisation in Australia (Burbidge et al. 2011). Current policies and procedures for the preparation of Translocation Proposals will require modification and expansion to deal with assisted colonisation, particularly in relation to risk management, genetic management, success criteria, moving associated species and community consultation. Further development of risk assessment processes, particularly for invasiveness, and guidelines for genetic management to maintain evolutionary potential are particularly important in the context of changing climate. Translocation Proposals should always be subjected to independent peer review before being considered by regulators. Burbidge et al (2011) conclude that consistent approaches by regulators and multilateral agreements between jurisdictions are required to minimise duplication, to ensure the risk of assisted conlisation is adequately assessed and to ensure the potential benefits of assisted colonisation are realised.

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BROADACRE GRAZING

SUMMARY

- Climate change will not only bring challenges for broad acre grazing, but also could well improve productivity in some locations.

- Extensive grazing of beef and sheep (meat and wool) is by far the most widespread agricultural land use in Australia, taking place over most of the country excluding areas suitable for more intensive agriculture, nature conservation reserves and desert areas (Australian Natural Resources Atlas 2001).

- Though conditions may become more favourable for extensive grazing in some areas the projected temperature and rainfall trends over most of the country are expected to result in declines in pasture productivity, reduced forage quality, increased livestock heat stress, more frequent droughts, increased soil degradation and greater pest and disease problems (Crimp *et al.* 2010, Stokes *et al.* 2010).

- The most arid and least productive rangelands may be the most severely impacted by climate change, while the more productive eastern and northern grazing lands may experience slight increases in production (Stokes *et al.* 2010).

- Adaptation may include increased use of climate-forecasting strategies that help graziers cope with climate variability and also to adjust management to the early stages of climate change (Stokes *et al.* 2010).\

CONTEXT

The main source of information was the chapter by Stokes *et al.* (2010), a review including more than 85 references. Other information was taken mainly from journal papers, which either were not cited by Stokes *et al.* (2010) or have appeared since the publication of that review.

EVIDENCE

Observed Impact: As with several other agricultural systems the impacts of climate change are so far difficult to distinguish from the effects of climatic variability.

CATEGORY(S)

Production systems: Food

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Solar Radiation
Extreme and variable weather patterns
Soil moisture

PRESSURE(S)

Black *et al.* (2008) have summarised likely climate changes across grazing lands. There is general agreement that the annual average temperature is likely to increase by between 1°C and 6°C over much of inland Australia by 2070, with the increase less in coastal than in inland areas. Expected changes in rainfall are much more variable and complex, both seasonally and regionally. Over most of Australia, rainfall is likely to decrease, particularly in the period to 2030, and especially over the south-west mainland (see a separate iClimate statement for 'northern Australia's grazing industry'). However, an increase in heavy rainfall is projected even in regions with small decreases in average rainfall. The increase in temperature will lead to greater potential evaporation and reduce the water balance, even in areas with slightly higher rainfall. These changes will lead to both more drought and to more severe droughts.

STATE(S)

The current condition of much of the rangelands is strongly influenced by variability associated with the El Nino-Southern Oscillation (ENSO). Clewett *el al.* (2007) have shown how seasonal rainfall, minimum temperature and maximum temperature, and evaporation affect pasture establishment and growth, and the onset of the growing season in grazing areas of the Murray-Darling Basin of southern Queensland.

Stafford Smith *et al.* (2007) have shown how this highly variable climatic environment across extensively grazed lands has often led to rangeland degradation through the following sequence of events: (*i*) good climatic and economic conditions for a period, leading to local and regional social responses of increasing stocking rates, setting the preconditions for rapid environmental collapse, followed by (*ii*) a major drought coupled with a fall in the market making destocking financially unattractive, further exacerbating the pressure on the environment; then (*iii*) permanent or temporary declines in grazing productivity, depending on follow-up seasons coupled again with market and social conditions.

IMPACTS)

Stokes *et al.* (2010) have reviewed climate change impacts on broad acre grazing systems across Australia. In common with many other agricultural systems atmospheric and climatic changes will affect grazing systems through complex interactions involving effects on plant growth. Rising temperatures could benefit pastures in southern cooler climates, by increasing the growing season and reducing frost damage. However, increased plant growth in the cooler months could deplete soil moisture at the expense of subsequent growth. In warmer climates increased heat stress, and possibly increased evaporative demand would be likely to have negative impacts on pasture growth.

The effects of CO_2 have yet to be fully included in grazing models, but early efforts suggest that the effects of increased temperatures (+3^{o}C) and declining rainfall (-10%) may outweigh conservatively represented benefits of increasing CO_2 (from 350 ppm to 650 ppm) in many areas of inland Australia (McKeon *et al.* 2009).

RESPONSE(S)

Stokes *et al.* (2010) have reviewed options currently used for dealing with climate variability. Australia's rangelands are characterised by high year-to-year variability in rainfall that in turn drives high variability in plant growth, nutrients available to livestock and availability of land management options (e.g. use of fire and spelling).
Land degradation is often a result of inappropriate management responses to drought. Improvements in forecasting El-Nino-Southern-Oscillation (ENSO) events are assisting management. As well as using seasonal forecast information other options include conservative stocking, income diversification and spatial diversification of management strategies across vast properties.

Stokes *et al.* (2010) also reviewed options for dealing with climate change including grazing/pasture management (for example, stocking adjustments in extensively grazed areas and possible pasture genotype changes in more intensively grazed temperate regions), pest/disease/weed management (e.g. use of quantitative modelling to identify areas and periods of greatest risk, as already used for cattle tick control), livestock management (including selecting stock lines better adapted to hotter and drier conditions), and broader-scale policy options (e.g. defining 'exceptional circumstances' of drought in such a way as to encourage adaptation to changing climates).

The Australian Collaborative Rangelands Information System (ACRIS) (Bastin *et al.* 2009) collates and analyses data on topics such as climatic variability, total grazing pressure, fire regimes, landscape function, sustainable management of forage for grazing, biodiversity and socio-economics to understand changes at regional to national scales. It is being developed with a view to assisting adaptation to climate change.

At a finer scale Crimp *et al.* (2010) have analysed the adaptive capacity of rural households concerned with livestock systems in the Murray-Darling Basin, expressed as a function of the diverse forms of human, social, natural, physical and financial capital from which livelihoods are derived. They found adaptive capacity was 'low' in the northern and central-west regions of the MDB and higher in the central and eastern parts, possibly indicating a greater propensity to adapt to climate change in these regions.

Past experience has shown how climatic variability can hinder local learning (see State section of this statement and also Stafford Smith *et al.* 2007). Future adaptation must deal not only with continuing variability, but also climate change.

BACKGROUND

A potential barrier to climate adaptation in rangelands is a widely held view that existing strategies for dealing with climate variability together with autonomous incremental changes to management will be sufficient. If, as seems increasingly likely, global warming exceeds 2^{o}C, more proactive coping strategies will likely be required to supplement 'business as usual' approaches to deal with the unique gradual, but progressively strengthening, impacts that climate trends will bring (Stokes *et al*. 2010).

See also an iClimate statement for 'northern Australia's grazing industry'.

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CLIMATE AND HABITAT LOSS INTERACTIONS

SUMMARY

- Mantyka-Pringle et al. (2012) present the first meta-analysis of studies that quantify the effect of habitat loss on biological populations and examine whether the magnitude of these effects depends on current climatic conditions and historical rates of climate change.

- They examined 1,319 papers on habitat loss and fragmentation, identified from the past 20 years, including 23 papers from Australia, representing a range of taxa, landscapes, land-uses, geographic locations and climatic conditions.

- They find that current climate and climate change are important factors determining the negative effects of habitat loss on species density and/or diversity. The most important determinant of habitat loss and fragmentation effects, averaged across species and geographic regions, was current maximum temperature, with mean precipitation change over the last 100 years of secondary importance.

- Habitat loss and fragmentation effects were greatest in areas with high maximum temperatures. Conversely, they were lowest in areas where average rainfall has increased over time.

- This is the first study to conduct a global terrestrial analysis of existing data to quantify and test for interacting effects between current climate, climatic change and habitat loss on biological populations.

CONTEXT

One of the most pressing questions of the twenty-first century in ecology and conservation is, how do multiple stressors interact and cumulatively impact ecosystems and their biodiversity? Climate change, habitat loss, invasive species, disease, pollution, and overexploitation are typically studied and managed in isolation, although it is becoming increasingly clear that a single-stressor perspective is inadequate when ecosystems and species are threatened by multiple, co-occurring stressors. This statement is based on a global meta-analysis by Mantyka-Pringle et al. (2012).

EVIDENCE

Observed Impact

CATEGORY(S)

Natural & Managed Ecosystems; Terrestrial Biodiversity

REGION

Australia; Global

DRIVER(S)

Temperature
Rainfall

PRESSURE(S)

Pressure 1

Global average temperatures have risen by about 0.7ºC over the past century. Warming was modest in Australia in the early part of the 20th century, followed by a slight decline from around 1935 to 1950, and then a rapid increase until 2010. Australian average temperature has increased by around 0.7ºC since the middle of the 20th century. This trend is continuing: the second half of 2009 was the warmest on record for Australia and 2010 was one of the hottest years in the instrumental climate record. The past decade (2000 to 2009) was Australia's warmest decade on record (Braganza and Church 2011).

STATE(S)

Since the beginning of the 20th century, human population growth has been exponential and has occurred largely in the subtropical and tropical ecoregions. Population growth has been accompanied by broad-scale changes in land cover and land use, typically in support of agriculture and urban development. The result is an ever increasing level of primary habitat loss, fragmentation and degradation.

IMPACT(S)

Habitat loss and fragmentation effects were greatest where maximum temperature of warmest month was highest (i.e. effects were greatest in areas with high temperatures). Conversely, habitat loss and fragmentation effects were lowest in areas where precipitation has increased most (i.e. smaller effects occurred in areas where average rainfall has increased over time than in areas where rainfall has decreased). These were the two most important variables, with mean temperature change as the third. Therefore both current climate (i.e. maximum temperature) and climate change (i.e. precipitation change) appear to be key determinants of habitat loss and fragmentation effects on terrestrial biodiversity (Mantyka-Pringle et al 2012).

With the exception of arthropods all taxonomic groups (birds, plants, arthropods, mammals, amphibians and reptiles), showed a consistent interaction between current temperature and habitat loss effects.

RESPONSE(S)

Understanding the synergistic effects between climate change and other threatening processes has critical implications for our ability to support and incorporate climate change adaptation measures into policy development and management response.

Response 1

Mantyka-Pringle et al (2012) suggest management strategies should focus towards areas with warmer climates, especially those that are more susceptible to precipitation change. Existing measures against drought should also be intensified, to reduce the negative interaction with climate change, especially in fragmented landscapes. In the case where biodiversity is threatened by interactions among climate change and other stressors, there are essentially two main approaches to minimising loss.

They state "Where climate change interactions are expected to be relatively small and knowledge and capacity high, the best feasible option might be to continue what we are already doing. That is, building resilience in a system to climate change, for example, through habitat restoration, and continued management of other stressors such as pest management, and fire and grazing management. However, in areas where the effects of climate change and interactions are expected to be severe, our current suite of management actions may be ineffective. It may be appropriate in these cases to use a mixture of more proactive management strategies instead; such as species translocation (McDonald-Madden et al. 2011), engineering habitat to reduce impact of interactions, and even abandoning effort on saving species in one area in favour of other areas. Monitoring that informs management is thus essential here to pre-emptively identify populations that may suffer decline, and to assess cost-effective and feasible management actions (Carwardine et al. 2011)."

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CORAL BLEACHING

SUMMARY

- Coral reefs are threatened by a combination of local (e.g. pollution, fishing) and global stressors (e.g. warming, ocean acidification)
- Recent warming has led to repeated mass coral bleaching, not observed in the world's oceans before 1979. If prolonged or severe, coral mortality occurs.
- Temperature thresholds for bleaching may be exceeded every year in Australian waters by the end of this century. Bleaching and other stressors will result in degradation and loss of coral reefs with negative economic impacts.
- Much is being done to reduce the local and regional pressures on the Great Barrier Reef and therefore improve its resilience
- Dedicated climate change programs are being implemented throughout the Great Barrier Reef Region and beyond

CONTEXT

This statement is a synthesis of a number of reports and scientific articles.

EVIDENCE

Observed and projected

CATEGORY(S)

Coastal and ocean biodiversity

REGION

North-west and north-east australia

DRIVER(S)

Temperature
Water CO_2

PRESSURE(S)

Coral reefs are threatened by a combination of local (e.g. water quality, coastal degradation, pollution and fishing pressure) and global (e.g. warming temperatures, rising sea-levels, ocean acidification) stressors (GBRMPA 2009, Carilli et al. 2010, Anthony et al 2011). Hoegh-Guldberg et al. (2007a) concluded that carbonate coral reefs such as the Great Barrier Reef are unlikely to maintain themselves beyond atmospheric carbon dioxide concentrations of

450 ppm. Neither temperature (+2°C above pre-industrial global temperatures) nor ocean carbonate concentration (<200 µmol kg-1) in these scenarios are suitable for coral growth and survival, or the maintenance of calcium carbonate reef structures.

STATE(S)

Recent warming throughout tropical oceans has led to repeated coral bleaching events, not seen anywhere in the world before 1979, affecting hundreds to thousands of square kilometres of coral reefs in almost every region of the world where coral reefs occur. In the most severe global episode of mass coral bleaching (1998), 16% of corals that were surveyed before that event had died by the end of the year (Hoegh-Guldberg 1999, Knowlton 2001).

Mass bleaching events over large sections of the Great Barrier Reef have occurred six times during the past 30 years: in 1983, 1987, 1991, 1998, 2002 and 2006 (Hoegh-Guldberg et al 2007b). Mortality rates in this region were relatively low however, primarily because warming on the Great Barrier Reef was less severe than in other parts of Australia and the world.

By the middle of this century, temperature thresholds for coral bleaching will be exceeded every year in Australia, if sea temperatures increase as projected by global climate models (Hoegh-Guldberg 1999). Based on the current responses of corals, it is estimated that an increase of 2°C in tropical and subtropical Australia would result in annual bleaching and quite possibly regular, large-scale mortalities (Hoegh-Guldberg 1999, 2004, Lough 2000). A geographic analysis of risk to the Great Barrier Reef associated with these changes in sea temperature indicated that the projected succession of devastating mass coral bleaching events will severely compromise the ability of reefs to recover, no matter where they are found along the Queensland coastline (Done et al. 2003). This analysis indicated that deterioration of coral populations is likely in most of the scenarios examined and this is reinforced by findings from other studies (Hoegh-Guldberg 1999, Donner et al. 2005, Donner 2009).

IMPACT(S)

Impact 1

Declining water quality and the direct and indirect impacts of climate change can degrade coral reefs (Hughes et al 2007). Whether or not degraded reefs continue to function will depend on a number of factors such as the severity of the bleaching event, the loss of coral cover and levels of herbivory (Hughes et al 2007, Baker et al 2008). Coral reefs support a considerable diversity of animals and plants. Declines and shifts in the assemblages of reef-supported organisms, such as reef fish, occur after severe coral bleaching events (Graham et al 2007, 2008, Cheal et al 2008).

Impact 2

The Great Barrier Reef contributes substantially to the economy, and industries such as tourism and reef-based fisheries rely on the health and quality of the reef (Hoegh-Guldberg and Hoegh-Guldberg 2008, STCRC 2009). The economic impacts of coral bleaching induced by climate change are likely to be large; the bleaching cost for the whole of the Great Barrier Reef is estimated to be roughly equivalent to a constant $1.08 billion per annum over the course of a century (Oxford Economics 2009).

RESPONSE(S)

Much is being done to reduce the local and regional pressures on the Great Barrier Reef and therefore improve its resilience, for example improvements in land management practices and careful management of use of the Region (GBRMPA 2009). Management initiatives that further improve the resilience of the Great Barrier Reef ecosystem will mean that the ecosystem is better able to cope with and recover from the impacts of climate change in coming years. The focus of the Great Barrier Reef Climate Change Action Plan, 2007-2012 (GBRMPA 2007) is to increase knowledge about the implications of climate change for both the Great Barrier Reef and the people who depend upon it, and to develop and support strategies to foster adaptation and minimise impacts through improving and maintaining resilience (GBRMPA 2009). Other dedicated climate change programs are being implemented throughout the Great Barrier Reef Region and beyond by the Australian and Queensland Governments (GBRMPA 2009). As an example, real-time seasonal forecasts are being used, as part of a strategic framework to prepare and respond to bleaching events, to gain advance warning of warm bleaching conditions and allows for a proactive management approach (Maynard et al. 2009; Spillman 2011)

In 2007, the Great Barrier Reef Foundation (www.barrierreef.org) launched its own climate defence fund for the reef, ZooX^{TM}Fund. The Fund provides a way for everyone to do something positive about climate change and details of research projects being supported can be found at http://www.barrierreef.org/OurProjects/ZooXFund.aspx.

In Western Australia, the Western Australian Marine Science Foundation (WAMSI http://www.wamsi.org.au/) is conducting climate change research on Ningaloo Reef, e.g. downscaling ocean climate into the Ningaloo Reef tract.

BACKGROUND

The symbiosis between corals and the unicellular algae (dinoflagellates from the genus *Symbiodium*) that live within the coral tissues is highly sensitive to temperature stress and other stressful environmental conditions. Bleaching events are induced by prolonged warmer-than-average temperatures. During bleaching, the symbiosis between the coral and the unicellular algae (dinoflagellates from the genus *Symbiodium*) that live within the coral tissues, disintegrates (Weis 2008). Bleached corals may recover their symbiotic populations of *Symbiodium* in the weeks and months after a bleaching event if the conditions triggering the event are mild and short-lived, but coral mortality has reached 100% in bleached corals when stressful conditions have persisted for days to weeks.

The genus *Symbiodium* is currently divided into 8 distinct clades and corals form associations with 6 of these clades. The potential exists in corals for acclimization to warming by altering the symbiont types harboured (Jones et al 2008). However, the tradeoffs of altering symbionts are likely to come with physiological costs such as reduced growth rates (Jones and Berkelmans 2010). Only some corals will be able to adapt to warming oceans by acquiring more stress-tolerant symbionts, so climate change is likely to lead to decreases in coral biodiversity and loss of reefs (Coffroth et al 2010, Jones and Berkelmans 2010).

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COTTON PRODUCTION

SUMMARY

- Cotton production will need to respond to climate changes as well as decreasing water availability.

- Australian cotton production is located mainly in New South Wales and central/southern Queensland. About 400 000 ha of irrigated cotton is grown annually with rainfed areas varying widely between 5 000 and 120 000 ha (McRae *et al*. 2007, Bange *et al*. 2010).

- Increased CO_2 may increase yield in well-watered crops and higher temperatures will extend the growing season especially in current short season areas. However, higher temperatures also have the potential to cause significant fruit loss, lower yields and reduced water use efficiencies (Bange *et al*. 2010, Sankaranarayanan *et al*. 2010).

- There is a need for experimental investigations of the integrated effects of climate change (temperature, CO_2, humidity, and water stress) and incorporation of results into simulation models (Reddy *et al*. 2007).

- The vast majority of Australian cotton production is located in the Murray Darling Basin (see map in McRae *et al*. 2007) where availability of water is likely to decline not only as a result of climate change but also due to policies to increase environmental flows (CSIRO 2008).

- Though reductions in water availability for irrigation will probably be not as great as those in the 'Guide to the proposed Basin Plan' (Murray-Darling Basin Authority 2010) they may have significant impacts on overall industry production.

- Adaptation will require cultivars tolerant to more frequent hot and water-deficit conditions as well as capable of more efficiently delivering improved yield and fibre quality (Bange *et al*. 2010).

CONTEXT

The main source of information was the review by Bange *et al* (2010), supplemented by information from published papers (eg Sankaranarayanan *et al*. 2010), papers and reports available from the internet (McRae *et al*. 2007, CSIRO 2008) as well as books (Mauney *et al*. 2010) and journal articles (Constable *et al*. 2011).

EVIDENCE

Projected Impact

CATEGORY(S)

Production systems: Fibre

REGION

Queensland
New South Wales

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Solar Radiation
Extreme and variable weather patterns
Soil Moisture

PRESSURE(S)

Temperature trends throughout cotton growing regions are consistent with general Australian trends. Average annual minimum temperatures have increased by 0.9°C and average annual maximum temperatures by 0.6°C since 1950 (McRae *et al*. 2007).

STATE(S)

McRae *et al*. (2007) summarised key climate change issues for cotton growing areas including:

- A tendency towards an increase in potential evaporation of 0 to 8% per degree of warming with the larger tendency where there is a corresponding decrease in rainfall.

- A tendency towards a decrease in the annual water balance of 40 to 120 mm per degree of warming.

- This represents a water balance decrease of 15 to 160 mm by 2030 and 40 to 500 mm by 2070 with the largest impact in spring.

Even if rainfall remains consistent with long term averages, the rise in overall temperatures and potential decreases in water balance indicate the likelihood of greater moisture stress throughout cotton growing areas of Australia. Therefore water use efficiency, access to water and soil water management will remain dominant issues into the future.

IMPACT(S)

Bange *et al*. (2010) have reviewed climate change impacts on cotton. Vegetative and reproductive growth occur simultaneously making interpretation of the crop's response to climate change and management sometimes difficult. Controlled environment research summarised by Reddy *et al*. (1996) suggested that increased growth and yield would be produced by doubling CO_2 concentrations even in dry conditions. However, in contrast to the work of Reddy *et al* (1996) controlled environment research by Samarakoon and Gifford (1996) found transpiration was only reduced by 15%. These results need to be reconciled as cotton is likely to experience the additional confounding effects of limited water availability and increased evaporative demand.

A free air CO_2 enrichment trial that raised CO_2 levels to 550 ppm (Pinter *et al*. 1994 and Mauney *et al*. 1994) indicated increases in lint (ie. cotton fibre) yields of 43% that was attributed to increased early leaf area and a longer flowering period.

Water stress in cotton restricts both vegetative and fruit growth (Bange *et al*. 2010) Research in Australia has shown that to optimise yield, cotton crops require enough water to allow an average of 700 mm of evapotanspiration (Tennakoon and Milroy 2003). Research is currently underway to quantify the effects of evaporative demand on cotton growth and water use efficiency.

Rising temperatures under climate change may (1) extend the growing season and reduce frost damage (a positive effect), (2) cause quicker emergence and flowering (a positive effect), (3) reduce disease, (4) increase the number and severity of days with very high temperatures during the cotton season (a negative effect), (5) increase average temperatures during boll filling, predisposing crops to high micronaire (fibre fineness and maturity) issues (both a positive and a negative effect depending on the region) and (6) increase abundance, development and mortality of certain pests (may be a positive or negative effect) (Bange *et al*. 2010).

In common with many other agricultural systems the ways in which CO_2, water and temperature impacts will interact is complex, so that it is not easy to predict if impacts will be positive or negative for particular regions.

RESPONSE(S)

Bange *et al*. (2010) have reviewed adaptation options for dealing with climate variability including water management, pest/weed/disease management and extension materials/decision tools. They also reviewed adaptation options for dealing with climate change including improved cultivars, planting time variation, optimising efficiency of resource inputs, matching crop maturity with season length, regional opportunities, improving crop returns, and crop substitution.

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BACKGROUND

The Basin Plan is a high level plan to ensure that the water resources of the Murray Darling Basin can be managed in a sustainable way. It will be prepared by the Murray-Darling Basin Authority and may have major influence on water availability for crops such as cotton and rice. It was not available when this statement was prepared in early June 2011, but is expected to be released for public comment in mid-2011.

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DISTRIBUTIONAL SHIFTS OF SPECIES IN SOUTH-EAST AUSTRALIAN MARINE WATERS

SUMMARY

- Over 1944-2002, the waters off eastern Tasmania have become warmer, with mean trend of 2.28°C/century, and saltier, with mean trend of 0.36 psu/century. The changes correspond to a southwards shift in sea surface climatology of around three degrees latitude or 350 km over 1944-2002.

- Southern range extensions observed in eastern Tasmanian waters in several species of fish, invertebrates**,** the invasive European shore crab *Carcinus maenas*, the sea urchin *Centrostephanus rodgersii* and dinoflagellates have been ascribed to enhanced transport of larvae and juveniles in the stronger East Australian Current and regional warming.

- Establishment of exotic species such as the invasive European shore crab *Carcinus maenas*, the sea urchin *Centrostephanus rodgersii* and dinoflagellates represent novel threats to native species and to fishing and aquaculture industries in Tasmania.

- Monitoring programmes have been initiated for fish and cephalopods (RedMap www.redmap.org.au) and plankton (IMOS/AusCPR (http://www.imos.org.au/auscpr.html))

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Ocean biodiversity; Fisheries; Aquaculture; Ocean climate and sea level

REGION

South-east marine

DRIVER(S)

Temperature
Ocean currents
Ocean climate and sea level

PRESSURE(S)

Pressure 1

Long-term monitoring of oceanographic data from the Maria Island Station (east Tasmania 42.6°S, 148.23°E) shows that the southward penetration of the East Australian Current has increased since monitoring commenced in 1944 (Hill et al. 2008). Model simulations also show this intensification of the East Australian Current, with a weakening in the north and a strengthening in the south, and predict a strengthening of 9 Sv* south of 30°S from 1978-2002 (Cai 2006).

The averaged results of an ensemble of four climate change experiments with the CSIRO Mark 3 model (2 x scenario A2, 1 x A1B, 1 x B1) for the period 2055-2085, project an annual mean increase of 20%, or about 10 Sv*, in the mean flow of the East Australian Current passing through the Tasman Sea at 36°S (Cai et al. 2005, Cai 2006). The intensified East Australian Current generates a warming rate in the Tasman Sea that is the greatest in the Southern Hemisphere with significant implications for sea level rise.

* 1 Sv = 10^{6} m^{-3} s^{-3}

STATE(S)

State 1

Over 1944-2002, the waters off eastern Tasmania have become warmer, with mean trend of 2.28°C/century, and saltier, with mean trend of 0.36 psu/century (Hill et al. 2008). Trends are greater in the summer, when the greatest East Australian Current flow occurs seasonally. The changes correspond to a southwards shift in sea surface climatology of around three degrees latitude or 350 km over 1944-2002 (Ridgway and Hill 2009).

IMPACT(S)

Southern range extensions observed in (I1) several species of fish, (I2) a barnacle *Austromegabalanus nigrescens*, octopus *Octopus tetricus*, coral *Plesiastrea versipora* and eastern rock lobster *Jasus verreauxi* (I3) the invasive European shore crab *Carcinus maenas*, (I4) the sea urchin *Centrostephanus rodgersii* and (I5) dinoflagellates have been ascribed to enhanced transport of larvae and juveniles in the stronger East Australian Current and regional warming.

Impact 1

45 species of coastal fish from 27 families (about 30% of the inshore fish families occurring in the region) exhibited polewards shifts in distributions or increased abundance in Tasmanian waters comparing present day information (1995-2009) to the 1980s (1970-85) (Last et al. 2010). These responses are ascribed to regional warming and increased transport by the East Australian Current and tended to be reef dwellers from coastal waters of southern and eastern mainland Australian. 1980s data was an amalgamation of data from field surveys in 1982, records from spear fishing competitions, divers photographic records and a

subsequent regional guide to 461 Tasmanian fishes. Present knowledge is based on fishery catches (both commercial and recreational), diver observations and information provided by scientists, scuba divers and recreational and commercial fishers. 7 species that were previously rare, unlisted or recovering (recorded in 1800s, but absent or low abundance in 1980s and now increasing) in Tasmanian waters are strongly associated with *Centrostephanus rodgersii* barrens (see **I4**).

In contrast, a study of animal (fishes, benthic invertebrates) and plant communities (macroalgae) at 136 rocky reef sites around Tasmania found no significant changes on communities when census data from 1992-1995 was compared with 2006-2007 (Stuart-Smith et al. 2009). However, the study may have encompassed a relatively stable period following an abrupt change. Some species-level responses could be interpreted as symptomatic of ocean warming including several species with warm water affinities that appeared to extend their distributions further polewards.

Impact 2

The giant rock barnacle, *Austromegabalanus nigrescens*, was absent from intertidal surveys conducted around Tasmania in the 1950s, but in 2007/08 was recorded widely along the eastern coastline and probably arrived in Tasmania during the 1980s if not earlier (Pitt et al. 2010). During the 1950s, *A. nigrescens* was recorded on the mainland Australian coastline in the south-east but was yet to cross the Bass Strait. It is likely that dispersal of larvae and establishment in north-east Tasmania was aided by a stronger East Australian Current and warming.

Photographic evidence from the Redmap citizen science project (www.redmap.org.au) has provided evidence from eastern Tasmania of polewards range expansions in the order of 350-650km for the octopus *Octopus tetricus*, 80-100km for the tropical scleractian coral *Plesiastrea versipora* and 80-100km for the eastern rock lobster *Jasus verreauxi* (Johnson et al. 2011).

Impact 3

The European shore crab, *Carcinus maenas*, is a successful invasive species globally (Carlton and Cohen 2003). The invasion front typically expands by only a few kilometres per year punctuated by rare, long-distance dispersal events (Carlton and Cohen 2003, Thresher et al. 2003). *C. maenas* was first recorded in Port Phillip Bay in 1800s and spread along the Australian south-east coast. In 1993, >100 years after its establishment in Victoria, *C. maenas* was reported from Tasmania and genetic studies indicates this population was founded from the southern Australian population (Carlton and Cohen 2003, Thresher et al. 2003). *C. maenas* is currently found in northern and eastern Tasmania but its range expansion appears to have halted (1997-2003, Thresher et al. 2003) although all of Tasmania is considered to lie within its potential climatic range (Carlton and Cohen 2003, Thresher et al. 2003). *C. maenas* larvae were likely transported to Tasmania by a stronger East Australian Current (Thresher et al. 2003). *C. maenas* may represent a threat to the Tasmanian clam *Katelysia scalarina* fishery (Walton et al. 2002). Invasion by *C. maenas* in other regions of the world has coincided with rapid declines on commercially valuable shellfish (Walton et al. 2002).

Impact 4

The urchin *Centrostephanus rodgersii* has spread from mainland Australia to Tasmania in 1978 and subsequently increased both range and abundance and is now the dominant invertebrate on shallow subtidal rocky reefs over much of eastern Tasmania (Johnson et al. 2011). The polewards range shift in the urchin *C.s rodgersii* appears to be the result of enhanced delivery of larvae by the intensified East Australian Current and regional warming (Ling et al. 2008, Ling et al. 2009a,b). The sequential poleward discovery of the sea urchin, a pattern of declining age and a general poleward reduction in abundance along the eastern Tasmanian coastline as consistent with a model of range extension driven by recent change in patterns of larval dispersal (Ling et al. 2009a). Genetic studies indicate a high connectivity between pre- and post-extension zones so the range shift appears to be an extension of the highly-connected range wide population of *C. rodgersii* assisted by increased advection of larvae and warming of sea temperatures above the species' lower developmental threshold (Banks et al. 2010). Coastal water temperatures in eastern Tasmania now fluctuate around the 12°C threshold for successful *C. rodgersii* larval development during August (time of peak spawning) (Ling et al. 2008). The strengthening of the East Australian current has improved climatic suitability of novel habitat for *C. rodgersii* and provided the supply of recruits necessary for colonisation (Banks et al. 2010).

Overgrazing of macrolagae (kelp beds) by *C. rodgersii* has led to the formation of 'urchin barrens' with considerable loss of biodiversity (Ling 2008, Johnson et al. 2011). In central and southern New South Wales, *C. rodgersii* maintains barrens on around 50% of near-shore rocky reefs and is now overgrazing kelp beds in eastern Tasmania following its range expansion. Intensive fishing of spiny lobsters *Jasus edwardsii* by fishing, may have reduced the resilience of kelp beds against the sea urchin threat (Ling et al. 2009b). Large *J. edwardsii* (> 140mm) are the principle predator of *C. rodgersii* in Tasmanian waters therefore the reduction the stock of large lobsters through intensive fishing has reduced their potential to control the invading urchin (Ling et al. 2009b). In addition, *C. rodgersii* has been shown to be a superior competitor with the valuable commercially fished abalone *Haliotis rubra* therefore loss of kelp and interactions with *C. rodgersii* threatens the Tasmanian abalone fishery as well as the rock lobster fishery (Strain et al. 2009, Johnson et al. 2011). Rock lobsters and Tasmanian abalone are unlikely to occur on commercial quantities on urchin barrens (Johnson et al. 2011).

Under scenario A1B, using an ensemble of nine GCMs, it is projected that sea surface temperatures along the Tasmanian East coast during August and September in 2025 will be above the threshold 12°C for *C. rodgersii* larval development, increasing the risk of urchin barren formation, and by 2055 this risk will spread to the entire Tasmanian coastline (Pecl et al. 2009).

Impact 5

The red dinoflagellate *Noctiluca scintillans* has expanded from Sydney into southern Tasmanian waters since 1994 (Hallegraeff 2010). *Noctiluca* blooms have not been reported for Tasmania before 1994. *Noctiluca* appears to have established permanent over-wintering populations in Tasmanian waters assisted by regional warming and the strengthening of the East Australian Current (Hallegraeff et al. 2009; Hallegraeff 2010). *Noctiluca* blooms are a novel significant threat for the salmonid fish farm industry in Tasmania which can result in fish kills. However, the first tropical red blooms of *Noctiluca* were reported in Cairns, northern Queensland, Post Esperance, Western Australia and Port Lincoln, South Australia in

2008, suggesting an epidemiological spread of an invasive species rather than climate change (Hallegraeff et al. 2009).

RESPONSE(S)

Response 1: to I1-4:

The Range Extension and Mapping project (Redmap www.redmap.org.au) allows recreational and commercial fishermen and divers to log observations of uncommon and novel marine species in Tasmanian waters. Over time, Redmap will provide information on changes in species' distribution as well as providing educational resources.

Response 1: to I5

The Australian Continuous Plankton Recorder surveys (part of the Integrated Marine Observing System IMOS) are surveying phytoplankton in the East Australian Current (http://www.imos.org.au/auscpr.html). National Reference Stations are characterising water column properties and phytoplankton composition.

Response 1: to I4

Experiments are underway to determine the density of large rock lobsters that is needed to prevent the formation of urchin barrens (Pecl et al. 2009). If successful, then rock lobster stock management can be used to maintain appropriate lobster densities and size structure (Pecl et al. 2009).

BACKGROUND

An upward trend in the Southern Annular Mode (SAM) since the late 1970s has resulted in a stronger South Pacific gyre forced by an intensification of the wind stress curl arising from a southwards shift in circumpolar westerly winds (Cai 2006). This change in the wind stress curl causes a spin-up of the entire southern midlatitude ocean circulation including a southward strengthening of the subtropical gyres, particularly the East Australia Current (EAC) (Cai 2006). The cause of the trend is contentious but it is, or is partly, attributable to ozone depletion of the last few decades (Cai et al 2005). However, while the overall contribution of increasing atmospheric CO_2 to the observed SAM trend is uncertain, but climate models predict an upward SAM trend in response to increasing atmospheric CO_2 concentration (see Cai et al. 2005). This is one of the most robust and consistent responses of the global climate system to climate change.

The stronger South Pacific gyre is producing (1) stronger northward flows in the interior and off New Zealand's northeast coast, and (2) swifter southward East Australian Current (EAC) flows through the Tasman Sea (Cai et al. 2005, Cai 2006). Further discussion of the changes in oceanography in the region since 1950 is given in Johnson et al 2011.

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UNPREDICTABLE ECOLOGICAL CASCADE

SUMMARY

- Interacting affects of climate variability with invasive species result in complex cascade of sea bird declines and vegetation change in the Coral Sea islands.
- Increased sea surface temperatures associated with an exceptionally long El Niño event during the 1990's reduced nutrient upwelling in the western Pacific Ocean lowering populations of plankton leading to a reduction in food availability for seabird chicks on the Coral Sea islands (Congdon et al 2007).
- As a result of lowered abundance of nesting seabirds, fertilisation of islands via bird guano was reduced. This reduction in nutrients combined with prolonged drought increased the stress on the endangered tree species *Pisonia grandis,* a key nesting resource for seabirds (Greenslade 2008).
- At the same time a scale insect, *Pulvinaria urbicola* (Cockerell) and at least one species of attendant ant, *Tetramorium bicarinatum* (Nylander) were undergoing a population explosion further stressing the tree, *Pisonia grandis* (Bationoff et al 2010).
- The climate and nutrient induced stresses on Pisonia trees, that is reduced fertiliser from birds together with water stress, particularly in winter, are thought to result in a mobilisation of nutrients within the tree making it more attractive to herbivorous insects (Greenslade 2008).
- The result is a complex cascade of interacting biological phenomena leading to lowered abundance of seabirds and conversion of littoral rainforest vegetation to shrub/herbland, facilitated by climate variability and population explosion of exotic insects.

EVIDENCE

Observed Impact;

CATEGORY(S)

Natural and managed systems and their uses: Terrestrial ecosystems: biodiversity

REGION

Coral Sea Islands

DRIVER(S)

Temperature
Precipitation
Sea Surface Temperature

PRESSURE(S)

Aspects of climate variability that could be influential in this cascade of ecological change are rising sea surface temperatures, increased frequency and depth of El Nino events during the last 15 or so years and/or increasing drought as shown in the Palmer Drought Severity Index (Lough 2007). Climatic changes at Coringa-Herald National Nature Reserve (CHNNR) on the Coral sea islands in the past 82 years include a 0.7C rise in mean minimum winter temperature and increases in drought duration and frequency (Bationoff et al 2010).

STATE(S)

During the last two decades, widespread dieback of trees and annual/short-lived grass species across all islands in CHNNR suggest islands are experiencing environmental stress. The result has been a replacement of *Pisonia grandis* littoral rain forest with herbland/shrubland communities. This species turnover at CHNNR and/or fluctuating change of dominance between different species is an ongoing natural phenomenon that provides coral cay resilience to changing environmental conditions. However in the last 20 years it has been more pronounced. Tree dieback has been facilitated by two potentially climate induced events. First prolonged El Niño has led to reduced upwelling in the pacific which in turn has resulted in lowered plankton abundance and thus food availability for sea birds. This is in turn has reduced the nutrient load from nesting seabird bird guano on these islands, on which the *Pisonia* rely (Greenslade 2008). Second under current climatic trends of prolonged drought and temperature increases, insects pests benefit from warmer winters during wet years by the onset of earlier breeding and consequently higher populations that damage vegetation (Smith et al. 2004; Batianoff 2010).

Work on Black Noddies, a seabird on Michaelmas Cay, showed a negative relation between the El Niño index and numbers of breeding pairs (Congdon et al. 2007). These authors also demonstrated a negative relationship between sea surface temperatures at Heron Island and feeding frequency, meal mass and chick mass in 2005.

The population explosion of scale insects and attendant ants was observed not only in the Coringa Herald Group (Coral Sea) but also in the Capricorn Group of islets (Great Barrier Reef) Palmyra Atoll and Samoa in the Pacific and in the Seychelles (Indian Ocean) (Greenslade 2008).

IMPACT(S)

Large scale loss of rainforest trees has led to a new dominant low-growing vegetation type across the island. This in turn has led to a loss of arboreal nesting habitat for seabirds such as Red-footed Booby, Great and Lesser Frigatebirds, and Common and Black Noddies (Batianoff

2001a) and sheltering habitat for ground-nesting birds such as the Red-tailed Tropicbird and the Brown Booby.

The reasons for current Pisonia dieback on the coral islands are complex. The increased winter temperatures may have resulted in the earlier breeding onset of scale insect generations during favorable wet seasons. However, the main reason for current Pisonia dieback seems to be the combination of climatic factors that favour native and exotic insect herbivores, together with the natural vulnerability of Pisonia to scale insect damage (Batianoff et al 2010) along with nutrient poor conditions and water stress facilitated by prolonged El Nino events (Greenslade 2008).

RESPONSE(S)

To maintain biodiversity, wildlife habitats, and ecosystem function in CHNNR, Batianoff et al. (2009) and Greenslade (2008) have listed several biosecurity procedures designed to minimize the risk of further pest introduction. Batianoff et al. (2009) recommended corrective interference and restoration of some habitats to facilitate desirable ecosystems after establishment of pest populations at conservation reserves. For example, biological control programs to control scale populations using the predatory ladybird *Cryptolaemus montrouzieri* and parasitoid wasps have been relatively successful (Smith et al. 2004, unpubl. data cited in Batianoff et al 2010). If rain forest diversity that is functional for wildlife such as seabirds is to be maintained and/or restored at CHNNR, then management interventions may be necessary to restore former *P. grandis* rain forest including planting stem cutting and continued control of scale insects to protect cuttings from insect damage (Batianoff et al 2010).

While, much effort is currently being put into modeling possible changes in pest species abundances and distributions as a result of climate variability, it should be noted that the phenomenon described here is likely to have been an unpredicted and probably an unpredictable effect of climate change (Greenslade 2008).

BACKGROUND

Pisonia grandis has a widespread distribution in the Indian and Pacific Oceans but is only found on small, usually isolated, islands and where there is a large population of nesting sea birds. It is classified as an endangered species in Australia because only small stands (in total area 190 ha) occur in the country. Most populations occur on islands in the Coral Sea and Great Barrier Reef (Greenslade 2008).

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FARMERS AND CLIMATE CHANGE

SUMMARY

- Australian farmers include climate change adaptors, non-adaptors and transistioners.

- A survey of 4000 Australian farmers completed in 2008 (Hogan *et al.* 2011) showed that they tend to fall into the following groups: cash poor long-term adaptors (55%), comfortable non-adaptors (26%) and transitioners (19%).

- **Cash poor long-term adaptors** actively sought to adapt their farming practices to manage climate change-related risk and to be sustainable into the long term. They were younger than other farmers, healthy, socially well-connected, information-seeking and believed in climate change. They were also resilient: though affected by climate change-related threats, they were actively responding to these challenges by implementing longer-term adaptive strategies and participating in government assistance programs (Hogan *et al.* 2011).

- **Comfortable non-adaptors** were a group of older, socially well-connected farmers enjoying comparatively good farming conditions and income. These farmers were well resourced financially and in other ways. They also enjoyed ample social support, good physical health and confidence that they could continue to cope with change. They did not tend to use government support. They did not believe in climate change and did not perceive any immediate pressure for change (Hogan *et al.* 2011).

- **Transistioners** were farmers under considerable pressure and thus had low adaptive capacity. They reported the greatest levels of farm-related pressures, the lowest incomes and the fewest resources with which to adapt to the demands of climate change. They also reported the worst health. They were generally isolated from information sources and reported the most problems accessing support services (Hogan *et al*. 2011).

CONTEXT

This statement is mainly based on the Hogan *et al.* (2010) report, with additional information from published journal papers (e.g. Nelson *et al.* 2010a,b) and a book (Ellis 2000).

EVIDENCE

Projected Impact

CATEGORY(S)

Production systems: Food
Production systems: Fibre

REGION

Queensland
New South Wales
Victoria
South Australia
Western Australia
Tasmania
Northern Territory
ACT

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Solar Radiation
Extreme and variable weather patterns
Soil moisture

PRESSURE(S)

Climate change pressures on wheat, cotton, rice, sugarcane, winegrapes, horticulture, forestry, broadacre grazing and intensive livestock enterprises have been described in separate statements.

STATE(S)

The current state of conditions in wheat, cotton, rice, sugarcane, winegrapes, horticulture, forestry, broadacre grazing and intensive livestock regions have been described in separate statements.

IMPACTS)

Likely impacts of climate change on the wheat, cotton, rice, sugarcane, winegrapes, horticulture, forestry, broadacre grazing and intensive livestock sectors have been described in separate statements.

RESPONSE(S)

Nelson *et al.* (2010a,b) have assessed the vulnerability of Australian rural communities to climate change. Their work built on Ellis' (2000) rural livelihoods approach, which uses five broadly defined types of capital: human, social, natural, physical and financial to provide a measure of adaptive capacity. They concluded that hazard/impact modelling needs to be integrated with measures of adaptive capacity to provide policy-relevant insights for adaptation planning. In other words, the agricultural regions that appear most vulnerable under just a biophysical analysis of climate change impacts may not necessarily be the ones where most action is appropriate when adaptive capacity is also taken into account (Nelson *et al.* 2010a,b).

In carrying out the survey of 4000 farmers Hogan *et al.* (2010) were well aware of previous work by Nelson and colleagues and noted that 'understanding the factors that underpin adaptive capacity and, therefore, farmer decision-making is critical'.

An adaptation cycle that first provides a reflective analysis-action continuum; second, ensures broad-based scientific input and feedback; and third, helps to increase the adaptive capacity of everyone involved (including farmers, policy-makers and scientists) has been proposed to assist developing effective responses (Meinke *et al.* 2009).

A small survey in Tasmania suggests that farmers' perspectives on climate change and sustainability are based around four discourses: money (i.e. business viability), earth (i.e. environmental concern), human responsibility (i.e. social action) and questioning (i.e. issues of trust and information)(Fleming and Vanclay 2010). Addressing these concerns will assist achieving appropriate change.

BACKGROUND

See statements on wheat, cotton, rice, sugarcane, winegrapes, horticulture, forestry, broadacre grazing and intensive livestock sectors for further information on pressure, state, impacts and responses relevant to each sector.

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FISHERIES

SUMMARY

- Australia’s fisheries are valued at $2.19 billion.
- Fisheries operate within an environment of uncertainty and climate change is a new, additional pressure on fisheries
- As knowledge and understanding of likely climate impacts evolves, the ability for fisheries to adapt will improve
- The *National Climate Change Action Plan for Fisheries and Aquaculture* (2010) provides a framework to develop responses appropriate to the various fisheries needs

CONTEXT

This statement is based on the ABARES technical report *Fisheries and climate Change: potential challenges and opportunities for Commonwealth fisheries* (Sands 2011) which contains >40 references. Case studies are given in the report for the Eastern Tuna and Billfish Fishery, Northern Prawn fishery and Southern and Eastern Scalefish and Shark fishery – Commonwealth Trawl Sector.

EVIDENCE

Projected Impact

CATEGORY(S)

Ocean biodiversity; Fisheries

REGION

Australia marine

DRIVER(S)

Temperature
Ocean currents
Sea level
Rainfall
Ocean acidification
Extreme events

PRESSURE(S)

Fisheries operate within an environment of uncertainty which includes fluctuations in fish price, fish abundance and availability and weather. Climate change is a new additional pressure on fisheries.

STATE(S)

In 2008–09, the total production of Australia’s commercial fisheries (including aquaculture) was approximately tonnes, with a value of $2.19 billion (ABARE 2009). Estimates from the Australian Bureau of Statistics Labour Force Survey indicate that total employment in the fishing, hunting and trapping industry in 2008–09 was around 9200 people (ABARE 2009). About half of these were employed in aquaculture. Recreational fishing is also important; it is estimated that approximately 19.5 per cent of Australia’s population over five years of age fishes at least once a year (Henry and Lyle 2003) and spends an estimated $1.85 billion on fishing-related activities and equipment (Campbell and Murphy 2005).

IMPACT(S)

Climate change will bring many challenges and opportunities for fishers (Hobday et al 2008). Depending on the fishery, climate change may cause changes (either positive or negative) to access and fishing costs, catch quality, storm activity, abundance and catch levels and distribution. Fishers switching target species may have difficulties in fisheries with quotas, unless trading and asset value are properly managed.

While the possible changes due to climate change are an important issue for Australia’s fisheries, in the short term other issues such as markets, cost of inputs and overexploitation are likely to have a greater effect and be higher priority for individual operators (Sands 2011).

RESPONSE(S)

The *National Climate Change Action Plan for Fisheries and Aquaculture* (Australian Fisheries Management Forum 2010) was the result of collaboration between Australian governments and fisheries (including aquaculture) stakeholders, and was released in March 2011. It is relevant to all Australian jurisdictions and fisheries. The Action Plan identifies strategies and actions to guide management, policy, research and operational decisions in light of climate change. The Action Plan recognises that as knowledge and understanding of likely climate impacts evolves, the ability for fisheries to adapt will improve. The actions in the Action Plan are not prescriptive but provide a framework to develop responses appropriate to the various fisheries needs.

http://www.daff.gov.au/fisheries/environment/climate_change_and_fisheries

BACKGROUND

Of the Commonwealth managed fisheries, the Northern Prawn fishery was the most valuable in 2008-09, contributing $74 million of the gross value of production of Australia’s fisheries ($2.19 billion, ABARE 2009). The second and third most valuable were the Commonwealth trawl sector of the southern and eastern scalefish and shark fishery ($46 million) and the southern bluefin tuna fishery ($45 million) (ABARE 2009).

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FORESTRY PLANTATION PRODUCTIVITY

SUMMARY

- Regions where forest plantation productivity is likely to increase and regions where it is likely to decrease under climate change have been identified.

- Australia's plantation forests are located mainly in Victoria, Western Australia, New South Wales, Tasmania, Queensland and South Australia. They are dominated by *Pinus radiata* (radiata pine) and *Eucalyptus globulus* subsp. *globulus* (blue gum), which together account for about 69% of the total plantation area (BRS 2004, Garvan and Parsons 2010).

- Rising levels of atmospheric carbon dioxide have been demonstrated to increase productivity and water use efficiency. Increasing temperatures may increase productivity in some cool forests, but at warmer sites productivity may be reduced by increased temperature and increased water loss, that will be compounded if rainfall is reduced (Booth *et al.* 2010, Medlyn *et al*. 2010, Pinkard *et al.* 2010).

- Any reduction in rainfall, as seen particularly for southern Australia in several climate change scenarios (e.g. CSIRO/BoM 2007), coupled with increased water requirements in a warmer climate, may lead to increased risk of tree mortality (Booth *et al*. 2010).

- There are also potential problems from increased pest and disease risks, as well as more frequent and severe bushfires (Booth *et al*. 2010, Medlyn *et al*. 2010, Pinkard *et al.* 2010).

- A simulation analysis of representative sites across the entire resource indicates that some plantations are likely to increase in productivity (e.g. *E. globulus* and *P. radiata* in Tasmania), while others may decline in productivity (e.g. eastern and northern extents of the Western Australian *E. globulus* and *P. radiata* estates))(Battaglia *et al.* 2009)

- As both *P. radiata* and *E. globulus* are grown over relatively wide climatic ranges, there is potential for locations experiencing extreme conditions to provide early warning of potential problems, so core areas should not be highly vulnerable to climate change in the short to medium term, unless serious pest and/or disease problems arise (Booth *et al.* 2010).

- If climatic conditions do become limiting at particularly hot and/or dry sites, alternative species better suited to warmer and/or drier conditions could be considered as well as changed management (e.g. planting at wider spacings at drier sites) (Booth *et al.* 2010).

CONTEXT

The main source of information was the chapter by Booth et al. (2010), the reviews by Medlyn et al. (2010), Wilson and Turton (2010) and Pinkard *et al*. (2010), also a report by Battaglia *et al*. (2009) for Forest and Wood Products Australia and journal papers (e.g. Pinkard *et al*. 2011).

EVIDENCE

Projected Impact

CATEGORY(S)

Production systems: Forestry

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Soil Moisture

PRESSURE(S)

Australia's plantation forest resources are broadly located in similar regions to its major native production forests i.e. along the east and south-east of the mainland, in Tasmania and in the south-west of Western Australia (Bureau of Rural Sciences 2010). An important exception is South Australia, which has a significant plantation resource, but no major native production forests.

The best estimate of annual warming for these regions by 2030 relative to 1990 is about 1.0°C. Temperature increases by 2070 will be greatly affected by the level of emissions, but around 3.4°C is expected for a high emissions scenario (CSIRO and Bureau of Meteorology 2007).

The consensus on projected changes in rainfall for the end of this century is high agreement for southwest Western Australia, where almost all models project continuing dry conditions, and moderate agreement for southeast and eastern Australia, where a majority of models project a reduction (Climate Commission 2011).

The South Eastern Australian Climate Initiative (CSIRO 2010a) has concluded that it is prudent to plan for conditions that are likely to be drier than the long-term historical average conditions because the recent drought appears to be at least partly linked to climate change and climate model projections of a drier future across the south-east.

Results from the Indian Ocean Climate Initiative indicate that relative to 1960-1990 annual rainfall in south-west Western Australia is expected to decrease by between 2-20 per cent by 2030 and by between 5 to 60 per cent by 2070 (Bates *et al*. 2008).

STATE(S)

The growth of plantation forest species, such as *P. radiata*, is greatly influenced by rainfall (Fielding and Millett 1941) and the South Eastern Australian Climate Initiative (SEACI) found that the drought in the southern Murray-Darling Basin (MDB) and Victoria that ended in 2010 was unprecedented compared with other recorded droughts since 1900. The recent drought is considered more severe on any time scale between 3 and 20 years and this includes comparisons with the Federation (1895-1902) and 'World War II' (1937-45) droughts (CSIRO 2010b).

The Indian Ocean Climate Initiative (IOCI 2009) has found a step decrease in total annual rainfall averaged across southwest Western Australia of almost 10% since the mid-1970s.

IMPACT(S)

A four volume NCCARF report has assessed the vulnerability of Australia's forests, both native and plantation, to climate change (Wood *et al*. 2010, Medlyn *et al*. 2010, Cockfield et al. 2010, Wilson and Turton 2010). They concluded that the impact of climate change, and of changing concentrations of CO_2 on forests is not simple, with precise responses being species dependent and no single factor working in isolation. The interaction of factors is not well understood. Medlyn *et al*. (2010) describe how rising atmospheric CO_2 concentrations along with changing temperatures and water availability may affect plant processes such as water use and phenology, as well as indirect climate related stresses such as fire, insect pests, pathogens and invasive weeds.

Booth *et al*. (2010) have also reviewed the complex ways in which changing atmospheric and climatic conditions may interact to provide both positive and negative impacts on productivity.

A particularly interesting simulation study by Battaglia *et al.* (2009) has analysed likely impacts across Australia's plantation estate using the CABALA process-based simulation model. Three aspects of climate are of particular importance to forestry: rises in temperature, changes in rainfall distribution manifesting as changes in soil water, and changes in atmospheric CO_2 concentration. Recognising that individual plant species responses are still unclear, the model was changed in a way that allowed for the testing of three hypotheses of plant response: i) no increase in photosynthesis; ii) a rise in photosynthesis consistent with the average observed in all trees species from free air CO_2 experiments; iii) that no down-regulation of photosynthesis occurs and the short-term and long-term effects of elevated CO_2 exposure on photosynthesis are the same. Simulations were carried out for present conditions, 2030 and 2070 for three climate scenario models. For each location 20 separate rotation length weather sequences were generated and simulations were carried out recognising that production under average conditions does not reflect what occurs under real weather sequences. The model was calibrated for Australia's main plantation species: *E. globulus*, *E. nitens*, *P. radiata* and the pine hybrid (*P. caribaea* *var. hondurensis and P. elliottii var. elliottii x PCH).* In summary, the combinations were: 3 climate models x 3 time periods x 3 plant photosynthetic responses x 134 bellwether sites (spp x site combinations) x 20 planting dates. In all more than a million simulation runs were made, but these allowed uncertainties both in physiological responses and scenarios to be incorporated. Maps of change and uncertainty were generated.

Battaglia *et al*. (2009) found that in some regions productivity was predicted to increase with little uncertainty (e.g. *P. radiata and E. globulus* plantations in East Gippsland and higher altitude parts of central and north-east Victoria). In other regions the impact on productivity had a high level of uncertainty (e.g. plantations of radiata pine in northern and central New South Wales/ACT), while in some regions productivity was likely to decrease unless significant adaptation occurs (e.g. *P. radiata* plantations in southern New South Wales, and possibly at the western edge of the southern and central estates).

This general approach of using multiple simulation runs to generate maps of change and uncertainty across an entire crop resource has not been widely applied in agricultural studies in Australia, but it would appear to be very useful, particularly if it goes hand-in-hand with experimental work to reduce the level of uncertainty concerning specific factors.

RESPONSE(S)

Booth *et al*. (2010) have reviewed adaptation options for Australia's plantation forests. Managing for rainfall variability is likely to become more important as new plantations are increasingly being located in lower rainfall regions to meet natural resource management goals such as carbon sequestration (Consortium 2001). Booth *et al*. (2010) also considered adaptations for dealing with projected climate change including site selection, genotype (selection, breeding, genetic modification), establishment strategies, spacing and thinning, nutrient management, fire management and pest/disease/weed management.

Pinkard *et al*. (2010) have also reviewed adaptation options that may be required in Australia's plantations. There is a need to incorporate the effects of climate change and extreme conditions into management systems. Uncertainty should be acknowledged and integrated into adaptation strategies. A proactive approach is required that promotes stakeholder, community and institutional involvement and includes cost-benefit analyses of adaptation options (including a 'do nothing' approach'). Though plantation forests are moderately vulnerable to climate change Australia's plantations have a high adaptive capacity and this presents the industry with opportunities as well as challenges.

The current approach to modelling pest impacts on forest net primary productivity is to apply a constant modifier. The key physiological processes that need to be included in forest growth models to adequately capture pest impacts under future climate scenarios, equations to describe them and empirical data required have recently been described (Pinkard *et al*. 2011).

Wilson and Turton (2010) reviewed adaptation options for both Australia's native and plantation forests. The production forestry sector operates in a highly variable climate and has a long history of adaptation through experience, scientific research and implementation. The study collated a wide range of climate change adaptation options for the forestry sector, many of them adaptations to climate variability already in use. They include the application of new and innovative land management approaches, adoption of specific silvicultural practices, enhancing social and community skills through increased knowledge and better planning for climate change. A large range of biophysical, socio-economic and policy tools are available to assist the forest sector with adapting to climate change. On-ground monitoring and modelling tools will form the basis of tool kits to respond to climate change adaptation, including fire, thinning and other management techniques used in forest management cycles.

Irrespective of available adaptation measures and tools, Wilson and Turton (2010) found that there is still a disconnect between climate change adaptation science and the on-ground management of native forests and plantations. Of particular concern is that many stakeholders still confuse climate change adaptation with climate change mitigation. Moreover, many of the adaptation strategies identified through stakeholder interviews were not strictly strategies for adapting to climate change, but essentially strategies for adopting environmentally sustainable land management practices.

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FRESHWATER ECOSYSTEMS AND BIODIVERSITY

SUMMARY

- Freshwater ecosystems in Australia have already experienced significant changes due to anthropogenic activities. Climate change is likely to exacerbate these impacts (Aldous et al. 2011). Increases in air temperature, rainfall variability and drought, and sea level rise due to increasing ocean temperatures are principle drivers.

- Flow regimes in freshwater ecosystems are likely to change significantly, and will decrease in many dry regions (Kingsford 2011). This will alter connectivity for populations of freshwater species and has the potential to drastically change movement of individuals, species ranges and genetic flow, leading to changes in assemblages and species declines.

- Sea level rise will cause saltwater incursion on coastal freshwater systems, altering habitats and resulting in movement of habitats and species upstream where possible (Finlayson et al. 2009).

- Water temperature in freshwater systems will increase as a result of increased air temperatures, affecting ecosystem processes such as metabolism, respiration and eutrophication. Incidences of algal blooms are likely to increase.

- Strategies to mitigate the negative effects of climate change on freshwater ecosystems and biodiversity include: restoring flow regimes, managing dams, protected area management (Arthington et al. 2010; Doll and Zhang 2010).

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Projected Impact

CATEGORY(S)

Freshwater ecosystems; Freshwater biodiversity

REGION

Australia

DRIVER(S)

Temperature
Rainfall
Ocean climate and sea level rise

PRESSURE(S)

Pressure 1

Air temperature is expected to increase across Australia by approximately 1°C on average by 2030, with inland regions are expected to experience more significant rises in temperature (CSIRO and BOM 2007). Temperature increases of around 0.7-0.9°C are expected in coastal areas and 1-1.2°C inland. Warming is slightly lower in winter, down to 0.5°C in southern parts of the country, there will be fewer days with frost, and the number of hot nights and days per year will increase in summer. Even accounting for uncertainty in emission scenarios, warming is at least 0.4°C in all regions, and may be as large as 1.8°C in some regions by 2030, and ranges from 1.0°C to 2.5°C by 2070 (CSIRO and BOM 2007).

Pressure 2

Changes in rainfall are expected to be variable across Australia, with an overall decrease in precipitation (CSIRO and BOM 2007). Best estimates by 2030 are -2 to -5% decreases in precipitation, though little of these changes will occur in the northern part of Australia. By 2050 these changes will be more extreme, from decreases of -5% to -20% across the country. A future warmer atmosphere under climate change has the ability to hold more water vapour, leading to increases in intensification of rainfall events. The number of dry days and the number of rain-per-wet day will both increase. Drought is expected to be more widespread in Australia, particularly in the south-eastern regions (CSIRO and BOM 2007).

Pressure 3

A warming air temperature has the effect of warming the ocean, causing a thermal expansion of the upper ocean. As a result, sea levels are rising: in Australia the overall sea level rise between 1993 and 2003 was 3mm, which is an order of magnitude faster than background rates of rise in the past few thousands of years (CSIRO and BOM 2007). Global sea levels are predicted to rise 18-59 cm by 2100, with changes in many parts of Australia, including the east coast, being higher than the global average (CSIRO and BOM 2007). Further unknown increases in sea level may occur due to the melting of ice sheets.

STATE(S)

Freshwater ecosystems hold a wealth of values and resources that are critical for human survival. These ecosystems have been more detrimentally modified by human activity than most other systems (Millennium Ecosystem Assessment 2005). Aquatic biodiversity is threatened by overexploitation, water pollution, modification of water flows and hydrology, habitat destruction and degradation, and invasion by non-native species (Aldous et al. 2011; Arthington et al. 2010; Dudgeon et al. 2006; Kingsford 2011). Freshwater systems are particularly sensitive to the impacts of climate change, largely due to changes in the amount and quality of water (Aldous et al. 2011). Every freshwater system has a unique environmental flow regime, upon which balances the functionality of the system and the biodiversity it sustains (Kennard et al. 2010), as defined by the Brisbane Declaration in 2007:

> ‘‘Environmental flows describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend upon these ecosystems.’’
> (Brisbane Declaration, 2007, Appendix 1)

Climate change is likely to influence the degree to which existing threatening processes further affect aquatic ecosystems and their biodiversity in the medium to long-term (Arthington et al. 2010; Doll and Zhang 2010; Lake and Bond 2007; Paerl and Huisman 2009). The direction and rate of change in aquatic biodiversity will differ across Australia, as it depends on the pathway of climate impact on environmental drivers that influence aquatic ecosystems.

IMPACT(S)

Impact 1

Changes in flow regimes

Rises in temperature and changes in extent and seasonality of rainfall, including increased intensity and lengths of extreme wet and dry periods, will alter flow regimes in freshwater systems across Australia. Runoff and water availability is expected to be significantly altered by climate change by the year 2050, decreasing flow in freshwater ecosystems in dry regions by 10–30% (Kingsford 2011). The impacts on flow regimes as a result of climate change are expected to be significant and in the long term will rival impacts caused by human activity so far (Doll and Zhang 2010). Specific characteristics of flow regimes drive primary production, migration & movement, reproduction, and spawning, and changes in flow regimes can result in disruption and a-synchrony (Aldous et al. 2011; Doll and Zhang 2010; Dudgeon et al. 2006; Lake et al. 2006).

The increased incidence of extreme flood and drought events will change genetic connectivity between populations (Aldous et al. 2011; Lake et al. 2006). Extreme floods will distribute species to new locations, and exchange species assemblages in floodplains, lakes, and ponds (Lake et al. 2006). Conversely, extreme droughts will limit dispersal pathways of individual species, and reduce exchange of genetic material (Aldous et al. 2011; Bond et al. 2008). This could consequently have genetic and demographic consequences for lotic species by affecting dispersal routes and available patches of suitable habitat. Dryland rivers are reliant on the boom and bust cycle of flood and drought and may be particularly sensitive, particularly aquatic refugia created by the permanent waterholes within these systems (Sheldon et al. 2010).

Impact 2

Intrusion of saltwater into coastal freshwater ecosystems

There is evidence of changes in the dynamics of freshwater and brackish ecosystems in Australia which can be partly attributed to sea level rise (Finlayson et al. 2009; Williamson et al. 2011). Salinity can directly influence behavioural and physiological responses and species exhibiting different capabilities to adjust to a change in salinity (Beatty et al. 2011; Jin 2008; Lyons et al. 2007; Smith et al. 2009). Some species will move to freshwater habitats (where connectivity exists), whilst others will move into more saline habitats (e.g. estuarine and marine species) (Beatty et al. 2011). This process is likely to have genetic and demographic consequences for lotic species by affecting dispersal routes and available patches of suitable habitat. Freshwater habitats will move upstream where possible (i.e. connectivity), modify or disappear altogether (Smith et al. 2009). In some cases, saltwater intrusion may result in re-establishment of brackish ecosystems that have been cleared or drained for coastal development.

Impact 3

Increases in water temperature

Increases in air temperature will cause a resultant increase in water temperature within freshwater ecosystems. This will affect a wide range of ecosystem processes, such as biological productivity and stream metabolism, increased respiratory oxygen demand in aquatic animals, potential changes in contaminant toxicity, and enhanced hypoxic or anoxic conditions, whilst a higher incidence of eutrophication can be expected (Arthington et al. 2010; Doll and Zhang 2010; Kingsford 2011; Paerl and Huisman 2009). Water temperature can also directly influences behavioural and physiological responses, with species exhibiting different capabilities to adjust to a change in temperature. Some species will move to cooler habitats where connectivity exists (Lake and Bond 2007). Phenological changes may occur, with flow-on effects on existing trophic interactions. Less surface mixing is likely to occur in lakes, leading to more stable stratification (Lake and Bond 2007). Higher water temperatures which occur earlier and for longer may promote the growth of potentially toxic cyanobacteria blooms with a higher optimal temperature (Johnk et al. 2008; Paerl and Huisman 2008, 2009).

RESPONSE(S)

Response 1

Restore and protect flow regimes

Flow regimes of the vast majority of rivers in Australia are already altered by dams, weirs, earthworks and water extraction, and in many cases these activities are becoming less sustainable under a changing climate (Arthington et al. 2010). A number of recommendations have been made for managing river flows under a changing climate (Kingsford 2011). First, protect the flow regimes of rivers that remain predominantly natural, as exemplified by the Wild Rivers legislation). Second, establish environmental flows to regulate rivers that are ecologically significant and/or legally protected. Finally, improve modeling techniques to allow for complex trade-offs and decision making in systems that are heavily used by people. This can be exemplified by the efforts put into improved modeling and trade-off analysis in the Murray Darling, which has the potential for improving the sustainability of water use decisions in this typically over-allocated system (Aldous et al. 2011). Currently many freshwater specialists believe that inadequate water has been allocated to satisfy ecological flow regime requirements, and that more efforts are required to strike an appropriate balance in this system (ABC News 2011).

Response 2

Altering dam operations

Legislate time-limited licensing on all rivers with dams with the goal of regular checks for safety and environmental impacts of water extraction (Kingsford 2011). Create pulses and cascades where appropriate to mimic natural systems and investigate options for groundwater storage and rehabilitating floodplains, including pumping of water to produce flooding to wetlands (Doll and Zhang 2010).

Response 3

Protected areas

Use a systematic conservation planning approach for identifying and gazetting freshwater protected areas using the principles of comprehensiveness, adequacy, representativeness and efficiency (Kingsford 2011; Nel et al. 2011). This involves prioritizing the protection of rivers and building biological databases to feed into robust conservation planning analyses.

Response 4

Governance and adaptive management

Establish a coherent approach to policy and management, including legislation for supporting the resilience of rivers and wetlands, changing land use practices and allocations and limiting the effects of regulatory structures (Aldous et al. 2011; Kingsford 2011). Where feasible and appropriate, ensure a full stakeholder engagement process involving goal setting, identifying management options, operationalising management, evaluation and learning and reporting and updating management approaches based on the improved information (Kingsford 2011; Nel et al. 2011). Changing and adapting the land use activities surrounding freshwater systems has the potential to mitigate some of the negative climate change effects (Aldous et al. 2011).

In an article outlining the policy options and constraints on effective adaptation for rivers and wetlands in northeast Queensland, Boer (2010) suggests that statutory planning schemes, water resource planning and protected area frameworks provide limited scope to address the more serious threats to these systems from rising sea levels, extreme cyclones, floods and droughts. In many locations, the effectiveness of adaptation policies is constrained by existing land uses and demands from communities and industry sectors. To prevent further widespread loss of habitat may require the development and implementation of new policies that prioritise adaptation management for freshwater and estuarine ecosystems (Boer 2010).

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FROGS AND FUNGUS

SUMMARY

- In Australia, it is now widely accepted that the invasion and spread of a pathogen *Batrachochytrium dendrobatidis*, known as chytrid fungus is the probable cause of many frog declines (Skerratt et al. 2007), including the extinction of seven rainforest frogs in Queensland (Laurance 2008; Laurance et al. 1996; McDonald et al. 2005) and more than 70 frogs in central and South America (Pounds et al. 2006).

- Chytrid fungus (*Batrachochytrium dendrobatidis*) causes chytridiomycosis, a skin disease that under certain climatic conditions causes mass deaths.

- *Batrachochytrium dendrobatidis*'s current occurrence pattern in Australia is highly consistent with the hypothesis that environmental characteristics, such as climate or habitat type, place direct limits on its distribution (Murray et al. 2011).

- Chytrid is very responsive to temperature, proving most active and harmful between 17 and 25ºC (Berger et al. 2004). It stops growing at 28 ºC and dies at 30 ºC. High summer temperatures may eliminate it from some areas. In Queensland and New South Wales, most chytrid infections and most frog deaths occur during winter (McDonald et al. 2005).

- While debate is still underway as to the role of climate change in the spread of chytrid fungus (*Batrachochytrium dendrobatidis*) (Pounds et al. 2006; Rohr et al. 2011; Rohr and Raffel 2010), modeling suggests chytrid fungus has probably reached its broad geographic limits within Australia (Murray et al 2011). There are, however, at least two areas that show marginal suitability for chytrid beyond the known range of the pathogen where testing has failed to detect it: Cape York (Skerratt et al. 2008) and Tasmania's World Heritage south-west (Pauza et al. 2010).

- Low (2008) has suggested that spread to Tasmania in particular could benefit from climate change, whereas in Queensland and New South Wales temperatures in the mountains already fall within its optimal range.

CONTEXT

This statement draws on information presented in a report prepared by Tim Low, *Climate Change and Invasive Species* (2006) as well as a synthesis of peer-reviewed journal articles

EVIDENCE

Projected Impact

CATEGORY(S)

Natural & Managed Ecosystems; All Ecosystems; Biodiversity

REGION

Australia; Global

DRIVER(S)

Temperature
Rainfall
Soil Moisture
Ocean climate and sea level rise

PRESSURE(S)

Pressure 1

In Australia, there has been a 0.9 ºC warming since 1950. Air temperature is expected to increase further by approximately 1^{o}C on average by 2030, with inland regions are expected to experience more significant rises in temperature (CSIRO and BOM 2007). Temperature increases of around 0.7-0.9^{o}C are expected in coastal areas and 1-1.2^{o}C inland. Warming is slightly lower in winter, down to 0.5^{o}C in southern parts of the country, there will be fewer days with frost, and the number of hot nights and days per year will increase in summer. Even accounting for uncertainty in emission scenarios, warming is at least 0.4^{o}C in all regions, and may be as large as 1.8^{o}C in some regions by 2030, and ranges from 1.0^{o}C to 2.5^{o}C by 2070 (CSIRO and BOM 2007).

Pressure 2

Changes in rainfall are expected to be variable across Australia, with an overall decrease in precipitation (CSIRO and BOM 2007). Best estimates by 2030 are -2 to -5% decreases in precipitation, though little of these changes will occur in the northern part of Australia. By 2050 these changes will be more extreme, from decreases of -5% to -20% across the country. A future warmer atmosphere under climate change has the ability to hold more water vapour, leading to increases in intensification of rainfall events. The number of dry days and the number of rain-per-wet day will both increase. Drought is expected to be more widespread in Australia, particularly in the south-eastern regions (CSIRO and BOM 2007).

STATE(S)

Frogs are faring much worse from global changes than other vertebrates, with more than 400 species listed as ‘critically endangered’ by the Global Amphibian Assessment and many assumed to be extinct (Pounds et al. 2006). Of particular concern is the disappearance of frogs not only from disturbed sites but also from pristine habitats remote from human interference. In Australia, twenty seven species (13%) of Australia’s frog species are currently nationally threatened, and of these, eight species may have disappeared altogether. An additional 14 species are declining. For seven rainforest species in Queensland, a pathogen is implicated in their extinction, chytrid fungus.

Chytrid fungus is very responsive to temperature, proving most active and harmful between 17 and 25ºC (Berger et al. 2004). It stops growing at 28 ºC and dies at 30 ºC. High summer temperatures may eliminate it from some areas. In Queensland and New South Wales, most chytrid infections and most frog deaths occur during winter (McDonald et al. 2005).

IMPACT(S)

Debate is still underway as to the role of climate change in the spread of chytrid fungus (Laurance 2008; Laurance et al. 1996; Lips et al. 2008; Pounds et al. 2006; Rohr et al. 2011; Rohr and Raffel 2010).

In a review of the evidence for the role of climate change in triggering disease outbreaks of chytridiomycosis in Lower Central America and Andean South America, Lips (2008) concluded that available data support the hypothesis of multiple introductions of this invasive pathogen into South America and subsequent spread along the primary Andean cordilleras. Additional analyses found no evidence to support the hypothesis that climate change has been driving outbreaks of amphibian chytridiomycosis, as has been posited in the climate-linked epidemic hypothesis.

Current infection with *B. dendrobatidis* occurs across a broad range of climates in Australia, in areas that are at times very hot, cold, dry or wet. Those locations range from the hot, humid coastal lowlands of north-eastern Australia to the highest peaks of the Australian Alps, where winter snow occurs. Despite its broad tolerance of conditions, the modeling the distribution of *B. dendrobatidis* suggested that specific environmental conditions will restrict infection with *B. dendrobatidis* to the generally cooler and wetter areas of Australia with the majority of central (arid) Australia being broadly unsuitable for *B. dendrobatidis* persistence (Murray et al 2011).

Modelling of environmental suitability of chytrid fungus across Australia by Murray et al (2011) indicated that environmental suitability increased with annual precipitation (with a minimum extreme of c. 500 mm). This is consistent with research showing that desiccation is known to rapidly kill *B. dendrobatidis* in vitro and the presence of permanent water is known to be an important feature for sustaining *B. dendrobatidis*, probably because the transmission stage for *B. dendrobatidis* is an aquatic zoospore (Berger et al. 2004). Murray et al’s (2011) model also suggested that mean diurnal temperature range was an important variable; the response curve indicated that environmental suitability declined rapidly in highly variable temperature regimes, where the difference in daily maxima and minima is greater than 11 C.

Modelling by Murray et al (2011) suggest chytrid has already spread across most of its predicted suitable range under current climatic conditions. There are, however, at least two areas that show marginal suitability for chytrid beyond the known range of the pathogen where testing has failed to detect it: Cape York (Skerratt et al. 2008) and Tasmania’s World Heritage south-west (Pauza et al. 2010).

Low (2008) has suggested that spread to Tasmania in particular could benefit from climate change, whereas in Queensland and New South Whales temperatures in the mountains already fall within its optimal range.

Actual disease risk will be a product of the environmental suitability for the pathogen, the susceptibility of the species and the factors that make it susceptible to decline (range size and other threatening processes) given the former (Bielby et al. 2008; Murray et al 2011).

RESPONSE(S)

In 2006 the Australian Government released a Threat Abatement Plan *(for infection of amphibians with chytrid fungus resulting in chytridiomycosis* (Department of Environment and Heritage 2006) to guide management of this disease. Current evidence suggests the spread of cytrid fungus is not driven by climate change but that climate change could be one of many pressures leading to habitat loss and degradation, resulting in reduced range and population size and thus increased risk of infection.

BACKGROUND

Dramatic declines in some Australian frog species have been reported since the 1980's. Of particular concern is the disappearance of frogs not only from disturbed sites but also from pristine habitats remote from human interference. Twenty seven species (13%) of Australia's frog species are currently nationally threatened, and of these, eight species may have disappeared altogether. An additional 14 species are declining. For most of these species, the causes of decline are not known or are poorly understood. However where species have disappeared from mainly undisturbed forests, a pathogen *Batrachochytrium dendrobatidis* or chytrid fungus is often implicated.

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HORTICULTURE

SUMMARY

- Horticulture is vulnerable to increasing temperatures advancing phenology, reducing chilling, and also factors affecting crop quality (sunburn, colour).
- Major horticultural regions include Tasmania/Victoria, the Murray-Darling Basin, coastal NSW and Queensland, Far North Queensland, Darwin-Kimberley and south-west WA. Major crops in temperate and Mediterranean regions include potatoes, onions, brassica, lettuce, tomatoes, carrots, pumpkins, stone fruit, pome fruit (apples, pears), citrus (oranges) and berries; in subtropical regions tomatoes, potatoes, capsicum, brassica, beans, lettuce, pumpkins, bananas, pineapples and citrus; in tropical regions cucumbers, melons, chillies, capsicum, tomatoes, mangoes, pineapples and bananas (Deuter 2008, Webb and Whetton 2010).
- There will be a reduction in areas suitable for growing stone-fruit (e.g. peaches and cherries) and pome-fruit (e.g. apples and pears) varieties that require chilling, and an expansion in areas suitable for growing subtropical crops (Hennessy and Clayton-Greene 1995, Webb and Whetton 2010, Darbyshire *et al.* 2011).
- Increased temperatures will advance plant development with likely affects on flowering, pollination and harvest dates. Vegetable growers may experience problems with premature flowering (bolting) (Webb and Whetton 2010).
- Rainfall is projected to decline in many horticultural regions. Annual crops are likely to be more vulnerable than perennials, but annuals can be grown on an opportunistic basis (Webb and Whetton 2010).
- Adaptation may include varietal selection to match crops to new climatic regions, as well as breeding new varieties to assist adaptation (Webb and Whetton 2010).

CONTEXT

The main source of information was the chapter by Webb and Whetton (2010), which cites more than 100 references. Other useful sources included summary reports such as Deuter (2008) for the Garnaut Climate Change Report and an information booklet (Turnbull *et al*. 2008) produced by the Climate Change Research Strategy for Primary Industries (CCRSPI), as well as journal papers (e.g. Darbyshire *et al.* 2011).

EVIDENCE

Projected Impact

CATEGORY(S)

Production systems: Food

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Extreme and Variable Weather Patterns
Soil Moisture

PRESSURE(S)

Though many horticultural centres are located near the coast, crops such as citrus, almonds, pistachios, pecans, grapes, stonefruit, and pome fruit are grown across major areas in the interior. Mean annual temperature increase by 2030 relative to 1990 should be about 1°C. For high emissions scenarios there is around a 30% chance of exceeding a 3°C increase by 2070 in southern and eastern coastal areas and a much greater chance inland (see CSIRO/BoM 2007). Little change is expected in rainfall in the far north by 2030 while decreases of 2% to 5% are expected elsewhere. In 2070 the best estimates for annual rainfall under a high emissions scenario are for little change in the far north, while southern areas may experience a decline of around 10% (CSIRO/BoM 2007).

STATE(S)

Deuter (2008) reported that many horticultural regions have already experienced a rise of about 1°C in both mean monthly maximum and mean monthly minimum temperatures compared with the 1961 to 1990 base period, and provided data for three important regions (Burdekin, north Queensland; Lockyer Valley, south-east Queensland; Riverina, southern NSW). Notable recent declines in chilling have been observed at Orange, Lenswood, Tatura, Yarra Valley and Bacchus Marsh (Darbyshire *et al.* 2011).

IMPACT(S)

Deuter (2008) summarised impacts on horticulture including i) changes in the suitability and adaptability of current cultivars as temperatures change, together with changes in the optimum growing periods and locations for horticultural crops, ii) changes in the distribution of existing pests, diseases and weeds, and an increased threat of new incursions, iii) increased incidence of physiological disorders such as tip burn and blossom end rot, iv) greater potential for downgrading product quality e.g. because of increased incidence of sunburn, v) increases in pollination failures if heat stress days occur during flowering, vi) increased risk of spread and proliferation of soil borne diseases as a result of more intense rainfall events (coupled with warmer temperatures), vii) increased irrigation demand especially during dry periods viii) changing reliability of irrigation schemes, through impacts on recharge of surface and groundwater storages, ix) increased atmospheric CO_2 concentrations will benefit productivity of most horticultural crops, although the extent of this benefit is unknown, x) increased risk of soil erosion and off-farm effects of nutrients and pesticides, from extreme rainfall events, xi) increased input costs—especially fuel, fertilisers and pesticides and xii) additional input cost impacts when agriculture is included in an Emissions Trading Scheme (ETS).

Webb and Whetton (2010) note that most deciduous fruit and nut trees require sufficient accumulated chilling to break winter dormancy. A warmer climate will reduce the suitability of certain regions for growing these crops (Hennessy and Clayton-Greene 1995, Darbyshire *et al.* 2011).

Turnbull *et al* (2009) also identified some opportunities, such as how increasing temperatures may improve growing rates and lengthen the growing season in some areas.

RESPONSE(S)

Webb and Whetton (2010) have reviewed options currently used for dealing with climate variability. These include site selection, crop management, varietal selection, water management, pest and disease management, and seasonal forecasts. Similar general areas will need to be considered for climate change adaptations. In the past, site selection has been concerned mainly with assessing meteorological records for a particular site, but in the future increasing consideration will be given to considering likely future trends (see, for example, Hood *et al*. 2002 and CSIRO/BoM 2007). Similarly, crop management, such as planting times, and varietal selection, will focus more on adapting to changing conditions rather than focusing too much on past experience.

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INTENSIVE LIVESTOCK INDUSTRIES

SUMMARY

- Intensive livestock industries must adapt to climate change, particularly the increasing threat of heat stress.
- Intensive livestock industries include dairy, pig, poultry and beef feedlot enterprises. The Australian dairy industry, which is the third largest rural industry behind beef and wheat, is located mainly in eastern and southern Australia, including Tasmania, as well as southeastern WA. Pig production and beef feedlots are usually located in grain producing areas. Poultry enterprises are generally located close to metropolitan centres (Miller *et al.* 2010).
- Warmer and drier conditions are projected for most intensive livestock-producing regions, raising the likelihood and incidence of heat stress in stock. Low energy and low emission adaptation options should be identified and evaluated (Miller *et al.* 2010).
- Livestock enterprises must have the flexibility to change management systems rapidly in response to dynamic environmental, economic and social conditions (Miller *et al.* 2010).
- In common with broadacre grazing, potential adaptation options are available for intensive livestock industries for moderate climate changes, with these often being variations of existing climate risk management strategies (Howden *et al.* 2008).
- Dealing with the many barriers to effective adaptation in both the broad acre and intensive sectors will require ‘mainstreaming’ climate change into policies covering a range of scales, responsibilities and issues. This mainstreaming will facilitate the development of comprehensive, dynamic and long lasting policy solutions (Howden *et al.* 2008).

CONTEXT

The main source of information was the chapter by Miller *et al.* (2010), which cites more than 65 references. Other information was taken mainly from reports available on the internet (e.g. CCRSPI 2007 and CSIRO/BoM 2007) and journal papers.

EVIDENCE

Observed Impact: As with several other agricultural systems the impacts of climate change are so far difficult to distinguish from the effects of climatic variability.
Projected Impact: Yes (e.g. Cullen *et al.* 2009)

CATEGORY(S)

Production systems: Food

REGION

Queensland
Victoria
New South Wales
South Australia
Tasmania
Western Australia
Northern Territory
ACT

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Solar Radiation
Extreme and variable weather patterns
Soil moisture

PRESSURE(S)

Most intensive livestock-producing regions of Australia are located in temperate or subtropical regions with annual rainfall greater than 550 mm. Climate change projections for these regions, particularly dairy regions, in 2030 indicate that conditions will be generally warmer and drier, resulting in increased evaporation and reduced runoff (Hennessy 2007). Temperatures are projected to increase by between 0.4^{o}C and 1.5^{o}C by 2030. The greatest declines in rainfall are projected to occur in spring and winter.

STATE(S)

The intensive livestock industries, which are broadly distributed through Australia, have experienced a rise in average temperatures of about 0.9°C since 1950 (CSIRO/BoM 2007) along with significant regional droughts particularly in 1994-95, 2002-03 and 2006-07.

During the current decade, overall dairy production (in terms of milk products) has been falling. While the average size of dairy farms has increased, the expansion in average farm size has not offset the fall in the total number of farms (Nossal *et al.* 2009).

IMPACTS)

Miller *et al.* (2010) have reviewed climate change impacts on intensive livestock industries across Australia. Heat stress is likely to be an increasing problem as temperatures rise. For example, milk production of dairy cows tends to decline when they experience temperatures above 26°C. Heat stress can also reduce reproductive success of livestock. The Temperature-Humidity Index (THI, Johnson *et al.* 1963) is a robust predictor of heat stress.

Impacts of climate change on intensive livestock systems are difficult to predict as the plant growth that all intensive enterprises rely on will be affected in complex ways by both atmospheric as well as climatic change. Increasing levels of atmospheric CO_2 should offset some or all of the negative impacts in regions that experience higher temperatures and lower rainfall. For example, Cullen *et al.* (2009) have examined climate change impacts on pasture production used by dairy systems. In the absence of other climate changes, increasing CO_2 from 380 ppm to 550 ppm was predicted to increase pasture production by 24-29% in temperate (C3) species-dominant pastures in southern Australia, with lower mean responses in a mixed C3/C4 pasture in northern NSW (17%) and less response (4%) in a C4 pasture in Queensland. In some southern sites, such as Wagga Wagga, NSW and Ellinbank, Victoria, climate change projections indicated warming of up to 3.3°C, with annual rainfall reduced by up to 28%. These conditions increased winter and early spring pasture growth rates, but this was counteracted by a predicted shorter spring growing season, with annual pasture production higher than the baseline under the 2030 climate scenario, but reduced by up to 19% under the 2070 high scenario.

Potential impacts on the pork industry have been summarised by CCRSPI (2007). Climate change is expected to increase problems, such as feed shortages and reduced water availability, that have been experienced in recent droughts.

RESPONSE(S)

Tactical and strategic adaptation options have been used for many years by Australian farmers to cope with climatic variability (Miller *et al.* 2010). Tactical options are used for dealing with within season variability, including the increased use of seasonal forecasts to adjust stocking rates. Strategic options involve longer term structural changes, including management adjustments or even transformational change to different production systems.

Options for dealing with climate change include protecting stock from sun and heat, developing more tolerant pasture or fodder crop varieties, breeding more thermo-tolerant stock (see, for example, Hayes *et al.* 2009), modifying livestock feeding systems (to reduce heat stress), redesigning buildings (for more efficient cooling), developing supplementary on-site power (e.g. solar or wind), clustering compatible industries, increasing landscape resilience (through revegetation, rehydration and soil organic carbon) and increasing use of seasonal climate forecasts (and other decision-support tools) (Miller *et al.* 2010).

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INVASIVE PLANT SPECIES

SUMMARY

- Various modeling results suggest (1) that not all weed species are going to increase in distribution as a result of climate change, in fact the distribution of some will decrease; (2) that targeted strategic control in the southern parts of species ranges will be extremely important for reducing future impacts.

- Rising temperatures will relax cold range boundaries, leading to range extensions into higher latitudes or elevations for many weeds including warm season growing grasses (C4) such as buffel grass *Pennesetum ciliare* (Martin et al. 2010) and other tropical and sub-tropical invasive such as prickly acacia *Acacia nilotica* (Kriticos et al. 2010).

- The effect of increases in water use efficiency as a result of increasing CO_2 is likely to be a less important factor influencing plant species distributions than previously thought (Kriticos et al. 2010).

- Modeling using standard bioclimatic modeling techniques such as CLIMEX and BIOMOD will need to be cautious when using only native range data to train the model, since predictions of invasive range have been shown to include novel climates not found in the training model (Beaumont et al. 2009b; Van Klinken et al. 2009). Including data on current distribution in the training model, or using other species distribution modeling techniques which can accommodate many different types of environmental variables such as MaXEnt (Gallagher et al. 2010) or Bayesian Belief Networks (Martin et al. 2010) will help circumvent this problem.

- Climate change will interact with current control methods including biological control and observed declines in abundance of groundsel bush *Baccharis halimifolia* over the past 50 years throughout its Australian range may be a result of changes in climatic suitability rather than the effect of biocontrol agents (Sims-Chilton et al. 2010).

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles and reports

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Natural and managed systems and their uses: Terrestrial ecosystems: Terrestrial biodiversity

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Soil Moisture

PRESSURE(S)

Temperature drives the development of plants, their seasonal phenology and geographical distributions. Soil moisture affects survival and growth and CO_2 acts as a fertilizer for plants when other nutrients are not limiting. In the context of climate change invasive plant species impacts fall into four categories; the invasive fails to survive or is less competitive, the invasive tolerates the changed climate or has increased competitive ability, the invasive evolves to maintain or increase abundance in situ or the weed migrates to a more suitable climate (Kriticos et al. 2010).

STATE(S)

Projected changes in habitat suitability under different climate change scenarios suggest the range of some invasive will expand while other may contract. In South Australia for example, the northern regions face a reducing threat from the prominent weed threats that are presently facing the state, but face increased threat from weeds invading from Western Australia, Northern Territory and Queensland. The presently wetter, more southerly regions of South Australia are generally facing an increased threat from invasive plants (Kriticos et al. 2010).

IMPACT(S)

Impact 1 – Shifts in species distributions

The climatically suitable habitat for three species of hawkweed *Hieracium* modeled using BIOMOD, is projected to decline with climate change although suitable areas will remain in sub-alpine and alpine regions until at least 2070 (Beaumont et al. 2009a). Likewise, the habitat suitability for five species exotic vine, *Anredera cordifolia* (Ten.) Steenis, *Ipomoea indica* (Burm.) Merr., *Ipomoea purpurea* (L.) Roth, *Passiflora subpeltata* Ortega and *Solanum seaforthianum* Andrews, found predominantly along the eastern seaboard and threatening littoral rainforest, is projected (using BIOMOD) to contract under both 2020 and 2050 climate scenarios (Gallagher et al. 2010).

The environmental suitability for buffel grass *Pennesetum ciliare,* a warm season (C4) growing grass modeled using a Bayesian Belief Network, is projected to shift southward as rainfall coincides with warmer temperatures in the south, allowing the grass to invade areas that currently lack sufficient warmth to establish and persist (Martin et al. 2010). Likewise the distributing of another tropical/sub-tropical invasive, prickly acacia *Acacia nilotica* is also projected to shift southward according to CLIMEX model projections (Kriticos et al. 2010). As a result of the southward shift in buffel grass, and the higher proportion of the National Reserve System located in the southern rather than northern part of the continent, the overall risk of buffel grass to the NRS is likely to increase in the future (Martin et al. 2010). The distribution of a further two species of exotic grass, a tropical species, *Andropogon gayanus* Kunth (Gamba grass) and *Nassella neesiana* Trin. & Rupr.

Barkworth (Chilean needle grass) have been modeled using MaXEnt. *Andropogon gayanus* is projected to increase its distribution southwards but also increase the area of highly suitable climate within its current distribution. In contrast, *Nassella neesiana* shows a southward trend but an overall decrease in highly suitable habitat.

These different modeling results highlight (1) that not all weed species are going to increase in distribution as a result of climate change; (2) that targeted strategic control in the southern parts of species ranges will be extremely important for reducing future impacts (Wilson et al. 2009).

Impact 2 – Interaction between biocontrol and climate change

The decline in groundsel bush (*Baccharis halimifolia*) over the last 50 years has until recently been attributed to the release of a bio-control agent. Sims-Chilton et al. (2010) demonstrate that this decline in distribution is more likely to be explained by a change in growth conditions as a result of a change in the favorability of the climate throughout its Australian range. Using CLIMEX they demonstrate that the distribution of the species is projected to continue to decline throughout Queensland under IPCC future climate scenarios as its distribution shifts further south into New South Whales and Victoria. Evaluating the effectiveness of biocontrol agents will be challenging as their impacts may be confounded with climate change. The effects of biological control agents themselves may also change with their tolerances to climatic conditions (Sims-Chilton et al. 2010).

Impact 3 – Challenges modeling species distributions

The emergence of novel climates will challenge current bioclimatic modeling techniques such as CLIMEX and BIOMOD. A predictive model developed for *Parkinsonia aculeata* using CLIMEX fitted against distribution data and abundance data its native range in the Americas, revealed that 9 of the 19 parameters could not be modeled as a result of novel climates. In this case predictions were more sensitive to parameter uncertainty than climate change scenarios (Van Klinken et al. 2009).

In a similar case, Beaumont et al. (2009b) illustrate that calibrating a bioclimatic model BIOMOD, using data on the native range (Europe) for three species of *Hieracium* to predict invasive distribution misrepresented their potential distribution. Incorporating data from the species entire distribution resulted in more thorough assessment of current and future distributions.

Another tool currently being used to project invasive plant species distributions and widely used in other species modeling contexts, MaxEnt, highlights those parts of the predicted distribution that represent environmental conditions not experienced in training the model (Wilson et al. 2009).

RESPONSE(S)

The following recommendations are drawn from Kriticos et al. (2010):

1. Maintain or establish long term monitoring plots or procedures in key environmental and agricultural areas so that changes in distribution and abundance of invasive plant species can be detected early enough to apply appropriate management strategies.
2. Introduce climate change considerations to Australian weed risk assessments: a) to incorporate expected changes in distribution and abundance into strategic management plans for priority weeds; and, b) to develop an alert species and sleeper weeds list for South Australia.

3. Use climate change considerations to identify the future risks posed by invasive species that may either not be present, or may be currently present as benign (sleeper) populations within NRM regions.
4. Encourage NRM regions to undertake a program of surveillance and local eradication of possible climate change sleeper populations.
5. Consider the placement of quarantine barriers or strategic containment lines in anticipation of weed species range expansion as climates change.
6. Maintain or establish ongoing monitoring of biological control of weeds, especially for currently successful programs, so that the trends in changes can be detected early and acted on accordingly.

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NATIVE FOREST PRODUCTIVITY

SUMMARY

- Some native production forests should increase in productivity under climate change while others may decline in productivity.

- In 2005-06 112.6 million hectares of native forest was in tenures in which timber harvesting is allowed, though only a small proportion of this area is actively managed for timber production (including well under 10 million ha in public ownership) (Montreal Process Implementation Group for Australia 2008).

- Native forests produce only about one third of the volume of logs produced by about 2.0 m ha of plantations (Montreal Process Implementation Group for Australia 2008).

- Australia's native production forests are located mainly in Victoria, Queensland, New South Wales, Western Australia and Tasmania. Logs are produced mainly from eucalypt species (Bureau of Rural Sciences 2010)

- Climate change impacts on native forests should be somewhat similar to those on plantations. Rising levels of atmospheric carbon dioxide have been demonstrated to increase productivity and water use efficiency. Increasing temperatures may increase productivity in some cool forests, but at warmer sites productivity may be reduced by increased temperature and increased water loss, that will be compounded if rainfall is reduced (Medlyn *et al*. 2010).

- A simulation analysis across plantation forest sites indicated that some plantations are likely to increase in productivity (e.g. *E. globulus* in Tasmania, which is both a plantation and a native species there), while others are likely to decline in productivity as a result of climatic and atmospheric change (Battaglia *et al*. 2009). It is likely that native forests will show also show variations in response, but a similar analysis is needed for native forests.

- There are likely to be potential problems from increased pest and disease risks, as well as more frequent and severe bushfires (Medlyn *et al*. 2010).

- Increasingly native forests used for commercial timber production are managed in similar ways to plantation forests, so if climatic conditions do become limiting at particularly hot and/or dry sites, alternative species or provenances better suited to warmer and/or drier conditions could be considered as well as changed management (Booth *et al*. 2010).

CONTEXT

The main sources of information were the reports by Medlyn *et al*. (2010) and Wilson and Turton (2010). The chapter by Booth *et al*. (2010) on plantations also has some relevant information. Other reports mentioned include Battaglia *et al* (2009), Pinkard *et al*. (2009), Williams *et al*. (2009) and Kriticos *et al*. (2010).

EVIDENCE

Projected Impact

CATEGORY(S)

Production systems: Forestry

REGION

Queensland
New South Wales
Western Australia
Victoria
Tasmania

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Soil Moisture
Extreme and variable weather patterns

PRESSURE(S)

Publically-owned native production forests are part of the multiple use forest category (see forest tenure map in Bureau of Rural Sciences 2010). These are located mainly along the east and south-east of the mainland, in Tasmania and in the south-west of Western Australia.

The best estimate of annual warming for these regions by 2030 relative to 1990 is about 1.0°C. Temperature increases by 2070 will be greatly affected by level of emissions, but around 3.4°C is expected for a high emissions scenario (CSIRO and Bureau of Meteorology 2007).

The consensus on projected changes in rainfall for the end of this century is high agreement for southwest Western Australia, where almost all models project continuing dry conditions, and moderate agreement for southeast and eastern Australia, where a majority of models project a reduction (Climate Commission 2011).

The South Eastern Australian Climate Initiative (CSIRO 2010a) has concluded that it is prudent to plan for conditions that are likely to be drier than the long-term historical average conditions because the recent drought appears to be at least partly linked to climate change and climate model projections of a drier future across the south-east.

Results from the Indian Ocean Climate Initiative indicate that relative to 1960-1990 annual rainfall in south-west Western Australia is expected to decrease by between 2-20 per cent by 2030 and by between 5 to 60 per cent by 2070 (Bates *et al*. 2008).

STATE(S)

The growth of native forests is greatly influenced by rainfall (Medlyn *et al*. 2011) and the South Eastern Australian Climate Initiative (SEACI) found that the drought in the southern Murray-Darling Basin (MDB) and Victoria that ended in 2010 was unprecedented compared with other recorded droughts since 1900. It included 180 consecutive months (January 1995 to February 2010) without a 'very wet ' month, that is, a month with rainfall greater than the 90th percentile of the long-term rainfall for that month (CSIRO 2010b).

The Indian Ocean Climate Initiative (IOCI 2009) has found a step decrease in total annual rainfall averaged across south west Western Australia of almost 10% since the mid-1970s.

IMPACT(S)

The majority of commercial production from native forests is from eucalypt species (Bureau of Rural Sciences 2010). Eucalypt species have very poor dispersal abilities, so potential effects of climate change on their natural distributions are not considered here.
A four volume NCCARF report has assessed the vulnerability of Australia's forests, both native and plantation, to climate change (Wood *et al*. 2010, Medlyn *et al*. 2010, Cockfield *et al*. 2010, Wilson and Turton 2010). They concluded that the impact of climate change, and of changing concentrations of CO_2 on forests is complex, with precise responses being species dependant and no single factor working in isolation. The interaction of factors is not well understood. Medlyn *et al*. (2010) have summarised likely CO_2, temperature and water impacts in the following paragraphs.

Although Australian forest species are physiologically capable of strong positive growth responses to rising CO_2, evidence is mounting that limited nutrient availability will restrict these responses. In moderately infertile sites, carbon uptake is enhanced by rising CO_2, but stem growth does not increase proportionately. Very infertile sites are not of major importance for commercial timber production. Rising CO_2 also affects plant water use. Across a wide range of experiments with forest tree species, there are consistent increases in plant water use efficiency at elevated CO_2. However, it is unclear how this change in water use efficiency will manifest in Australian forest ecosystems. Forest leaf area index and productivity may increase, or runoff and water yield may increase. Further large scale experiments are urgently needed to determine which of these outcomes is most likely.

Photosynthesis and respiration are dependent on temperature, but in most plants both processes have the capacity to acclimate to some extent to growth temperature. The response of plant growth to temperature may therefore be quite different from the response of net photosynthesis. Despite relatively narrow natural climatic distributions, experimental manipulations suggest that many Australian species thrive at a wide range of temperatures. Extreme high temperatures are predicted to increase more than average maximum temperatures, so heat stress may negatively affect performance of a wide range of species, and further research quantifying the effects of extreme high temperatures on plant growth is required. There are several interactions between rising temperature and moisture availability. One important effect is that rising temperatures could increase potential evapotranspiration, reducing water availability.

The impact of drought on plantations and native forests will differ depending on species, provenance and site conditions. Also, impacts of drought on forests will depend on the intensity and duration of drought, and the seasonality and timing of rainfall events, as well as interactions with fire and pests. There is a cascade of responses depending on drought severity: forest trees are likely to recover from slight drought, productivity may decline from moderate drought, whereas if drought is prolonged and severe, mortality may result. It is unclear whether physiological differences among species correspond with ecological observations of drought tolerance in the field. There is a real need for research that bridges these different scales. We need to quantify drought tolerance in the field, particularly for native forest species, and link it with understanding derived from physiological research.

Booth *et al*. (2010) have also reviewed the complex ways in which changing atmospheric and climatic conditions may interact to provide both positive and negative impacts on productivity in plantations and some of this discussion is also relevant to native forests.

In addition to direct effects of climate change on growth Medlyn *et al*. (2010) reviewed indirect climate related stresses such as fire, insect pests, pathogens and invasive weeds.

The systems most likely to suffer an increased frequency of fires are the dry temperate forest systems found in the southeast and southwest of Australia. However, it is largely unclear how the projected changes in climate will affect the build up of fuel in forest systems (Williams *et al*. 2009).

Generally, insect pest species have been predicted to have an increasingly negative impact on native forest system functioning across Australia with predicted increases in temperature, variations in rainfall, and higher frequencies of extreme weather events such as droughts, storms and fires (Pinkard *et al*. 2009).

Compared to insect pests, pathogens show more variability in their responses and potential future effects on forest systems in relation to the projected changes in climate. Pinkard *et al*. (2009) concluded that in general, leaf diseases, shoot blights and some root pathogens will be favoured by warmer wetter conditions, while cankers and some root pathogens are likely to be favoured by warmer temperatures and periodic drought.

The predicted changes in climate factors are likely to make areas currently unaffected by invasive weeds more suitable over time. Modelling projections using a general rise in temperature and decrease in rainfall have indicated a future spatial boundary shift of weed species from the north to the south of Australia (see, for example, Kriticos *et al*. 2010).

RESPONSE(S)

Wilson and Turton (2010) reviewed adaptation options for Australia's native and plantation forests. The production forestry sector operates in a highly variable climate and has a long history of adaptation through experience, scientific research and implementation. The study collated a wide range of climate change adaptation options for the forestry sector, many of them adaptations to climate variability already in use. They include the application of new and innovative land management approaches, adoption of specific silvicultural practices, enhancing social and community skills through increased knowledge and better planning for climate change. A large range of biophysical, socio-economic and policy tools are available to assist the forest sector with adapting to climate change. On-ground monitoring and modelling tools will form the basis of tool kits to respond to climate change adaptation, including fire, thinning and other management techniques used in forest management cycles.

Booth *et al* (2010) also considered adaptations for dealing with projected climate change in plantations including site selection, genotype (selection, breeding, genetic modification), establishment strategies, spacing and thinning, nutrient management, fire management and pest/disease/weed management. As many native forests are increasingly managed like plantations, some of this information would be applicable to native forests.

Irrespective of available adaptation measures and tools, Wilson and Turton (2010) found that there is still a disconnect between climate change adaptation science and the on-ground management of native forests and plantations. Of particular concern is that many stakeholders still confuse climate change adaptation with climate change mitigation. Moreover, many of the adaptation strategies identified through stakeholder interviews were not strictly strategies for adapting to climate change, but essentially strategies for adopting environmentally sustainable land management practices.

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GRAZING IN NORTHERN AUSTRALIA

SUMMARY

- By 2030, some areas of northern Australia could experience more droughts and lower summer rainfall which in turn will affect forage and animal production, and ecosystem functioning (Cobon *et al.* 2009).

- Despite uncertainties in climate models, decreases in Livestock Carrying Capacity) LCC are predicted given that the ‘best estimate’ of climate change across the rangelands is for a decline (or little change) in rainfall and an increase in temperature (McKeon *et al.* 2009).

- Overall, a medium decline in beef production of around 3.5% by 2030 is predicted (Heyhoe *et al.* 2008).

- Among the negative impacts of climate change are reduced pasture growth and surface water availability; increased competition from woody vegetation; decreased production per head (beef and wool) and gross margin (Cobon *et al*. 2009).

- Among the positive impacts are increased CO_2, higher minimum temperatures, less frost and increased storm frequency which all potentially have a positive impact on pasture growth and quality (Cobon *et al*. 2009).

- A major uncertainty in quantifying climate impacts on the northern grazing industry concerns rainfall projections. The range of rainfall projections for Northern Australia is broad and includes both wetting and drying trends for most locations (CSIRO Australian Bureau of Meteorology 2007, McKeon *et al.* 2009).

- Other known uncertainties include: (i) carbon dioxide effects on forage production, quality, nutrient cycling and competition between life forms (e.g. grass, shrubs and trees); and (ii) the future role of woody plants including effects of fire, climatic extremes and management for carbon storage (McKeon *et al.* 2009).

- Risk and vulnerability assessment will help industry and primary producers assess risks associated with climate change and to assess the effectiveness of adaptation options in managing those risks (Cobon *et al.* 2009).

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CONTEXT

This statement is largely drawn from papers by McKeon *et al*. (2009) and Cobon *et al.* (2009).

EVIDENCE

Projected Impact

CATEGORY(S)

Natural and managed systems and their uses; Production systems; Food

REGION

Queensland
Northern Territory
Western Australia

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Soil Moisture
Solar Radiation
Extreme events
Increased evapotranspiration

PRESSURE(S)

The impact of climate change via changes in 13 climate variables, on the grazing industry of northern Australia was assessed in a risk and vulnerability impact assessment (Cobon *et al.* 2009). Elevated CO2, increased evaporation, higher minimum and maximum temperatures, less frost and more days over 35 C, were variables with the highest degree of confidence with respect to projections, whereas storm frequency, wind speeds and frequency of wildfires had the lowest degree of confidence. The degree of negative and positive impacts of changes in these 13 variables was assessed across 19 characteristics of the grazing industry from pasture growth, surface water availability and surface cover (Cobon *et al*. 2009) to livestock carrying capacity (McKeon *et al.* 2009ab).

STATE(S)

Of the 19 variables assessed, in Cobon *et al.*'s (2009) risk assessment, that are likely to be impacted by changes in climate, positive impacts are predicted for only two; pasture nutrition and selling prices due to higher demand and higher cost of production. All other variables are predicted to be negatively affected by climate change including decreased pasture growth, water availability, beef per head, wool per head, increased costs, and decreased gross margins.

Modelling by McKeon *et al*. (2009) however suggests that there are likely to be both positive and negative trends in forage production. For example, in a simulation of climate change impacts on forage production, they found that increased temperature (38C) was likely to result in a decrease in forage production for most rangeland locations (e.g. –21% calculated as an unweighted average across 90 locations). The increase in temperature exacerbated or reduced the effects of a 10% decrease/increase in rainfall respectively (–33% or –9%). Estimates of the beneficial effects of increased CO2 (from 350 to 650 ppm) on forage production and water use efficiency indicated enhanced forage production (+26%). The increase was approximately equivalent to the decline in forage production associated with a 38C temperature increase. The large magnitude of these opposing effects emphasises the importance of the uncertainties in quantifying the impacts of these components of climate change.

IMPACT(S)

Despite model uncertainties, the ‘best estimate’ of climate change across the rangelands is for a decline (or little change) in rainfall and an increase in temperature. As a result, a decrease in livestock carrying capacity (LCC) is projected (McKeon *et al.* 2009ab). The impact risk and vulnerability assessment indicated that drought and lower summer rainfall have the potential to drive the industry in some regions into transformational change. Incremental changes may be adequate in the short term but transformational change will be required in the long term (Cobon *et al.* 2009).

RESPONSE(S)

As a consequence of projected declines in livestock carrying capacity, public policy will need to have regard for: (i) the risk of enterprise failure with implications for regional communities; (ii) potential resource damage; and (iii) human distress including the risk of increased mortality. McKeon *et al.* (2009) note that the capability to quantify these warnings is yet to be developed and this important task remains as a challenge for rangeland and climate systems science. Further research is needed to identify regions requiring transformational changes to maintain a healthy industry and natural resource base (Cobon *et al.* 2009).

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OCEAN ACIDIFICATION

SUMMARY

- The average surface-ocean pH, which is currently close to 8.1, has already fallen by 0.1 units since the beginning of the industrial era. Since pH scale is logarithmic this translates as a 30% increase in acidity. It is likely to decline by another 0.2 to 0.4 units by the end of this century, a further increase in acidity of about 100%.

- Impacts are likely to manifest first in the Southern Ocean followed the Great Barrier Reef region

- Ocean acidification will reduce the ability of calcifying organisms to produce their shells and structures and may also impact the physiology of water-breathing animals

- Reductions in the shell weights of planktonic foraminifera shells in the Southern Ocean and in the growth and calcification rates of massive corals on the Great Barrier Reef has raised concerns that ocean acidification impacts are already occuring

- Ocean acidification has the potential for widespread disruption of marine ecosystems and the services they provide including fisheries.

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles and reports.

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Marine biodiversity, ecosystems services

REGION

Marine

DRIVER(S)

Water CO_2

PRESSURE(S)

The global ocean absorbs around one-quarter of the CO_2 added to the atmosphere each year and 40% of this is absorbed by the Southern Ocean (ACE CRC 2011). The uptake of CO_2 is changing ocean chemistry and lowering ocean pH (see Background). In laboratory experiments, calcifying species exhibit reduced calcification and growth rates under high-CO_2 conditions (Royal Society 2005, Doney et al 2009). The degree of sensitivity to pH and aragonite or calcite saturation state varies among species. Generally, the experiments so far are for only a limited number of species, are short-term, and do not test interacting stressors e.g. reduced pH and warmer temperature.

The average surface-ocean pH, which is currently close to 8.1, has already fallen by 0.1 units since the beginning of the industrial era (Denman et al 2007). Since pH scale is logarithmic this translates as a 30% increase in acidity. It is likely to decline by another 0.2 to 0.4 units by the end of this century, a further increase in acidity of about 100%. Ocean chemistry is changing at rates at least 100 times more rapid than it has changed during the 650,000 years preceding the Industrial Revolution. Over the next century, the extent and rates of change may be unprecedented in millions of years (Caldeira and Wickett 2003, Pelejero et al. 2010). Ocean acidification is essentially reversible in the short-term, it will take tens of thousands of years for ocean chemistry to return to a condition similar to that occurring at pre-industrial times (see Royal Society 2005 for more information).

STATE(S)

Saturation states are highest in shallow, warm tropical waters and lowest in cold-high latitude waters and at depth, reflecting the increase in calcium carbonate solubility with decreasing temperature and increasing pressure (Feely et al. 2004). If the ocean continues to acidify large regions of the surface of the Southern Ocean will become corrosive to calcium carbonate structures as atmospheric CO_2 increases beyond 450 ppm (McNeil and Matear 2008). The greatest declines in pH and aragonite saturation state around Australia are projected for north-east waters.

IMPACT(S)

Impact 1: Biological

Ocean acidification will affect calcifying organisms such as corals, mollusks, coccolithophores and forams (Orr et al. 2005, Royal Society 2005, Kleypas et al 2006, Hoegh-Guldberg et al 2007). Reef building corals have received the most intensive examination of all taxa to date and are likely to be among the most severely impacted. Modelling work predicts that even with conservative projections of atmospheric CO_2 level rise by 2069, the Pacific Ocean is likely to be marginal habitat for coral reefs by the end of the 21st century (Guinotte et al. 2003, Kleypas et al. 1999). All coral reefs globally are projected to cease growing and to start to dissolve when pCO_2 reaches 560 ppm (Hoegh-Guldberg et al 2007, Silverman et al. 2009).

Evidence is emerging of ocean acidification impacts. A recent reduction in coral growth rates has raised concerns that ocean acidification is already impacting corals (Bak et al. 2009).

Analysis of cores from 328 massive corals on 69 reefs on the Great Barrier Reef showed 14.2% decline in calcification and 13.3% decline in linear growth since 1990 (De'ath et al. 2009). It is likely the decline is caused by increasing temperature stress and declining aragonite saturation state of seawater. In the Southern Ocean modern planktonic foraminifera have shells that are 30-35% lighter than shells from pre-Industrial times (Moy et al. 2009).

Ocean acidification can also affect the physiology of water-breathing animals with long-term effects on metabolic functions (Portner 2004). Such processes are expected to affect long-term growth and reproduction and thus may be harmful at population and species levels. Experimental studies using reef fish from eastern Australian have found potentially profound effects on chemosensory cue detection and predator-advoidance behavior on settlement-stage larvae (Dixson et al 2010, Munday et al 2009a.b, Munday et al 2010).

Impact 2: Socio-economic impacts

Ocean acidification is an environmental security issue for Australia – the economic importance of the ocean is significant and Australia is also committed to addressing security challenges faced by neighbouring countries in the South Pacific (Allen and Bergin 2009). The socio-economic impacts of ocean acidification are uncertain but likely to be sizeable (Cooley et al. 2009, Cooley and Doney 2009). Ocean acidification will decrease calcification rates of organisms that form the basis of fisheries, aquaculture and tourism activities. Globally, by 2050, both population increases and changes in carbonate saturation states will be greatest in low-latitude regions, multiplying stresses on tropical marine ecosystems and societies (Cooley et al. 2009). Declines in key species may mean substantial revenue declines, job losses and indirect economic costs (Cooley and Doney 2009).

RESPONSE(S)

Mitigation

Reducing CO_2 emissions to the atmosphere appears to be the only practical way to minimize the risk of ocean acidification (Royal Society 2005). Other options are being proposed (e.g. iron fertilization, CO_2 injection into geologic features, adding carbonate to oceans) to reduce ocean acidification but are generally untested, effective only at local scales and may have considerable impacts on the functioning of marine ecosystems (Logan 2010).

Research Programs

Co-ordinated strategies across institutions for ocean acidification research have been set up in the USA and Europe. At the end of 2008, NOAA commissioned a National Research Council study on ocean acidification that was publically released in 2010 (Logan 2010). It recommends a strategy of ocean acidification research, monitoring and assessment for the US federal government and includes guidelines for the implementation of a national ocean acidification program (Logan 2010). In 2010, NOAA launched a US$5.5 million research program (Schiermeier 2011). Europe has invested in a four-year European Project on Ocean Acidification (EPOCA www.epoca-project.eu) which began in 2008 and encompasses 31 laboratories across 10 countries (Schiermeier 2011).

The Report Card Southern Ocean Acidification (AEC CRC 2011) sets out the current state of knowledge of ocean acidification impacts in the Southern Ocean, what's at stake and research responses (http://www.acecrc.org.au/Research/Ocean%20Acidification)

BACKGROUND

Ocean acidification is the term used to describe the decrease in seawater pH that occurs in response to rising CO_2 in the ocean. As CO_2 enters the ocean, it not only increases the carbon content of the ocean it also changes speciation of carbon in the seawater. In seawater, inorganic carbon is present in three distinct species - dissolved carbon dioxide ($CO_{2\,(aqueous)}$ + H_2CO_3 latter is less than1/1000 of the first term), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). The relative fractions represented by the three species are 1%, 90% and 9%, respectively. The relatively small fraction of carbon in the form of CO_2 aqueous enables the ocean to store large amount of carbon (39,000 Pg C)

Two reactions are particularly important as CO2 rises in the ocean. First, as carbon dioxide ($CO_{2\,(aqueous)}$) dissolves in seawater it reacts with the water to form carbonic acid (H_2CO_3):

$$CO_{2\,(aqueous)} + H_2O \leftrightarrow H_2CO_3$$

The formation of carbonic acid with the subsequent release of hydrogen ions increases the acidity (reduces pH). Second, the increase of CO_2 alters the two other dissolved inorganic carbon species, bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions through the following reactions:

$$CO_{2\,(aqueous)} + H_2O \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + 2\,H^+$$

The combined effect of these reactions not only increases acidity but also lowers carbonate ion concentration. Carbonate ions are used in the production of calcareous shells and skeletons (calcification) by the following reaction:

$$CO_3^{2-} + Ca^{+2} \rightarrow CaCO_3$$

The reduction in carbonate ions with ocean acidification is biologically significant, since it can affect the rate at which marine organisms – such as corals, molluscs, crustaceans, sea urchins and coralline algae – build their calcareous shells or skeletons. Under low pH conditions (higher acidity), carbonate ions are less available and calcification is harder to achieve, and may be prevented altogether.

Marine biota form three different calcium carbonate minerals: aragonite, calcite, and magnesium calcite. Aragonite and calcite are naturally occurring polymorphs of calcium carbonate with differing crystal lattice structures and hence solubilities, aragonite being about 1.5 times more soluble than calcite at 25°C. Magnesium calcite is a variety of calcite with magnesium ions randomly substituted for the calcium ions in a disordered calcite lattice. At low fractions of magnesium, the solubility of this phase is lower than that of calcite, whereas at high fractions, the solubility is greater than that of aragonite. Calcite is laid down by pelagic coccolithophores and forams, aragonite by reef-building corals, pelagic pteropods and some mollusks and magnesium-calcite by coralline algae, bryozoans and echinoderms. If the seawater becomes under-saturated with aragonite or calcite, then the hard parts of these organisms, and others, will start to dissolve. Because aragonite is more soluble than calcite, the aragonite saturation horizon (the limit between undersaturation and oversaturation) is always nearer the surface of the ocean than the calcite saturation horizon.

Ocean acidification has the potential for widespread disruption of marine ecosystems and the services they provide including fisheries. Our knowledge of the geochemical and biological impacts of ocean acidification are not well developed, with many urgent knowledge gaps

Atmospheric concentrations of CO_2 (ppm), average pH of surface oceans

Pre-industrial	280ppm	pH 8.18
Today	380ppm	pH 8.07
2 x pre-industrial	560ppm	pH 7.92 (~IPCC B1 scenario 2100)
3 x pre-industrial	840ppm	pH 7.77 (~IPCC A2 scenario 2100)
4 x pre-industrial	1120ppm	pH 7.65
5 x pre-industrial	1400ppm	pH 7.56
6 x pre-industrial	1680ppm	pH 7.49

(from Royal Society 2005)

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PLATYPUS

SUMMARY

- Platypus, *Ornithorhynchus anatinus*, are vulnerable to changes in stream flow and water quality
- Warming temperatures and reduced rainfall are projected to lead to a 30% decline in platypus climatic habitat by 2070, with main losses occurring at northern and inland extents.
- Managing platypus habitat may be important to reduce climate change threats or provide refugia.

CONTEXT

This statement is based on the PhD thesis of Melissa Klamt, Monash University supervised by Professor Jenny Davis and Dr Ross Thompson from Monash University

EVIDENCE

Projected Impact

CATEGORY(S)

Terrestrial Biodiversity

REGION

Queensland, NSW, Victoria, Tasmania, ACT

DRIVER(S)

Temperature
Precipitation

PRESSURE(S)

Pressure 1

Australian average temperatures have increased 0.9°C since 1950, with significant regional variations (CSIRO and BoM 2007). Since 1950, most of eastern and south-western Australia has experienced substantial rainfall declines (CSIRO and BoM 2007). Across New South Wales and Queensland, these rainfall trends partly reflect a very wet period around the 1950s, though recent years have been unusually dry. From 1950 to 2005, extreme daily rainfall intensity and frequency has increased over the western tablelands of New South

Wales, but decreased in the south-east and south-west and along the central east coast (CSIRO and BoM 2007).

Pressure 2

Increasing water demand from cities and agriculture are leading to changes in river flow and runoff. Platypus are susceptible to changes in stream flow, poor water quality, loss of riparian vegetation, stream sedimentation (Grant and Temple-Smith 2003)

STATE(S)

The regions where platypus are currently found, namely South-east Queensland, New South Wales and ACT, Victoria and Tasmania, are all projected to warm further and experience declines in annual rainfall (Whetton 2011).

IMPACT(S)

Using a database of 11,460 platypus records over 1800 to 2009, Klamt et al (2011) constructed climatic envelopes for platypus. Up to the 1950s, total annual rainfall was a strong predictor of platypus distribution, however since the 1960s, annual maximum air temperature makes a stronger contribution. Projections for 2020 and 2070 under emission scenarios A1B, A2, B1, and B2* consistently show a decline in platypus distribution. Under scenario A1B, suitable habitat is projected to decrease by approximately 31% by 2070, with the main losses occurring at the northern and most inland extents of the range. Similar range reductions are projected under the most optimistic emission scenarios.

*Projected global average surface warming at 2090-2099 relative to 1980-1999 (IPCC 2007)

A1B: 2.8°C
A2: 3.4°C
B1: 1.8°C
B2: 2.4°C

RESPONSE(S)

Potential responses include habitat manipulation or restoration by planting shading trees and shrubs along waterways thus cooling both the water and platypus burrows and management of stream flows (Klamt et al. 2011):

BACKGROUND

The egg-laying monotreme, the platypus *Ornithorhynchus anatinus*, is the sole species in the family Ornithorhynchidae, and together with four species of echidna, is one of the five extant monotremes in the mammalian subclass, Prototheria. The platypus is endemic to freshwater ecosystems of eastern Australia where it feeds nocturnally on aquatic macroinvertebrates in streams and pools and uses in burrows in the banks (Grant 2007). It has limited ability to travel overland between streams. Platypus have poor heat regulation and only cool by immersion in cool water, retreating into burrows or through limited sweating.

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RICE

SUMMARY

- Rice production will have to adapt, primarily to declines in water resource availability.

- Rice production in Australia is mainly located in irrigated regions of southern New South Wales and northern Victoria. Reductions in water allocations following five years of drought led to production of only 61,000 tonnes in 2008-09 (ABARE 2010) , but improved conditions led to production of 205,000 tonnes in 2009-10 and forecast production of 802,000 tonnes in 2010-11 (ABARE 2011).

- Rice growing regions are expected to become hotter and drier (CSIRO/BoM 2007).

- Though international research has suggested increased average temperatures (in isolation from CO_2 increases) will have a negative effect on rice yields it is possible increasing temperatures in Australia may have a positive yield response as long as water is non-limiting (Gaydon *et al*. 2010).

- Given disparities in international studies and the lack of published Australian studies it is not possible to provide clear projections of the combined impacts of increasing temperatures and CO_2 concentrations on Australian rice production (Gaydon *et al*. 2010).

- The vast majority of Australian rice production is located in the Murray Darling Basin where availability of irrigation water is likely to decline both as a result of climate change as well as policies to increase environmental flows (CSIRO 2008).

- Though reductions in water availability for irrigation will probably be not as great as those in the 'Guide to the proposed Basin Plan' (Murray-Darling Basin Authority 2010) they may well have significant impacts.

- Declines in irrigation water supply under climate change are likely to have a negative impact on rice production (Gaydon *et al*. 2010).

- Adaptation may require changes to current management practices and use of improved cultivars. However, the capability to adapt existing systems is limited and new systems, such as the use of aerobic and alternate-wet-dry (AWD) rice, may be needed and require ongoing research (Gaydon *et al*. 2010).

CONTEXT

The main source of information was the review by Gaydon *et al.* (2010), supplemented by reports downloadable from the internet (e.g. ABARE 2010, Australian Greenhouse Office 2006) and peer-reviewed papers in journals (e.g. Lobell *et al*. 2011).

EVIDENCE

Projected Impact

CATEGORY(S)

Production systems: Food

REGION

New South Wales
Victoria

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Extreme and Variable Weather Patterns
Soil Moisture

PRESSURE(S)

AGO (2006) identified the following key climate change pressures for rice production:

- **Average temperatures** in Australia have risen by 0.7 degrees since 1910 and are projected to continue increasing in future years.
- **Rainfall** patterns, amounts and intensities are expected to change, with a general drying trend in south-eastern Australia.
- The frequency and intensity of **extreme weather events** such as storms, floods, fires, heat waves and droughts are likely to increase.
- **Soil moisture deficits** are likely to increase as a result of decreasing rainfall, increasing temperatures, and increasing rates of potential evaporation.

See maps in CSIRO-BoM (2007) for likely climate changes in the rice growing areas around such centres as Griffith, Leeton, Coleambally, Balranald, Hay, Moulamein, Jerilderie, Finlay and Berrigan.

STATE(S)

Average temperature increases in rice growing areas in southern New South Wales and northern Victoria have risen by about 0.05-0.10 °C since 1910 in line with national average increases (see Bureau of Meteorology web site www.bom.gov.au, Australian climate variability and change).

Average rainfall in rice growing areas in southern New South Wales and northern Victoria has been highly variable with no clear trend since 1910 (see Bureau of Meteorology web site www.bom.gov.au, Australian climate variability and change).

IMPACT(S)

Gaydon *et al.* (2010) have reviewed likely impacts of climate change on rice production. Practically all of Australia's rice is grown in conditions of shallow (10 cm) ponded water, so reduced supplies of irrigation water are likely to have the greatest impacts on production. Recent climate change projections suggest a 16-25% reduction in average Murray-Darling streamflows by 2050 and a 16-48% reduction by 2100

There is little published work on temperature impacts on Australian rice varieties. Welch *et al.* (2010) analysed rice yields from 227 farms in tropical/subtropical Asia and found that higher minimum temperatures reduced yield, while higher maximum temperatures increased yields. Looking ahead, they imply a moderate negative impact from moderate warming in coming decades. Prior research indicates the impact of maximum temperature becomes negative at higher levels. However, these varities are different from those grown in Australia and increased minimum temperatures may increase rice growth in the much cooler conditions of southern Australia

The impacts on rice yields of projected temperature changes and increased CO_2 levels in Australia are uncertain and require further research. It appears that yield reductions due to extreme high temperatures present a possible risk. It is unlikely that increases in average temperature over the growing period will present a significant production risk, as a considerable buffer already exists between current average temperatures and the reported thresholds for incurring yield losses (Gaydon *et al*. 2010).

RESPONSE(S)

Gaydon *et al.* (2010) have reviewed adaptation options for dealing with climate variability including cropping area modification, purchase/sale of water on the open market, flexible rotations, sowing winter crops directly after rice, nutrient management adjustment, water management and stubble retention. They also reviewed adaptation options for dealing with climate change including a) improving water use efficiency, b) use of seasonal climate forecasts, and c) new crops, rotations and priorities for water

BACKGROUND

The Basin Plan is a high level plan to ensure that the water resources of the Murray Darling Basin can be managed in a sustainable way. It will be prepared by the Murray-Darling Basin Authority and may have major influence on water availability for crops such as rice and cotton. It was not available when this statement was prepared in early June 2011, but is expected to be released for public comment in mid-2011

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ROCK LOBSTER STOCKS IN TASMANIA

SUMMARY

- In Tasmania, recruitment to southern rock lobster *Jasus edwardsii* stocks have recently declined in the north but growth rates have been enhanced in the south reflecting the warming pattern.

- The Tasmanian southern rock lobster fishery has shifted from the north-east to the southern waters reflecting the changes in the stock

- Over the coming decades, declines in southern rock lobster biomass in Tasmania with warming are projected to occur first in the north before eventually declining in the south.

- Fishing on large rock lobsters may have facilitated the establishment of the urchin *Centrostephanus rodgersii* in Tasmania following polewards range shift of the urchin due to warming and an enhanced East Australian Current

CONTEXT

This statement is based primarily on Pecl et al 2009 *The east coast Tasmanian rock lobster fishery – vulnerability to climate change impacts and adaptation responses*. Report to the Department of Climate Change, Australia.

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Ocean biodiversity; Fisheries; Aquaculture; Ocean climate and sea level

REGION

South-east marine

DRIVER(S)

Temperature
Ocean currents

PRESSURE(S)

Temperature is known to influence rock lobster population dynamics with growth, settlement and recruitment of lobsters related to temperature (Pecl et al. 2009, Pecl et al

2011). Sea surface temperatures have warmed around Australia over the past century. Mean temperatures are 0.7°C warmer over 1989-2008 compared to 1910-1929 (Lough 2009). The greatest warming rates are occurring off the south-east and south-west coasts (Lough 2009). Over 1944-2002, the waters off eastern Tasmania have become warmer, with mean trend of 0.23°C decade^{-1}, and saltier, with mean trend of 0.36 psu/century, driven by a strengthening of the East Australian Current (Hill et al. 2008). Trends are greater in the summer, when the greatest East Australian Current flow occurs seasonally. The changes correspond to a southwards shift in sea surface climatology of around three degrees latitude or 350 km over 1944-2002 (Ridgway and Hill 2009).

STATE(S)

State 1

Recruitment has declined in the north-east over 1963-2008 contributing to a decline in southern rock lobster stocks in the region (Pecl et al. 2009). Survival of southern rock lobster *Jasus edwardsii* larvae is reduced at higher temperatures with complete mortality above 21.5°C (Bermudes and Riter 2008). In addition, although no consistent pattern in settlement was found across rock lobster sites in eastern Tasmania, correlations with sea surface temperature support the hypothesis that the position of the sub-tropical convergence, where the East Australian Current meets cooler Southern Ocean water, is important in larval and peurulus supply (Pecl et al. 2009). Strengthening of the East Australian Current results in a less northerly position of the sub-tropical convergence and fewer larvae reaching east and north-eastern Tasmania and an increase in supply to southern regions (Pecl et al. 2009).

State 2

Southern rock lobster *Jasus edwardsii* stocks have increased in the south. Tagging data since 1995 from Maatsuyker Island, south-west Tasmania, reveals an increasing trend in lobster growth rate of ~4mm/decade (Pecl et al. 2009). Although this appears small, it represents a doubling of female growth rates in this region hence the potential to increase the proportion of the stock vulnerable to the fishery (as more females reach legal size limit). Translocation of southern rock lobsters from cool, deep water reefs off Maatsuyker Island (summer sea surface temperature range 12-14°C) to warmer, shallower sites on the east coast of Tasmania (summer sea surface temperature range 15-17°C) showed increased growth rates, up to four times that of residents at Maatsuyker (Green et al. 2010). The warming of southern Tasmanian waters over the coming decades is therefore expected to increase lobster productivity.

Modelling studies (rock lobster stock assessment model forced by scenarios A1B and A1FI) which include temperature effects in recruitment and growth, project that productivity of lobster stocks (and biomass of large lobsters) will initially increase due to the gains in growth rates, particularly in southern, but eventually with further warming decline when recruitment declines outweigh the benefits of increased growth rates (Pecl et al. 2009). By 2040, north-east region may not contribute at all to potential harvest (Pecl et al. 2009).

State 3

The eastern rock lobsters *Jasus verreauxi* may increase in Tasmanian waters (Pecl et al. 2009). Settlement of eastern rock lobsters has been monitored for the past decade at four sites in eastern Tasmania and only a few individuals have been recorded, it is assumed larvae are transported to Tasmania by the East Australian Current (Pecl et al 2009). Eastern rock lobsters are currently caught in small numbers in north-east Tasmania. Several species of fish, invertebrates and dinoflagellates have already been reported extending their ranges southwards into Tasmanian waters aided by a strengthening East Australian Current (Johnson et al. 2011).

State 4

Removal of large rock lobsters may have facilitated the southwards expansion of the sea urchin *Centrostephanus rodgersii* into Tasmanian waters with a strengthening East Australian Current and warming (Ling et al. 2009).

IMPACT(S)

Impact 1 to state 1-2

Fishery effort for southern rock lobster *Jasus edwardsii* in Tasmania has shifted from northern waters to the south-east based on records since 1970 reflecting the underlying changes in the stock (Pecl et al. 2009)

Impact 2 to state 3

Eastern rock lobsters *Jasus verreauxi* are currently managed under the same legislation as southern rock lobsters in Tasmania (minimum catch size) but given their differing size at maturity, current fishery management may be inadequate if numbers increase (Pecl et al 2009).

Impact 3 to state 1,2,4

In large numbers, *C. rodgersii* overgraze macrolagae (kelp beds) leading to the formation of ‘urchin barrens’ with considerable loss of biodiversity (Ling 2008, Johnson et al. 2011). Large lobsters are the only significant predator of *C. rodgersii* in Tasmanian waters (Ling et al. 2009). Fishing impacts on rock lobster may have exacerbated climate change effects on *C. rodgersii* (Ling et al. 2009, Pecl et al. 2009).

RESPONSE(S)

Response 1: to Impact 1

No adaptation responses have been trialed yet but several have been proposed to allow the Tasmanian rock lobster fishery adapt to changes in the stock such as a) incorporate recruitment changes into fisheries catch modelling ; b) establish long-term monitoring of rock lobster populations; c) develop regional management tools; d) incorporate responses to climate change within the standard risk management; e) develop long-term priorities reviewing multiple fisheries simultaneously; f) identify cost effective ‘no regrets’ adaptation measures (Pecl et al. 2009).

Response 2: to State 2 and Impact 1

If the eastern rock lobster *Jasus verreauxi* establishes in Tasmania, opportunity may exist to target this species but fishery management in the region will have to adjust for this new species (Pecl et al. 2009). However, productivity of eastern rock lobster is much lower the southern rock lobster so this will not approximate 'replacement'.

Response 3: to State 3

Experiments are underway to determine the density of large rock lobsters that is needed to prevent the formation of urchin barrens (Johnson et al. 2011). If successful, then rock lobster stock management can be used to maintain appropriate lobster densities and size structure (Pecl et al. 2009).

BACKGROUND

Waters around Tasmania are warmer in the north than the south. The warmest waters are found in the north-east due to the influence of the East Australian Current.

Rock lobsters form the basis of several state-managed fisheries in Australia. The southern rock lobster *Jasus edwardsii* is harvested in primarily in Tasmania, Victoria and South Australia. The southern rock lobster fishery is Tasmania's second most important wild harvest fishery valued at $72 million (at first point of landing; Pecl et al. 2009). Along the New South Wales coast, the eastern rock lobster *Sagmariasus* (*Jasus) verreauxi* forms about 99% of commercial landings of lobster in the state (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/375884/Eastern-Rock-Lobster.pdf). There are also large recreational fisheries for these rock lobsters.

Rock lobsters have a life span of 20 years or more. The eastern rock lobsters have faster growth rates and attain larger sizes than southern rock lobsters. For example, in New South Wales eastern rock lobsters mature at 165mm compared to 65mm for southern rock lobsters in southern Tasmania (Pecl et al. 2009). In Tasmania, lobsters in the north of Tasmania grow faster than lobsters in the cooler waters in the south. Lobsters in the south-west grow slowest and females do not reach legal catch size due to very slow growth rates (Pecl et al 2009). At present, management policies for the fishery do not explicitly account for climate change (Pecl et al. 2009)

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SUGARCANE

SUMMARY

- Sugarcane production is likely to require adaptation under a changing climate.
- Sugarcane production in Australia is mainly located along the northeastern coast from Harwood in northern New South Wales to Mossman in Far North Queensland (see map in Park *et al.* 2010).
- Sugarcane production may benefit from increased atmospheric CO_2, but suffer from decreased rainfall in some areas and increased rates of evapotranspiration if soil water is inadequate to maintain these rates (Park *et al*. 2010).
- Water relations are an important factor in production (Renouf *et al*. 2010) and have been recently reviewed (Carr and Knox 2011). There is a linear relationship between cane/sucrose yields and actual evapotranspiration (ETc) over the season, with slopes of about 100 (cane) and 13 (sugar) kg (ha mm)−1 (but variable).
- Climate change is likely to affect not only sugarcane growth, but also its processing e.g. alterations in the timing and duration of the crushing season and production volume (Park *et al*. 2010).
- Adaptation options include improvements to water management, genetic material, machinery, decision support and cropping system design and agronomic management (Park *et al*. 2010).
- Many adaptation strategies will simply involve an extension to current actions aimed at dealing with climatic variability (Park *et al*. 2010).

CONTEXT

The main source of information was the review of climate change impacts and adaptation for sugarcane by Park *et al* (2010), which cites 55 references. This was supplemented by information from reports downloadable from the internet (e.g. Park *et al*. 2007, USDA 2010) and papers in peer-reviewed journals (e.g. Carr and Knox 2011, Renouf *et al*. 2010).

EVIDENCE

Observed Impact: No
Projected Impact: Yes, see Silva *et al* (2008)

CATEGORY(S)

Production systems: Food
Production systems; Biofuel

REGION

Queensland
New South Wales

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Solar Radiation
Extreme and variable weather patterns
Soil moisture

PRESSURE(S)

Park *et al*. (2007) provided projections of temperature, rainfall and evapotranspiration for the four seasons for each of five sugarcane growing regions for 2030 and 2070 based on data of Cai *et al*. (2005). In terms of long term averages, increasing temperatures of about 0.7 to 4.8°C relative to 1990 are expected across the whole of the Australian sugarcane growing area by 2070. No consistent rainfall trend is apparent for these regions in the years to 2070, however evaporation rates appear certain to increase.

Atmospheric CO_2 levels will increase in the period to 2070. Actual levels reached by 2070 will depend on the effectiveness of measures to manage global emissions (Solomon *et al*. 2007).

STATE(S)

Australian average temperatures have increased by 0.9°C since 1950, with significant regional variations (CSIRO/BoM 2007). For example, sugarcane growing regions around Bundaberg and Mackay have experienced slightly greater warming of about 1.2°C.

IMPACTS)

Park *et al*. (2010) have reviewed impacts on production. For example, De Souza *et al*. (2008) have reported increased water use efficiency and biomass at doubled CO_2 levels. Higher temperatures should benefit cooler sugarcane growing locations in south-east Queensland and northern NSW (Park *et al*. 2010). Lower rainfalls may reduce yield in some areas, but benefit production in other areas, such as northern areas of present region, that currently experience seasonal waterlogging and flooding events.

Silva *et al*. (2008) have modelled likely impacts of climate change on production in Brazil and Australia. They predicted that productivity may increase by up to 13% in Queensland by 2070.

RESPONSE(S)

Park *et al*. (2010) have reviewed adaptation options for dealing with projected climate change including water management, plant breeding, machinery technology, cropping systems design, agricultural management, and decision-support tools.

In common with many other Australian crops sugarcane may benefit from some changes such as increased atmospheric CO_2, while at the same time suffering in some regions from other changes, such as reduced rainfall. There is a need for improved simulation models based on experimental evidence to be developed to predict how interacting factors will affect production in different regions under varying scenarios.

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TUNA AND BILLFISH FISHERIES

SUMMARY

- Tuna and billfish support high value Australian fisheries, and also capture a wide range of bycatch species.
- There are strong relationships between tuna and billfish catches and environmental conditions (e.g. water currents, temperature, and ocean productivity) at seasonal and interannual scales
- Climate change represents an additional challenge for fisheries management
- On the east coast of Australia, the core habitats for the main species in the Eastern Tuna and Billfish Fishery are projected to shift south. Overlap between warm-water Yellowfin tuna and cool-water Southern Bluefin Tuna is expected to increase in future, challenging management arrangements.
- Shifts in the distribution of key species will have impacts on economics of fisheries and management impacts
- Seasonal forecasts for Southern Bluefin tuna habitat are helping to inform operational decisions and reduce vulnerability to climate variability and change

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles and reports.

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Ocean biodiversity; Fisheries

REGION

East and west coast of Australia

DRIVER(S)

Temperature
Ocean currents
Ocean productivity

PRESSURE(S)

Tuna and billfish are high value fish that are under pressure from heavy exploitation in many parts of the world. Climate change is an additional challenge for fisheries management, both in the systems being governed and in the governance systems (McIlgorm et al. 2010).

STATE(S)

The target species are highly migratory, the Eastern Tuna and Billfish fishery stocks are part of broader western and central Pacific ocean stocks. El Nino Southern Oscillation (ENSO) events are a factor in determining the distributions of tuna and billfish and the migration of some tuna into Australia waters (Sands 2011). The East Australian Current is an important influence on the seasonal distribution of tuna off eastern Australia, tuna abundance follows the seasonal expansion and contraction of the warm-water East Australian Current (Hobday et al. 2008).

IMPACT(S)

Impact 1: Changes in distribution and timing of migration

There is a strong relationship between tuna availability and temperature off eastern Australia, although there is no evidence of climate change impacts to date (e.g. Southern Bluefin Tuna: Day 2011). However, analysis of long time-series in the Bay of Biscay (North Atlantic), reveal north Atlantic albacore tuna *Thunnus alalunga* are arriving 8 days earlier on feeding grounds compared to 40 years ago and eastern Atlantic bluefin tuna *Thunnus thynnus* are arriving 14 days earlier compared to 25 years ago (Dufour et al. 2010). Albacore tuna mean catch also show a shift towards higher latitude over time (Dufour et al. 2010).

The potential impacts of climate change by 2100 on fourteen large pelagic species captured by longline fisheries (mainly sharks, tuna and billfish) on the east and west coasts of Australia was investigated by Hobday (2010). An approach similar to bioclimatic modeling and based solely on temperature was applied. Over 95% of model predictions for the east coast suggest the core range would move south and shrink. There was less certainty on the west coast but a southern shift and shrinking of core range was generally projected. The overall rate of southern shift for the suite of species was 40km/decade.

Predictions for yellowfin, *Thunnus albacores,* and southern bluefin tuna, *Thunnus maccoyii,* habitat were generated for 2064 on the east coast of Australia. The CSIRO Mk3.5 A2 scenario for the years 2061-2064 was used (three spin-up years and 2064 analysis year) and dynamically downscaled (Hartog et al. 2011). The model predicts that habitat for yellowfin tuna and southern bluefin tuna will move further south on the east coast of Australia with an increase in the overlap of the species' distributions throughout the management season. A risk assessment of the impacts of climate change on southern bluefin tuna in south-east Australia is given in Pecl et al. (2011).

The potential impacts of climate change on bigeye tuna, *T. obesus,* populations in the Pacific Ocean was investigated using a spatial ecosystem and population dynamics model (SEAPODYM; Lehodey et al. 2010). Applying the SRES A2 IPCC scenario (atmospheric CO_2

concentration reaching 850 ppm in 2100) shows a displacement of stocks towards the eastern Pacific and a declining adult biomass at the end of the century (Lehodey et al. 2010).

Impact 2: Socio-economic impacts

The projected shift in yellowfin and southern bluefin tuna habitat on the east coast of Australia (see Impact 1 above and Hartog et al. 2011), indicate that the problems faced by management today, as a result of two species with different stock status sharing similar habitat, are likely to persist in the future and even increase. For example, fishers seeking yellowfin tuna may be excluded from yellowfin habitat when the southern bluefin tuna management lines are placed too far to the north. Climate change impacts on the fish stocks would result in economic impacts through changes in the cost to catch fish (McIlgorm et al. 2010)

Internationally, changes in the distributions of tuna and billfish stocks will impact availability to fishing nations, with potentially serious implications for some small island nations who depend on tuna for food security and their economies (Aaheim and Sygna 2000, McIlgorm 2010, McIlgorm et al. 2010). In the western equatorial Pacific, the observed changes in the distributions of tuna stocks and fisheries associated with El Nino-Southern Oscillation events provide expectations for responses under climate change (Lehodey et al 1997, 1998, 2003).

Impact 3: Management and operational impacts

At a local scale, changes in the availability of key species may affect local spatial management arrangements e.g. marine protected areas and area with restricted access and also fisheries closures, as these are typically based on historical patterns in fishing activities. For example, southern expansions of species in the Eastern Tuna and Billfish fishery may require changes in the delimitations of the Federal fishery and consultation with the Tasmanian State Government regarding jurisdictional limits (McIlgorm et al. 2010).

RESPONSE(S)

Southern bluefin tuna are restricted to the cooler waters of the East Australian Current and range further north when the current contracts up the coast of New South Wales (Hobday et al. 2008). Real-time spatial management has been implemented that restricts fishers access to ocean regions that are predicted to contain southern bluefin tuna habitat (Hobday et al 2008, Hobday and Hartmann 2006). Real-time maps of the distribution of tuna habitat are based on a relationship between water temperature and tuna abundance and these changes throughout the season. The current distribution is relayed to management throughout the season and management adjusts the location of restricted areas. This application has been extended to produce seasonal forecasts of southern bluefin tuna habitats out to 3-4 months and so inform operational decisions (Hobday et al. 2011).

BACKGROUND

Eastern tuna and billfish fishery (ETBF)

This fishery extends from Cape York to Victoria including waters around Tasmania. The tropical and sub-tropical target species are albacore tuna (*Thunnus alalunga*), bigeye tuna (*T.*

obesus), yellowfin tuna (*T. alacares*), swordfish (*Xiphius gladius*), and striped marlin (*Tetrapturus audax*). Historically, yellowfin tuna are the dominant species in the fishery. These species are highly migratory and are part of broader western and central Pacific Ocean stocks which extend into the high seas and into the Economic Exclusive Zones (EEZ) of other nations (Wilson et al. 2010). The broader stocks are managed by the Western and Central Pacific Fisheries Commission, of which Australia is a member (Sands 2011). The range of these tropical and sub-tropical species overlap with the more temperate southern bluefin tuna (*Thunnus maccoyii*). Some ETBF longliners target southern bluefin tuna off New South Wales during the winter, after fishing for tropical tuna and billfish earlier in the year, while others may take them incidentally when targeting other tunas (Wilson et al. 2010). All southern bluefin tuna must be covered by quota and landed in accordance with southern bluefin tuna management plan (Wilson et al. 2010). A history of the ETBF is given in Wilson et al. (2010; Table 22.3).

The gross value of production for the ETBF in 2008-09 was $38.9 million (Wilson et al. 2010). Fuel is a major cost for fisheries. In 2008-09, approximately 14% of cash costs for the average vessel in the ETBF was fuel (Perks and Vieira 2010).

Southern Bluefin Tuna fishery (SBT)

The Southern Bluefin Tuna fishery constitutes a single, highly migratory stock that spawns in the north-east Indian Ocean and migrates throughout temperate, southern oceans (Wilson et al. 2010). It is targeted by fishing fleets from a number of nations, both on the high seas and within the Exclusive Economic Zones of Australia, New Zealand, Indonesia and South Africa (Wilson et al. 2010). Juvenile southern bluefin tuna are targeted in the Great Australian bight by Australian purse seiners. Throughout the rest of its range it is targeted by pelagic longliners who harvest all ages (Wilson et al. 2010). A history of the SBT is given in Wilson et al. (2010; Table 24.3). Details of the species profile (fishery, life history, sensitivity and resilience to climate change and ecosystem interactions) is given in Day (2011).

Tuna is one of Australia’s most valuable finfish production species, valued at $210 million in 2007-2008 (ABARE 2009). Approximately 90 per cent of Australia’s tuna production is exported, mostly to the Japanese sashimi market. Most of this tuna is produced in South Australia’s aquaculture sector, which takes most of the Commonwealth Southern Bluefin tuna (*Thunnus maccoyii*) output (netted as juveniles in the Great Australian Bight) for fattening in purpose built tuna ranches off Port Lincoln over 3-5 months. Tuna production has almost halved compared to peak production in 2000-2001 (ABARE 2009). Although tuna production and value increased in 2007-2008 compared to 2006-07, the value of tuna sector has declined as a result falling unit prices influenced by exchange rate movements in recent years which simultaneously reduces the competitiveness of Australian exports and increases the attractiveness of imports to the domestic consumers (ABARE 2009). The real unit price of southern bluefin tuna from South Australian aquaculture farms has almost halved to $19 a kilogram since 2000-01, with production value falling by $135.3 million (in real terms) over the period 2000-01 to 2007-08 (ABARE 2009).

The growth of tuna ranching has contributed to a demand for sardines (used as feed in tuna ranching, in pet foods and as bait in the recreational fishery) and the subsequent growth of the Australian sardine fishery (ABARE 2009).

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VICTORIAN CLIMATE CHANGE ADAPTATION PROGRAM (VCCAP)

SUMMARY

- Agriculture in Victoria will have to adapt to climate change and a policy choice framework has been developed.
- Victoria is Australia's largest food and fibre exporting state. Its agricultural sector produces goods valued at around $9 billion a year or about 26 per cent of the national total (DPI 2011).
- Victoria's Department of Primary Industries ran the $9.2m Victorian Climate Change Adaptation Program (VCCAP) from July 2007 until June 2010 (Morris *et al*. 2010).
- The program focussed particularly on developing a methodology in a pilot region (SW Victoria). This involved developing scenarios of likely future agricultural systems, modelling likely impacts of climate change on key sectors, assessing economic impacts and developing a framework to assist policy development (Morris *et al.* 2010).
- The rate and magnitude of future climate change is highly uncertain. However, the future is likely to be water constrained. Accompanying higher temperatures and lower rainfall, the average annual runoff in South-West Victoria is anticipated to decrease by between 10% and 50% by 2030 (A1FI scenario) (Morris *et al.* 2010).
- Agriculture will have to adapt and a demonstration study of heat stress in dairy cows has shown how the Policy Choice Framework can assist this process (Sandall *et al.* 2010).

CONTEXT

This statement is based on the VCCAP Final Report (Morris *et al.* 2010) and two other VCCAP reports (Liu and Fitzsimons 2009, Sposito and Benke 2010).

EVIDENCE

Observed Impact: As yet it is difficult to distinguish effects of climate change from climatic variability in South-West Victoria.
Projected Impact: Yes (see Sposito and Benke 2010).

CATEGORY(S)

Production systems: Food
Production systems: Fibre

REGION

Victoria

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Solar Radiation
Extreme and variable weather patterns
Soil moisture

PRESSURE(S)

When considering climate change we need to keep in mind the uncertainty that exists about future rates of greenhouse gas emissions and the compounding, greater uncertainty about the effects of elevated greenhouse gases on future climate, particularly at regional to subregional scales. That said, the majority of global climate models project a warmer and dryer future climate for south eastern Australia (Morris *et al.* 2010).

STATE(S)

The current economic state of the South-West Region was reviewed by Liu and Fitzsimons (2009). The main findings in this report relevant to agriculture were:

- South West Victoria has 7% of its labour force employed in the agriculture, forestry and fishing industries which is significantly higher than the state (2.8%) and national (3.2%) levels.
- Two thirds of the working zones in south west Victoria have agriculture as their major employing industry.
- Average farm business profits in south west Victoria have fluctuated with the occurrences of droughts and commodity prices.
- Different areas of the south west region concentrate on producing a diverse range of agricultural commodities. For example, areas in and around Ararat concentrate on the production of sheep, lambs, wool, wheat and canola, Corangamite South and Moyne South concentrate on milk production, and the Glenelg region focuses on meat cattle production.
- The south west dairy industry is a significant contributor to the regional, state and national economy. Beef is south west region's second most valuable commodity. When wool prices fell many producers turned to other options.
- Drier climate has allowed more farmers in south west Victoria to grow more crops as water logging has previously prevented crop production.

IMPACTS)

Climate change impacts were analysed for the South-West Region (Sposito and Benke 2010) using three scenarios (B1, A2 and A1FI) scaled down to the regional level. Northern areas of the region are expected to become more suitable for phalaris/sub-clover growth, while the southern regional areas would be better suited for perennial ryegrass/sub-clover growth. Climate change would not have a major impact on the suitability of land for the cultivation of lucerne that currently grows well in most of the region with the exception of patches of land that have soils with high salinity, or low pH or very poor drainage. These analyses reflected the performance of current pasture systems in the likely future climatic conditions, but there appeared to be potential for developing appropriate adaptation strategies.

The three grain systems investigated – barley, oats and wheat – performed in a similar way under future climate change scenarios. A potential decrease in grains productivity of around 5% for the entire SW Region would occur if future climate unfolds as predicted in any of the three scenarios investigated. The critical issue for the grains industry would be the variability of rainfall during the growing season rather than the change in total rainfall during a year, as long as the rainfall level does not decline too significantly. It is possible that productivity advances over the next decades in genetics and agronomy may overcome any negative trend, thus probably turning a potential problem into an opportunity.

The productivity of forestry plantations – blue gum and radiate pine - is likely to be increased by the CO_2 fertilisation effects, although the amount of the increase would be limited by projected increases in temperature, changes in precipitation and by feed-back mechanisms such as nutrient recycling. Where tree growth is not water-limited, warming could additionally expand the length of the growing season in the SW Region, but pests, diseases and fire damages may negate some gains so that declines in productivity are also possible in the future as climate change unfolds.

RESPONSE(S)

Primary producer adaptive response strategies will be strongly influenced by the frequency, duration and severity of climate extremes, not just future climate averages. Regional agriculture operates within a complex business-socio-ecological system, so planning for change will require a holistic approach. Processes which use scenarios coupled with biophysical modelling and stakeholder experience to provide such a holistic assessment have been trialled (Soste 2010). Integration across all tiers of government will be required for effective regional adaptation, but this is not yet in place (Morris *et al.* 2010).

Diversity in agricultural enterprises and regional communities plays an important role in regional wellbeing. If diversity is lost, regional resilience is lowered. Innovation plays an important role regional adaptation. Innovation will come from individuals, not agencies, but needs to be facilitated. The Policy Choice Framework can operate as a tool for integrating biophysical, social and policy research to support policy formulation and instrument choice (Morris *et al*. 2010).

As the dairy industry is Victoria’s largest rural industry, this industry was chosen as a case study to explore (1) when policy responses may be justified to assist farmers to manage heat stress in dairy cows and (2) when policy responses are justified, efficient types of policy instruments. This case study provided a practical example of how the Policy Choice Framework can assist effective and efficient program delivery (Sandall *et al*. 2010).

Landscape visualisation was an important part of the VCCAP project and in another project Pettit *et al*. (2011) have shown how the technique can assist engaging stakeholders and inform climate change adaptation.

BACKGROUND

Other agriculture statements that have relevance to Victoria include ones on wheat, rice, winegrapes, horticulture, forests (native production), forests (plantation), broadacre grazing and intensive livestock industries.

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WET TROPICS BIODIVERSITY

SUMMARY

- The rainforests of the Wet Tropics in Northern Australia are considered to be one of the most vulnerable ecosystems to climate change in Australia (Williams et al. 2003). They are predicted to experience large increases in temperature, decreases in rainfall leading to drying and an increased risk of extreme events such as fires and category 4 and 5 cyclones. As a result, the region's high numbers of endemic and specialized species are threatened by a combination of physiological tolerance responses and indirect biotic interactions.

- The responses of biota are complex. Range shifts are predicted towards higher altitudes and latitudes, which is more challenging for high altitude species. Endemic vertebrates are predicted to lose significant proportions of core environment with tolerable temperature and moisture even at an increase of 1^{o}C. Population declines for many species are predicted to occur more rapidly than their habitats, such as the Grey Headed Robin (Li et al. 2009).

- Disturbances and drying will cause a shift to early successional plant species and those that are tolerant to fire. Enhanced CO_2 will increase overall productivity but decrease digestibility and nutritional value of foliage for herbivorous vertebrates. Change in the length of the dry season will lead to altered patterns of flowering, fruiting and leaf flush affecting resource for animals (Steffen et al. 2009).

- Systematic methods are being used to identify cool habitat refugia areas to protect and restore (Shoo et al. 2011). Direct management of related threats, such as fire and invasive species will improve the resilience of Wet Tropics biota to cope with climate change. Species with barriers to migrating towards more suitable habitats may be relocated, though as yet there are no examples of this in the Wet Tropics region.

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Wet tropics biodiversity; range shifts; responses;

REGION

North Queensland

DRIVER(S)

Temperature
Rainfall
Extreme events

PRESSURE(S)

Pressure 1

The average maximum temperature in north Queensland's Wet Tropics increased by 0.76^{0}C between 1950 and 2008, the average minimum temperature by 0.79 and the overall average by 0.78^{0}C (Suppiah et al. 2009). The trend has been steady but varied amongst decades with apparently lower rates of change in the past decade. Inland areas of the region are predicted to continue to warm faster than coastal areas. Under a medium emissions scenario the best estimate of regional average temperature increase is 0.9-3.5^{0}C by 2070.

Pressure 2

Rainfall in the Wet Tropics is concentrated during January to March. Changes in rainfall are more difficult to detect and predict than temperature, but decadal fluctuations have been recorded in the region during both wet and dry seasons of the year, with the 1920s, 1960s and 1990s being dry periods and the 1970s being a particularly wet period (Suppiah et al. 2009). Future rainfall predictions show both increases and decreases in total rainfall; by 2070 rainfall may change by -26% to +18%. However it is expected that rainfall will reduce in the cloud forests and that overall seasonality of rainfall will increase. Potential evaporation will increase by up to 8% over this period, with a range from 3-14%, which will reduce water availability.

Pressure 3

Fire, frequency of severe cyclones and other extreme events are predicted to increase in the Wet Tropics under a changing climate, though the actual frequencies of these events will remain difficult to predict (Lindenmayer et al. 2010). The overall increase in temperature and the reduction in moisture availability in north Queensland's tropical rainforests will cause drying and increase the frequency of fire in the region (Russell-Smith et al. 2007; Stork et al. 2007). The increased frequency of El Niño events along the east coast of Australia are predicted to cause increases in cyclone and rainfall intensity (Hughes 2011; Stork et al. 2007). These processes can be extremely destructive, particularly if they occur over larger areas and at frequencies high enough to prevent regeneration occurring.

STATE(S)

The Wet Tropics covers an area of 1.8 million ha composed predominantly of rainforest interspersed with fire-prone sclerophyll grasslands, woodlands and open forests. The rainforests are remnants of a much broader extent of rainforests that once covered around one third of the Australian continent, which contracted due to climatic changes (Graham et al. 2010; VanDerWal et al. 2009) and an increase in the incidence of fire (Suppiah et al. 2009; Williams and Hilbert 2006). While now less than 1% of Australia's landmass, north Queensland's tropical rainforests support some of the highest numbers of endemic and specialized species in Australia. This is in part due to their historical role as refugia during periods of climatic flux (Bell et al. 2010). The importance of the Wet Tropics rainforest as refugia for biodiversity is expected to increase under a warming climate, particularly the cool, montane environments embedded in mountainous regions (Laurance et al. 2011; Shoo et al. 2011).

Climate change, particularly when interacting with other threats, is highlighted as one of the predominant causes of species declines and extinction particularly in the tropics (Hughes 2011; Stork 2010). The predominant effects of climate change on species are increases in temperature, decreases in rainfall leading to drying, increases in seasonality, particularly of rainfall, and an amplified risk of extreme events such as fires and cyclones (Lindenmayer et al. 2010; Williams and Middleton 2008). These processes affect survival, growth, reproduction and dispersal, the stability of available food (Williams and Middleton 2008), water and habitat resources, and alter a range of interactions between species (Williams et al. 2010a; Williams et al. 2008).

Current species distributions and abundance in the Wet Tropics region are closely correlated with environmental variables, such as temperature and rainfall seasonality, in many cases due to resource availability (Williams and Middleton 2008). These biota are particularly vulnerable to the effects of climate change due to their endemism, specialization, the relatively large overall and seasonal climatic changes that will occur in these areas and the lack of scope for range shifts for many species (Isaac et al. 2009; Williams and Hilbert 2006). There is a high association of endemic species to cool mountain top environments (Williams and Hilbert 2006). Barriers to range shifts include the non-existence of higher altitude suitable areas and vegetation fragmentation (while vegetation clearing is now prohibited in the region, previous vegetation loss has resulted in the fragmentation of many areas of habitat).

Population declines have been observed for many species in the Wet Tropics both globally and here in Australia, which can be partly attributed to changes in climate already experienced in the region (Colwell et al. 2008; Laurance 2008; Williams et al. 2003). Climate change causes losses in habitat extent for species and also reductions in population size in the remaining habitat. Declines in core habitat for the cool-wet forests are likely to be as much as 50% of current extent at a temperature increase of just 1^{o}C and 74% of rainforests birds are predicted to become threatened under the IUCN criteria under just a mid-range warming projection (Hilbert et al. 2004; Hughes 2011; Shoo et al. 2005a). While the Wet Tropics shows evidence of resilience to ecosystem level shifts caused by isolated extreme events, this is likely to change with environmental parameters under a warmer climate (Warman and Moles 2009).

Geographic species range shifts as a result of climate change are already evident for many species globally, but are more difficult to detect for tropical species (Colwell et al. 2008; Stork et al. 2007), however this could be an artifact of the lack of long-term data. In the tropics elevational temperature gradients are particularly steep while latitudinal shifts are slight; hence range shifts are more likely to be elevational than latitudinal. Hence, lowland biotic attrition (the decline and loss of species at lower altitudes) in the tropics is predicted to reduce species richness in lowland tropical areas at a high rate compared with in highland areas, where species richness will be replenished by the shifting ranges of lowland species to higher altitudes (Colwell et al. 2008).

IMPACT(S)

Impact 1

Declines and changes in bird species distributions are projected for the Wet Tropics as a result of climate change. Specialists have narrow ranges and are more vulnerable to climate change impacts (Garnett and Brook 2007), and high altitude species are more likely to decline whilst medium or low altitude species are more able to shift their range of occupancy (Colwell et al. 2008). For example, the Grey Headed Robin is predicted to increase at higher altitudes but decline over their current range, primarily due to temperature increases and secondarily to changes in rainfall (Li et al. 2009). Increases in rainfall seasonality are likely to contribute to declines in many species due to causing resource bottlenecks (Williams and Middleton 2008). Because both physiological and habitat responses are at play, population size declines are likely to be more significant than the reduction in habitat area, indicating that species has the potential to become extinct before its habitat is entirely lost (Li et al. 2009; Williams and Middleton 2008).

Impact 2

Declines in amphibians, particularly upland species occurring at >400m elevation which are closely dependent upon freshwater streams, have been attributed to a warming climate (Laurance 2008) but the relative importance of climate change in causing this decline is still the focus of much debate (Pounds et al. 2006 see commentary following this paper) . Many Australian frogs are threatened by a chytrid fungus and declines and extinctions have already occurred. Researchers have proposed a climate linked epidemic hypothesis, suggesting that in some contexts a warming climate predisposes amphibian species to disease because the fungus grows more virulently. Frog declines in tropical eastern Australia tend to follow three year periods of elevated average minimum (night time) temperatures, but no support has been found for an effect of elevated maximum temperatures (Laurance 2008).

Impact 3

The responses of invertebrates, such as insects, to climate change are poorly studied relative to vertebrates, but are likely to be strong due to their relatively narrow altitudinal ranges (Yek et al. 2009). Recent research shows that monophyletic flies (Dipteran sub-order Schizophora) exhibit distinct assemblages with altitude. High elevation assemblages are predicted to be at risk of local extinction with 2-3^{o}C of warming while mid elevation assemblages are at risk at slightly higher levels of warming, 4-5^{o}C (Rohan et al. 2007).

Impact 4

Changes in vegetation communities are expected but are as yet difficult to detect. Repeated increased incidence of wildfire has the potential to cause declines in fire sensitive species and a resultant increase in fire tolerant vegetation communities (Warman and Moles 2009). Early successional species are favoured over late successional species due to an increase incidence in fire and other disturbances such as cyclones (Lindenmayer et al. 2010). This shift favours vines compared with larger trees, resulting in an increased tree mortality (Hughes 2011). Plant species adapted to high altitude cool forests dependent upon regular rainfall will also decline. Warmer temperatures will increase net primary productivity in the uplands (Williams et al. 2010a) but reduce the overall palatability of foliage (Hughes 2011) as a result of raised levels of tannins and decreased nitrogen phosphorus ratio and proteins (Stork et al. 2007). This is likely to have negative effects on herbivorous vertebrates and invertebrates. Forest canopy dynamics overall are expected to change in a complex variety of ways, but as yet models have limited predictive abilities (Stork et al. 2007).

RESPONSE(S)

Response 1

Predicting and measuring species declines

A body of research has focused on methods for quantifying the potential effects of changed climate on species ranges in the Australian Wet Tropics (Shoo et al. 2005a, b; Shoo et al. 2006; Williams et al. 2003) and the baseline data for these predictions can be found in Williams et al. (2010b). It is hoped that an improved understanding of the complex interactions amongst species and their environments in the Wet Tropics will assist in directing actions to promote the survival of the flora and fauna of the region. Highland species (Rohan et al. 2007) and narrow altitudinal range endemics (Yek et al. 2009) have been suggested for monitoring risks of decline for a broader range of species in order to determine when to intervene.

Response 2

Managing existing habitat

The management of existing threats and habitat will ensure that the biota of the Wet Tropics has the greatest chance of coping with the impacts of climate change. Threats aside from climate change include habitat fragmentation, weeds, feral animals, diseases, urban development, altered fire regimes and altered water flows and drainage. The region is predominantly managed by the Wet Tropics Management Authority (WTMA) in partnership with government agencies, land managers, landholders, Traditional owners, the tourism industry, conservation and community groups, and the broader community (see www.wettropics.gov.au/mwha). A community-based natural resource management approach is advocated in order to maximise biodiversity and other benefits to the region (Hill et al. 2010).

Response 3

Predicting and restoring key refugia

One particular joint WTMA project focuses on restoring key refugia and connecting habitat fragments. It is based on a systematic methods for prioritising locations for protection and restoration to improve species persistence under climate changes in the Wet Tropics (Shoo et al. 2011). Progress is being made on brokering refuge area agreements with landholders and some restoration is under way around the Herberton Range National Park, key habitat for endemic and sensitive species, including tree kangaroos, golden bowerbirds and northern barred frogs. For more information see www.atcbiz.com.au/ems/archives.php?n=24fu69mfua&c=yc6ztkhe6r#makingconnectionstablelands.

Response 4

Assisted colonisation of species to suitable environments

For many species migration to more suitable habitats may not be possible due to geographical barriers such as cleared land. The assisted relocation of species populations to more suitable habitats is a controversial response action under consideration and may offer the only chance of persistence for some species. The policy implications of assisted colonisation for Australia have been examined by Burbidge et al. (2011). Systematic methods for deciding when, how and where to translocate populations can assist managers to maximise the success of these projects (McDonald-Madden et al. 2011).

BACKGROUND

The seriousness of potential impacts of climate change to Australia's Wet Tropics was raised by Williams et al. (2003) using correlative bioclimatic models. Since, many other factors have been considered (Williams et al 2008) and current research is working to fill these gaps. For example, there may be considerable scope for some range restricted species to utilize buffered microhabitats (Shoo et al 2010). More sophisticated modeling is now being used to estimate the physiological tolerances of various species but much of this work is still in review or has not yet been published.

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WHEAT PRODUCTION

SUMMARY

- Wheat production adaptation will be important under changing conditions.
- Wheat production in Australia is located on about 11 M ha chiefly in an arc across the mainland through temperate and subtropical regions beginning in southeast Queensland and ending in southwestern Western Australia, with a gap in the Nullabor Plain where annual rainfall is below 300 mm (Australian Bureau of Statistics 2006).
- Wheat is the major crop in Australia. Production exceeds domestic consumption on such a scale that about 74% of the wheat produced is exported. These exports contribute about 12% to the international trade in wheat and to global food security. They also earn about 4% of Australia's exports, averaging $3.1B p.a. since 1990 (ABARE 2009)
- Wheat, as well as other grain, production is likely to be impacted by combinations of higher levels of CO_2, increased temperatures and changes in rainfall, in order of diminishing confidence (Howden *et al*. 2010).
- Anwar *et al* (2007) have suggested that if practices remain the same, wheat yields in north-western Victoria over the period 2000-2070 may fall by about 25% even taking into account the positive effects of elevated CO_2. O'Leary *et al*. (2010) also predicted declines in wheat yields in western Victoria in the period to 2070 without adaptation, but also possible significant gains in wetter areas of south west and north east Victoria.
- Howden *et al*. (2010) have identified a number of adaptations including changed crop management practices, new varieties, altered rotations and improved water management. Relatively simple adaptations may be worth between $100 million to $500 million per year at the farm gate.
- While increasing temperatures and decreasing rainfalls could reduce wheat productivity and may not be fully offset by increasing CO_2 levels, practical management adaptations such as modifying the planting window and optimising varietal selection, could reduce negative impacts and even produce higher yields than present ones at some sites (Crimp *et al*. 2008a).
- Effective monitoring of change and adaptation at a range of temporal and spatial scales, along with participatory approaches across the value chain, could help reduce the risks of maladaptation (Crimp et al. 2008b; Howden *et al*. 2010).

CONTEXT

The comments above are mainly based on the Howden *et al*. (2010) review paper that considered impacts on and adaptations for Australian wheat production sector as part of a general review of grain production and climatic change adaptation in Australia. The O'Leary *et al*. (2010) paper was a conference paper. The Crimp *et al*. (2008a) paper was a contribution to the Garnaut report and the Crimp *et al.* (2008b) report was for the Department of Climate Change. Other information is from peer-reviewed journal articles such as Anwar *et al*. (2007) and Lobell *et al*. (2011).

EVIDENCE

Projected Impact

CATEGORY(S)

Production systems: Food

REGION

Queensland
New South Wales
Victoria
South Australia
Western Australia
Tasmania

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Solar Radiation
Extreme and variable weather patterns
Soil moisture

PRESSURE(S)

In terms of long term averages, increasing temperatures and decreasing rainfall with significant regional variations are expected across the whole of the Australian wheat belt in the period to 2100 (CSIRO/BoM 2007).

Atmospheric CO2 levels will increase in the period to 2100. Actual levels reached by 2100 will depend on the effectiveness of measures to manage global emissions (Solomon *et al*. 2007).

Climate change will interact with increasing domestic wheat consumption to strongly reduce wheat surplus for export. In the event of the worst case climate change scenario, assuming no effective adaptation and high population change, Australia could become a net importer of wheat as soon as 2050. At 2070, if there is no effective adaptation to climate change, there is a 26% chance of Australia having to import wheat to meet domestic demand (Howden *et al.*, 2010a). The worst case scenario for 2070 is that Australia could become a net importer of 15Mt/year of wheat (Howden et al., 2010a). This is approximately the same amount as Australia currently exports. Under a moderate climate change scenario the combination of demand and climate change may result in a small surplus to export (2.5Mt/year). When practical adaptations to climate change are introduced into the analysis, the chance of becoming a net importer of wheat in 2070 is reduced to 10% (Howden *et al*., 2010a).

STATE(S)

Australian average temperatures have increased by 0.9°C since 1950, with significant regional variations (CSIRO/BoM 2007).

IMPACTS)

Tubiello *et al.* (2007) have reviewed crop responses to climate change including plant response to elevated CO_2 concentration, interactions with climate change variables and air pollutants, impacts of increased climate variability and frequency of extreme events, the role of weeds and pests, disease and animal health, issues in biodiversity, and vulnerability of soil carbon pools. They concluded knowledge of the likely responses of grains, including wheat, has greatly improved, but there are still challenges in scaling this knowledge to the field and regional scales.

Anwar *et al*. (2007) used low, mid and high emissions scenarios to generate daily climate datasets for the period 2000-2070. The CropSyst version 4 model (Stockle and Nelson 2001) was used to predict wheat yields for Birchip in north-western Victoria. Increasing temperatures are expected to shorten phenological stages, reducing time available for light and water capture. Expected decreases in rainfall will reduce water availability. Accelerated crop development and a short grain filling period will reduce grain yield. Though some positive effects on yield of doubling CO2 have been observed, these did not make up for yield losses when plants were grown at high temperatures that caused stress and a shortening of the grain filling period (Mitchell *et al*. 1993).

O'Leary *et al*. (2010) expected significant impacts on wheat yield in Victoria. Scenarios of reduced rainfall could produce yield reductions of 10-30% in the semi-arid north, though there are possible yield increases of around 10% for short-season crops sown early. Significant gains from +10 to +30% (0.7 to 1.8 t/ha) were also seen in the wetter areas of the south west and north east from the Mid- and Long-season crop types from 63% to 96% of the wetter areas.

Understanding the impacts of climatic and atmospheric changes on Australian grain production systems should improve as the results of the Australian Grains Free Air Carbon Dioxide Enrichment (AGFACE) trials become available (Mollah *et al*. 2009).

RESPONSE(S)

Howden *et al*. (2010b) have described adaptation options for grain production to deal with projected climate change. These include varietal change, species changes, planting time variation, crop management (spacing, tillage, fallows, rotations, irrigation), nutrient management change (fertilisation and rotations), erosion management, salinisation management, moisture conservation, use of seasonal forecasting, irrigation, monitoring and evaluation, management of pests, diseases and weeds, research and development and education, land use change (infrastructure, knowledge base), as well as financial institutions and trade. Many of the adaptations required are extensions of those currently used for managing climate variability (Howden *et al*. 2007).

Howden *et al*. (2010a) examined how climate change, population growth and consumption patterns could interact to affect wheat exports from Australia both negatively and significantly. Many farm-level adaptations to existing systems that could bring substantial benefit in the early stages of climate change. However, these benefits tend to plateau with larger degrees of climate change (approximately above 2^{o}C), requiring more transformational changes to agriculture. These transformations may include change in land use, change in location of agricultural activities or increased diversification of income streams.

While existing models can show some of the potential benefits of adaptation (e.g. Crimp *et al*. 2008a, b) improved models are needed to provide more reliable projections of the impacts of climate change. These should be based on experimental data concerning: (i) the role of extreme climatic events, (ii) the interactions between abiotic factors and elevated CO_2, (iii) the genetic variability in plant CO2 and temperature responses, (iv) the interactions with biotic factors, and (v) the effects on harvest quality (Soussana *et al*. 2010)

BACKGROUND

Australian wheat production at 21.7m metric tonnes (2009) is about 3% of the global total (see faostat.fao.org web site). Useful information about climate change impacts and adaptation is being contributed from other major producers, such as the United States and European Union.

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WINEGRAPE PRODUCTION

SUMMARY

- Winegrape production in Australia is already adapting to changing climates
- Wine growing regions in Australia are located mainly between 30°S-40°S in Mediterranean and cool-temperate climates (Webb et al 2010)
- A warmer climate will hasten phenological development, so that ripening will occur earlier in the season (Webb *et al.* 2011, Webb *et al*. 2007a, Webb *et al*. 2010).
- Warming conditions will tend to change the chemical composition of grapes (Cozzolino *et al*. 2010).
- With increasing evapotranspiration, water requirements are likely to increase, while rainfall and associated runoff to water storages are likely to decrease (Webb *et al*. 2010).
- The harvesting and processing period is likely to be compressed requiring possible changes to winery infrastructure and staffing (Webb *et al.* 2011, Webb *et al*. 2010).
- In most cases, quality of existing mainstream winegrape varieties will be reduced if no adaptation measures are implemented (Webb *et al*. 2008, Webb *et al*. 2010, Hall & Jones 2009).
- Some adaptation in the form of shifting to cooler sites is already taking place and will alleviate warming impacts (Webb *et al*. 2010, Smart 2010).
- Within existing regions, present varieties can be replaced with 'later season' varieties to compensate for warmer temperatures and compressed phenology (Webb *et al.* in press).

CONTEXT

The main source of information was the review chapter by Webb *et al.* (2010), which cites more than 110 references, supplemented by information mainly from peer-reviewed journal papers (e.g. Cozzolino *et al*. 2010).

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Production systems: Food

REGION

South Australia
New South Wales
Victoria
Western Australia
Tasmania
ACT

DRIVER(S)

Temperature
Precipitation
Atmospheric CO_2
Soil Moisture

PRESSURE(S)

Hall and Jones (2009) have analysed likely future temperature changes across Australian wine regions. The greatest change in GST (grapevine growing season temperature, above the 1971-2000 mean) was modelled to occur for the Perth Hills region, increasing by 1.0 degrees C by 2030, 1.9 degrees C by 2050 and 2.7 degrees C by 2070. The least change in GST was modelled to occur for the Kangaroo Island region, increasing by 0.5 degrees C by 2030, 0.9 degrees C by 2050 and 1.3 degrees C by 2070. Of the 61 recognised wine regions, a median GST of over 21°C (an indicator of the limit of quality wine grape production conditions) was found for three regions for the period 1971–2000, for eight regions for the 2030 scenario, 12 regions for the 2050 scenario and 21 regions for the 2070 scenario.

STATE(S)

Average temperature changes across winegrape growing regions have been generally consistent with Australian trends that have increased about 0.9°C since 1950. This is coincident with observed trends to earlier grapevine maturity (Webb *et al.* 2011). However, occasional heatwaves have increased concern about future climate changes (Hook 2008, Hayman *et al.* 2009a, Grace *et al*. 2009, Webb *et al.* 2010,).

IMPACT(S)

Webb *et al*. (2010) have reviewed impacts on winegrape production focussing on the impacts of temperature increases on development, CO_2 increases on growth, water balance changes particularly on irrigation requirements as well as frost and fire. Webb *et al*. (2007b) suggested that temperature changes may reduce the area suitable for viticultural production by 40% by the year 2050 (see also Hall and Jones 2009). Bindi *et al*. (1996) predicted a 35% increase in fruit yield with CO_2 increase from 350 ppm to 700 ppm. Annual rainfall totals for most of the grape growing regions are likely to decrease by 2-10% by 2030 and by 5-20% by 2070 (CSIRO and Australian Bureau of Meteorology 2007). Warmer conditions may reduce frost risk, but warming conditions will also result in earlier budburst, so frost risk may not be reduced.

RESPONSE(S)

Webb *et al*. (2010) have reviewed adaptation options for dealing with current temperature and rainfall variability. Maintaining well watered vines is the main option to reduce heat stress (Webb *et al.* 2010). Improved watering strategies have been developed to reduce costs as well as to reduce the impacts of droughts. Webb *et al*. (2010) have also reviewed adaptations for dealing with projected climate change. Adaptations to temperature increases include changing vineyard situation, variety selection and management strategies including pruning. A step-by-step guide has been produced for growers to take stock of their regional assets and their vineyard susceptibility to climate change, with options and actions to mitigate risk suggested (Hayman *et al.* 2009b). Methods for communicating to farmers have also been explored where the growers' own knowledge of climate variability is used (Hayman & Alexander 2010).

Adaptations to increased temperature may also include winemaking changes (e.g. possible need to reduce alcohol levels) and forecasting to match changed winegrape intake to winery capacity. The effects of elevated CO_2 will need to be monitored closely with particular attention to yield and its components. Adaptations may be necessary to deal with changing pest and disease risks.

Jones *et al*. (2010) have examined impacts of climate change in 2020, 2030 and 2050 on Australian tourism using the Margaret River region of WA as an example. Local respondents placed less emphasis on obtaining outside resources to support adaptation strategies and more emphasis on the provision of information and guidance to the local community.

A review has been undertaken of the genetic envelope of the winegrape vine in relation to adaptation to climate change, discussing both genetics, breeding, varieties and rootstocks (Webb *et al.* in press).

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AGRICULTURE-DEPENDANT COMMUNITIES

SUMMARY

- The combined and interacting influence of climate change and variability, mainly through temperatures and rainfall changes, are projected to adversely affect the Australian agricultural sector.

- Impacts, including land use changes, reduction and improvements in forage production, loss and improvements in agricultural productivity and flow-on effects on incomes, employment and the wellbeing of agricultural communities, are likely to be experienced differently across Australian regions.

- Short term and long term adaptation responses, including research and development, innovation adoption incentives and the diversification of crop varieties and rural livelihood sources are likely to reduce the impacts of climate change.

CONTEXT

This statement is compiled from the published literature

EVIDENCE

Projected Impact

CATEGORY(S)

Social well-being and security: Livelihoods

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Extreme and more variable weather patterns

PRESSURE(S)

The combined and interacting influence of climate change and variability, mainly through temperature and rainfall changes, are projected to adversely affect the Australian agricultural sector (Nelson et al. 2010, Gunasekera et al. 2008).

CSIRO and Bureau of Meteorology (BoM) (2007) using Global Climate Models projected increases in average temperatures ranging from 0.7 - 0.9°C and 1 - 1.2°C in coastal and inland Australia by 2030 respectively, which increases exposure of agriculture to climate change and variability. Overall increases of 1- 5°C (depending on region and emissions scenarios used) are projected by 2070.

Net changes in precipitation are not as great as temperature; however, it would vary more across regions. For example, CSIRO and BoM (2007) projections indicated little change in precipitation for the northern monsoonal climates, but up to 10% decreases for the southern areas by 2070 based on 1990 levels. The MP1-ECHAM 5 climate model also projected lower rainfall for the south-west Western Australia, south-east Queensland and Victoria for the A1F1 scenario by 2030 (Nelson et al.2010).

Year to year rainfall variability between seasons will exacerbate the pressure on agriculture. For example, winter and spring rainfall decreases of up to 40% are projected for the south western parts of Australia by 2070, while 40% and 80% more drought months are projected for eastern and south western Australia respectively (CSIRO and BoM, 2007). In addition, the projected patterns of rainfall characterised by heavy rains followed by longer exceptionally hot and dry periods resulting in moisture stress on plants, will exacerbate the effects of drought on agriculture.

The expected increase in magnitude and frequency of El Niño related events is also expected to increase the exposure of agriculture to extreme weather events. Increased La Niña events are expected to result in increased yield of some crops by bringing in more rainfall; however, it may also increase the incidence of flooding, waterlogging and diseases (Bureau of Meteorology 2010, Howden et al. 2008).

The environmental pressures are further compounded by issues such as rural-urban migration, which exacerbates skills shortages (Davies 2007), shifts in costs and availability of energy , water, fertilizer (Keating and Carberry 2011), and increasing demand for non-food services from agricultural land (Herzog 2005).

STATE(S)

State 1 Productivity

Australia has experienced increased agricultural production attributed to improvements in productivity (efficiency of converting inputs into outputs) averaging 2.8 % between the 1987-88 and 2007-08 seasons (Nossal and Gooday 2009). These levels of agricultural productivity exceeded the Australian market level average of 1.4%. However, productivity has been growing at a decreasing rate in recent years, partly attributed to the changing climate (Nossal and Sheng 2010).

While the agricultural sector has shown strong productivity growth in the last two decades, seasonal variability in rainfall and droughts have, in part, resulted in significant declines in seasonal productivity, particularly in recent years. Broad acre productivity grew 2% each year between 1977-78 and 2000-01 cropping seasons, after which growth began to fall by an average of 1% per year (Nossal and Sheng 2010). These changes are, in part, attributed to increasing prevalence of drought in the recent years, which has caused sharp declines in outputs and yields (Sheng et al. 2010).

State 2 Farm Income

There have been mixed results in financial performance of the agricultural sector since 2006, closely linked to climate variability. For example, the 2006-07 season was associated with a record low financial performance (e.g. Australian average farm business profit of $49 610 and rate of return of -0.4%), which reflected the pressure exerted by the widespread and prolonged drought during this season (Martin et al. 2010).

Average farm cash income for broadacre farms increased by 18% in 2008-09 from the 2007-08 average of $64 220 as climate conditions became more favourable. However, average farm cash income for dairy farms declined by 32% in 2008-09 from an average of $129 310 in 2007-08.

The average rate of return for Australia broadacre industries was -0.4%. 0.8% and 1% in 2006-07, 2007-08 and 2008-09 respectively (Martin et al. 2010, Hooper et al. 2008).

State 3 Employment

Agricultural employment has falling due to foregone production resulting from the negative effects of extreme weather events. The number of people employed in the agriculture sector fell by 16% in 2007-08 season from 430 000 persons in 1966-67 season; attributable in part to short term factors, such as drought, and long term factors, such as the capitalisation of the sector (Productivity Commission 2008).

State 4 Demand for Financial Assistance

Extreme weather events increased the demand for farm financial assistance. For example, in 2007-08 season around 29 000 farmers in drought declared areas received exceptional circumstances relief payment under the Exceptional Circumstances Relief Programmes at the cost of about $380 million (more than double the amount in 2002-03), while interest rate relief for farmers under similar circumstances exceeded $620 million in the same period (Productivity Report 2008).

State 5 Farm Debt

Debt servicing ratio (DSR) (proportion of farm cash income needed for debt interest payments an indicator of the farmers' ability to maintain debt payments) has shown an upward trend since 2001-02, with sharp rises recorded in 2002-03 and 2006-07, attributed to increasing farm debt as farmers have had low incomes due to adverse climatic conditions (Martin et al. 2010). Slight declines in DSR were experienced in 2007-08 and 2008-09 as climate conditions became favourable to agriculture and the consequent improvements in farm cash income, and the interest subsidies received under the exceptional circumstances relief.

IMPACT(S)

Impact 1: Land Use

Climate change is projected to have negative impacts on land suitability for the production of crops. Pelizaro et al. (2010) projected a change in land use suitability away from grain production to pasture production by 2050, using scenario A1F1, for the south west region of

Victoria and assuming no adaptation or mitigation of climate change. The study showed an increase in pasture land from 43% to 70% by 2050. The land suitable for wheat cropping is projected to decline 50% by 2050, compared with the suitable land in 2000, while 7% of the land will become unsuitable for all the agricultural crops analysed.

Impact 2: Forage Production

AussieGRASS simulations showed that a 5 – 20% decline in rainfall would result in the reduction in forage production of up to 40% in south east Australia and coastal Western Australia (McKeon et al. 2009). Mckeon et al. (2009) simulated climate change impacts on forage production and showed that an increase in temperature of up to 3°C would decrease forage production by 21%.

Nelson et al. (2010) also indicated that, using the A1F1 scenario, reductions in rainfall would result in pasture growth declines of more than 7% in 2030 for 10% of the regions, using the MP1-ECHAM5 climate model. However, increasing temperature could potentially increase the length of the growing season for pastures in the cooler southern parts of the country (Stokes et al. 2007). Nelson et al. (2010) projected pasture growth to increase by about 4% in 10% of regions across Australia by 2030, under the A1F1 scenario arguing that the declining rainfall will be offset by temperature changes, CO_2 and frost incidences combining to influence pasture growth.

Impact 3: Crop Productivity

Gunasekera et al. (2007) projected declines in the Australian production of major agricultural commodities due to changes in climate conditions using ABARE model. Wheat, beef, sheep meat, dairy and sugar are expected to decline by 9.2%, 9.6%, 8.5%, 9.5% and 10% respectively by 2030. Further declines in all agricultural produce are projected by 2050, ranging from 13%-19% (Gunasekera et al. 2007).

Impact 4: Agricultural Exports

With no climate change mitigation, loss in productivity is projected to negatively impact Australian agricultural exports. For example, sugar exports are projected to experience declines of up to 63% and 79% by 2030 and 2050 respectively (Gunasekera 2007). Beef exports are also projected to suffer major declines of 29% and 33% by 2030 and 2050 respectively.

Impact 5: Farm Income

The resulting effects on farm incomes is regionally differentiated with more income variability in northern Australia and some wheat-sheep zones of south west Western Australia and eastern Australia than southern Australia and in regions where extensive grazing dominates (Nelson et al. 2010). Farm incomes are projected to fall by more than 5% by 2030 in areas consistent with declines in rainfall, such as western Victoria and south-west of Western Australia. This is in sharp contrast to projected farm income increases in Tasmania and across central and southern Queensland. In addition to the changing climate, high income variability within the farming communities is also attributed to urbanisation and subdivision of farms particularly for coastal farming communities resulting in the reduction in farm sizes with the consequence of declining terms of trade (Nelson et al. 2010). The impacts of loss in agricultural income sources will be more severe in inland Australia in areas where alternative livelihood sources are limited.

Impact 6: Employment and Individual Income

Loss of employment and the consequent loss of income during droughts have been identified as a cause of financial hardship and the flow-on effects of such hardships will be psychological stress and mental health related problems for the already isolated agricultural communities (Sartore et al. 2008).

Edwards et al. (2009) estimated the economic well-being of people in drought and non-drought affected areas and showed an employment rate of about 83% in areas not affected by drought and 79% in areas with below average rainfall. The study also showed that households in drought affected areas were experiencing about 12% more financial hardship than in non-drought areas. Farmers were more likely to experience financial hardship than other groups within the farming communities with 47% of farmers having suffered financial hardship during droughts compared to 32%, 25% and 40% for farm workers, employed but not in agriculture and not employed community members, respectively.

A qualitative study on the effects of drought on farming communities involving interviews with farmers, farm business people and health workers reported all experienced significant emotional distress from financial hardship, which included loss of hope for the future and the consequent increased risk of mental health problems (Sartore et al. 2008). Edwards et al. (2009) further showed that financial hardship increased mobility out of drought prone areas, which was shown to be higher by up to 3% than non-drought areas.

RESPONSE(S)

Response 1: Research and Development

Increasing investment in research and development (RandD) provides an opportunity for advancing agricultural technologies, including the development of high yielding products adapted to the changing climate, which consequently improve productivity. ABARE modelling showed that adaptation strategies to improve agricultural productivity would reduce projected economic impacts of climate change on agriculture by 50% (Gunasekera et al. 2008).

The strong productivity registered in the agricultural sector in the last two decades has largely been attributed to favourable weather conditions, particularly in the 1990s, and rapid advances in technology, including high yielding crop varieties (Nossal and Sheng, 2010, Nossal and Gooday 2009, Liao and Martin 2009). However, RandD public expenditure growth has been declining to levels not matched by the increasing private investment in RandD (Nossal and Gooday 2009). The declining public RandD expenditure has been partly attributed to the slowing growth of agricultural productivity (Nossal and Sheng 2010). There is therefore need for continued focus on research and innovation across the agricultural sub-sectors including funding for breeding programmes, agricultural biotechnology, cropping systems management and further research in productivity and adaptation modelling in little studied subsectors such as horticulture, viticulture and dairy (Pearson et al.2008, Howden et al. 2008, Stokes et al. 2008).

Response 2: Innovation adoption incentives

While Research and Development may result in innovations that improve agricultural productivity, their adoption by farmers is not always guaranteed. This has resulted in calls for government policies that stimulate adoption of adaptive strategies, including improving labour skills, education, public health improvements, communication infrastructure, creation of new agricultural markets and regional economic diversification (Nelson et al. 2009, Nossal and Gooday 2009). The net adoption will ultimately depend on the benefits to farmers and economic incentives such as subsidies for the adoption of new innovations (Gunasekera, 2008).

Response 3: Farm level adaptation

Short term adaptation strategies commonly recommended, drawing from literature (e.g. Gunasekera et al 2007) and a survey of top grain farmers (Howden et al. 2008), include diversification of crops, altering planting to the changing seasons, changing crop management strategies (e.g. use of short season leguminous crops, manipulating crop cover and increasing crop residue during periods of high risk to manage erosion and soil moisture), salinization management, on-farm rainfall capture and storage, altering livestock breeds, pasture management (e.g. manipulating rotation lengths by increasing the use of legume based pastures), managing stocking rates, and increased use of insurance. Long-term strategies include the diversification of livelihood sources, non-farm asset investments and migration.

Response 4: Embracing predicted land suitability and use changes

In the event of the realisation of climate change scenarios, it may be necessary to embrace the predicted land suitability changes with governments managing the transitions, taking into account the potential negative environmental, economic and social implications including the potential for conflict (Stokes et al. 2008, Howden et al. 2008).

BACKGROUND

Australian agriculture has traditionally been dominated by extensive pastoral (e.g. broadacre grazing) and cropping activities (e.g. broadacre farming), which include wheat, oats, barley, beef cattle and sheep production (Productivity Commission 2009). Dairy farming, irrigated cropping and horticulture constitute a significant part of agricultural production. While agriculture constitutes only 2% of the total gross domestic product in Australia, it constitutes 18% of the total Australian exports with 60% of agricultural produce being exported (see Gunasekera et al 2007). Key exports include wool, beef and veal, mutton and lamb, wheat and sugar. In 2005-06, 82% of agricultural output was generated by 30% of the largest farms while 7% was generated by 50% of the smallest farms reflecting a high concentration of output from large farms (Productivity Commission 2009).

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COASTAL POPULATIONS

SUMMARY

- Australia is characterised by densely and increasingly populated urban coastal areas.
- About 80% of Australian population are located within 50kms of the coast
- With a sea level rise of 1.1m by 2100, between 187,000 and 274,000 residential buildings are potentially exposed to inundations and shoreline recession.
- Between 9,500 and 14,800 commercial and light industrial buildings, and between 27,000 and 35,000 of roads and rail are likely to be at risk to the combined effects of inundation and shoreline recession at sea level rise of 1.1m associated with 1-100 year storm events.
- Adaptation strategies have targeted early warning systems, effective emergency response, coastal planning, flood-mapping and relocation.

CONTEXT

This statement is compiled from published scientific papers and reports

EVIDENCE

Projected Impact

CATEGORY(S)

Social well-being: Livelihoods

REGION

Australia

DRIVER(S)

Temperature
Extreme and more variable weather patterns
Sea level rise

PRESSURE(S)

The combined and interacting influence of climate change and weather variability, mainly through temperature increase, sea level rise, extreme events (including cyclones), stronger winds and storm surges are projected to adversely affect Australian coastal communities through repeated short and long term disruption to physical infrastructure, social fabric, and interruption and loss of services (DCC 2009, Wang et al. 2010).

CSIRO and Bureau of Meteorology (BoM) modeling, using Global Climate Models (2007), projects coastal average temperatures to increase by 0.7 - 0.9°C by 2030, which potentially increases exposure to heat waves. A "higher end" sea level rise scenario of 1.1m by 2100 is widely adopted in Australia (e.g. DCCEE 2011, Climate Commission 2011). One-in-100 year inundation events are projected to occur several times every year under the high end sea level projections by 2050. More intense, but possibly fewer cyclones, are predicted for north Queensland (QCCCE 2010). Similarly, simulations of extreme rainfall, thunderstorms and large hail events showed rising intensities (CSIRO and BOM, 2007).

The extent of the impacts related to extreme weather events on the coastal populations is exacerbated by the increasing population of the potentially vulnerable groups such as the aged, low income earners, lone person households and one parent households (Australian Government 2010, Roiko et al. 2011). In south east Queensland, the population of single-occupancy households has been projected to double, while one parent households will increase by 60% (Roiko et al. 2011) by 2031.

STATE(S)

Many commercial buildings located in coastal Australia are exposed to sea level rise and extreme weather events, with projected high economic consequences. For example, 258 police, fire and ambulance stations, 102 nursing/retirement homes, and 170 industrial zones are within 200m of the Australian coastline, while 2795 bridges, 992 universities, colleges and schools, 199 hospitals and health services, 35 emergency services facilities and 11 power stations are within 500m of the Australian coastline in 2008 (Geoscience Australia 2009 in DCC 2009). In South East Queensland alone, an estimated 70% (68,000) and 90% (87,000) of commercial buildings are located within the 5km and 10km of the tidal zone respectively, while 80% of educational buildings, 28% of the 37 000kms of roads and 20% of the 932 km of rail are located within 5km of tidal zone (Wang et al. 2010). Between 9,500 and 14,800 commercial and light industrial buildings, and between 27,000 and 35,000 of roads and rail are likely to be at risk to the combined effects of inundation and shoreline recession at sea level rise of 1.1m associated with 1-100 year storm events. (DCCEE 2011). The Insurance Council of Australia (2008) estimated that there were 170,000 homes in Australia at high flooding risk, where insurers will not accept the risk level.

IMPACT(S)

The Australian coastal population is increasingly exposed to the impacts of climate change. About 80% of the Australian population is located within 50kms of the sea coast (Australia Government 2010). Chen and McAneney (2006) also estimated that about 50% of Australian addresses were located within 7km of the shore, with a marked decline in population as the distance from the shoreline increases[1]. Mainly using the digital elevation model (DEM) for the national assessment of potential coastal inundation and shoreline recession, 187,000 – 274,000 residential addresses were potentially exposed to inundation and recession with a sea level rise of 1.1m associated with 1-in-100 year storm events (DCCEE 2011).

Infrastructure damage and costs of replacement

High adaptation costs due to the increased exposure of coastal populations and infrastructure to hazards linked to climate change (e.g. storm surges, and coastal flooding) have been recorded in Australia (e.g. Apan et al. 2010, Queensland Government 2011). The replacement costs of coastal residential and commercial infrastructure exposed to the risk of inundation and shoreline recession with a sea level rise of 1.1m associated with a 1-in-100 storm tide was estimated to be over $226 billion, based on 2008 replacement value (DCCEE 2011). Residential addresses constituted between $51 and $72 billion dollars of this amount. New South Wales alone accounted for between $14 billion and $20 billion in replacement value of residential buildings (DCCEE 2011).

Costly infrastructure damages are experienced across Australia every year. The Queensland Government estimated total damage to public infrastructure alone to be between $5 and $6 billion as a result of the 2011 Queensland floods (Queensland Government 2011). In 2006, cyclone Larry, characterised by wind gusts of up to 240km/hr (category 4), and flooding of coastal rivers in north east Queensland, caused significant damage to infrastructure and crops worth an estimated total cost of $1 billion and $540 million worth of insurance claims (Insurance Council of Australia 2009). In the 2007 Newcastle flooding event, 5,000 cars were written off and 10,000 properties inundated (BMT WBM, 2009). Infrastructure damages worth $234 million were experienced in the 2008 heavy rainfall events that flooded about one million square kilometres in Queensland (Queensland Government 2009). In Mackay alone during the 2008 Queensland floods, schools and the Mackay airport were closed, and about 4000 homes were damaged, while more than 6000 homes lost services, such as power and telephone communications (Apan et al. 2010). As a result, assistance worth over $4 million was provided to almost 7,000 families through the Natural Disaster Relief and Recovery Arrangements (NDRRA) grants and a further 410 million was paid in insurance claims (Apan et al. 2010).

Community livelihood sources

Loss of coastal population livelihood sources is likely to result from climate change. Extreme weather events are likely to impact employment opportunities due infrastructure loses and damages, and the related changes in industrial viabilities (Stanely 2010); for example, changes in fish stock or agricultural productivity due to weather variability is likely to affect the fish and agricultural industries.

Living conditions

Net heat-related deaths in coastal populations are likely to increase with rising temperatures. For example, the annual heat-related death rate for people over 65 is estimated to rise from 82 per 100,000 in 1999 to 131 per 100,000 by 2100 in Australian

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[1] Chen and McAneney (2006) estimates are based on statistical and spatial relationships between very fine resolution Australian data sets and the recent high resolution global data sets on ambient population distribution (LandScan2003), shorelines (GSHHS) and elevation (SRTM).

capital cities (Woodruff et al. 2005 p. 21). Existing health issues will be exacerbated, while new health issues e.g., vector-borne diseases, are likely to emerge due to changing climate conditions.

RESPONSE(S)

Response 1: Coastal planning and emergency management

The combined challenges of increasing coastal urban growth and the increasing frequency and magnitude of projected climate change related impacts will require coordinated coastal planning (Norman 2010). The resultant plans will include regional and local proactive plans that enable integrated management of urban growth to account for climate change related risks, and emergency management to minimise the vulnerability of coastal communities.

Norman (2010) recommended the financing of the transition to a low carbon resilient built environment, including the development of the skill base to support such an environment. This included continued support of national, regional and local institutions that provide timely and informed advice to support sustainable coastal planning and adaptive management (e.g. the National Coastal and Climate Change Council, and Sydney Coastal Councils).

Engineers Australia (2008) recommended the inclusion of engineers in governance arrangements, including the planning for coastal adaptation to the impacts of climate change, to maximise the scope of engineering perceived vital for many adaptations necessary in coastal communities.

Response 2: Improving disaster preparedness, mitigation, response and recovery arrangements

The increasing frequency of extreme weather events will require further support of disaster mitigation preparedness, response and recovery arrangements. Effective and efficient early warning systems are recommended for disaster preparedness and management. The House of Representative Committee (2010) recommended improvement to early warning systems for Australian coastal areas, including improved data on coastal risk assessment and vulnerable coastal sites. Other response and recovery issues, included funding natural disaster mitigation projects (e.g. community education and awareness campaigns, land use planning that accounts for the risks of climate change, research) in the Australian coastal zone, and improved access and evacuation routes for coastal communities (House of Representatives Committee, 2010).

BACKGROUND

Australia is a highly urbanised society. Urban areas, constituting 100 000 people or more, account for 75% of the total population with high population concentrations in the five major cities – Sydney, Melbourne, Brisbane, Perth and Adelaide (Australian Government 2010). The areas of high population concentration are within the coastal zone and include commercial activity (including exports and imports) (Bambrick et al. 2011). The Australian population, currently 22 million, is projected to grow to 35.9 million by 2050, with the coastal major cities becoming home to the majority of the population (Attorney-General's

Department 2010). Population growth has been attributed to net overseas migration, which accounted for 60% of the growth experienced in 2007-08 (Australian Government 2010).

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FIHERIES AND AQUACULTURE DEPENDENT COMMUNITIES

SUMMARY

- Climate change is projected to bring both opportunities and challenges to the fisheries and aquaculture sector, but overall it will pose significant risks to this sector's sustainability, leading to threatened livelihoods and dependent communities.

- Both positive and negative impacts are expected, with impacts varying according to changes in the regional environment: south-east fisheries are most likely to be affected by changes in water temperature, northern fisheries by changes in precipitation, and western fisheries by changes in the Leeuwin Current.

- Atlantic salmon are cultivated close to their upper thermal limits for optimal growth during hot summer months, presenting challenges for the Tasmanian salmon aquaculture industry. However, warming temperatures will favour productivity during colder months. There have also been declines in rock lobster stocks in Tasmania attributed to warming temperatures and the enhanced southerly extension of the East Australian Current (EAC).

CONTEXT

This statement based on a report *Implications of climate change for Australian fisheries and aquaculture* (Hobday et al 2008) and published scientific papers and reports

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Social well-being and security: Livelihoods

REGION

Australia
Australian Antarctic Territory

DRIVER(S)

Temperature
Precipitation
Water CO_2
Solar radiation
Ocean currents
Extreme and variable weather patterns

Sea level rise

Sea ice and snow cover

PRESSURE(S)

Fisheries will be affected by climate change differently according to the physical changes in the regional environment and life histories. For example, south-east fisheries are most likely to be affected by changes in water temperature, northern fisheries by changes in rainfall and western fisheries by changes in the Leeuwin Current (Hobday et al. 2008).

Warming temperature may reduce production efficiency of key cool-water farmed species, and also increase the incidence of diseases. Altered precipitation patterns will change salinity, nutrient and suspended sediment levels of coastal waters with implications for coastal aquaculture (Hobday et al. 2008). Viable regions for aquaculture will shift, depending on species. Catches of prawns, barramundi and mud crabs are related to summer rainfall and may be adversely affected through changes in rainfall patterns and abundance. Tropical tuna will likely be found further south along the east coast of Australia.

Change in the physical ocean climate in eastern Tasmania and parallel shifts in species' distributions and ecological processes have precipitated cascading effects of ecological change in benthic (rocky reefs) and pelagic systems (Johnson et al. 2011). The result of these scenarios would be the loss of production both from wild harvest and aquaculture as well leading to financial and unemployment threats to the people dependent for their livelihoods on marine species harvest. Squid may grow faster, mature earlier, and require more food resources.

STATE(S)

The Australian Fishing Zone (AFZ) is one of the largest in the world, ranging from Torres Strait in the far north to waters adjacent to continental Antarctica, and from Lord Howe Rise in the east to Christmas Island in the west (Hobday et al. 2008). The gross value of Australian fisheries production was estimated to be A$2.12 billion in 2005-06, of which about 35% is from the aquaculture industry (ABARE 2007). Rock lobster, prawns, abalone and tuna are the most valuable fisheries, accounting for 55% of Australia's gross value of fisheries production in 2005-06. The Australian Government-managed fisheries contributed 13% of fisheries production, with major fisheries being the Northern Prawn, Southern Bluefin Tuna and the South East Trawl and Non-trawl Fisheries. Western Australia has the largest gross value of production accounting for 29% of total state fisheries production followed by Tasmania (22%) and South Australia (22%) (ABARE 2007).

In south eastern Australia the human population is strongly concentrated in coastal urban areas (Australian Bureau of Statistics, www.abs.gov.au). Fisheries in the region are among the most productive in the country, with New South Wales, Victorian and Tasmanian state waters together yielding ~33% (by value) of the total production of Australian state-based fisheries in 2008–09 (ABARE, 2010). Of individual states, Tasmania had the largest gross value of fisheries production (AUD$522.2 M), accounting for 23% of total Australian fisheries production (ABARE, 2010; Johnson et al. 2011). Tasmania's two most valuable fisheries are blacklip abalone (*H. rubra,* valued at ~AUD$100M pa before processing; Tasmania supplies

~30% of the global wild caught abalone market), and southern rock lobster (~AUD$70M pa; ABARE, 2010; Johnson et al. 2011).

Climate change is likely to affect all industrial fishers and processors due to changes in the location of fishing sites, with vessels spending several months of the year inside a national EEZ, as fish move to the high seas, or to an adjacent EEZ. This movement has implications for licensing of foreign fishing vessels and tuna canneries using local suppliers. The threats to fish availability will have implications for past and future capital investment, and labour requirements. Fishery governance systems need to be aware of potential climate change impacts on annual catches and the location of fish schools, increasing the variability in an already complex system (McIlgorm et al. 2010).

In the 2006 annual report on the state of Australia's fisheries, the Australian Bureau of Rural Sciences (ABARE 2007) classified 19 of the 97 stocks assessed as either overfished and/or subject to overfishing, 51 as status uncertain, and 27 as not overfished. The high proportion of stocks classified as uncertain reflects the addition of new stocks not previously classified and the revised classification of some stocks for which assessments were previously thought to be more reliable. The high proportion of uncertainty, especially considering the addition of cumulative pressures associated with a changing climate, highlights the need for reliable assessment information and a growing understanding of complex relationships between fisheries stocks and climate.

The aquaculture industry has been growing steadily; the value of Tasmanian salmon aquaculture increased to A$221 million in 2005-06 (a 65% increase from 2004-05) and new aquaculture industries for abalone and barramundi are expanding rapidly (ABARE 2007). This sector would also be challenged by a changing climate, particularly given the projected sea surface temperature warming hotspot off southeast Australia (Cai et al. 2005 cited in Hobday et al. 2008) which will impact the Tasmanian salmon industry, among others. It is expected that climate change will have adverse impacts on the production of species in Australia's cooler southern waters, particularly on the Tasmanian salmon industry. The Tasmanian salmon industry accounts for over 75% of the value of the state's aquaculture production (and 30% total Australian aquaculture production) and employs over 650 people (estimated for 2003-2004, ABARE 2007).

Resource-dependent industries are particularly vulnerable to climate change, and their ability to adapt will be as critical to society as to the natural systems upon which they rely. More than ever, resource users will need to anticipate, and prepare for, climate-related changes, and institutions will need to be particularly supportive, if resource industries and the extended social systems dependent on them are to be sustained (Marshall 2010).

IMPACT(S)

Observed

Climate change can significantly affect key parameters, such as recruitment, growth, reproduction or survivorship, in all important commercial species in Australia. The consequence is the likelihood of serious socio-economic decline, particularly in rural regions given that the major ports for the fisheries are distributed widely (Johnson et al. 2011). Despite livelihood impacts still relying on projected, there are observed incidents, such as the tropical cyclones, that seriously affect fisheries. The influence of tropical cyclones on the performance of the Coral Reef Fin Fish Fishery is an annual event, though mostly restricted to the loss of potential fishing days due to the inclement and unpredictable weather. The 'average' cyclone that impacts the Great Barrier Reef World Heritage Area, within which the fishery operates, is generally short lived and crosses the reef structure rapidly in an east to west direction (FRDC 2010).

The relatively long biological time-series on south-east demersal fisheries already in existence and documented range changes suggest this is an area where clear impacts will occur (Hobday et al. 2008). It is expected that the synergistic effects of warmer temperatures and increased ocean acidity will adversely affect growth and reproduction in marine fish and other fauna, although some species may be able to adapt to the change. Experiments have shown that metabolic efficiency, calcification rates and growth rates of molluscs, including the blue mussel *Mytilus edulis* and the Pacific oyster *Crassostrea gigas*, will be impaired (Michaelidis et al. 2005, Berge et al. 2006, Gazeau et al. 2007 in Hobday et al. 2008). A decrease in calcification rate in farmed molluscs may result in substantial economic loss (Gazeau et al. 2007)

Climate-related changes to northern Australian marine and coastal ecosystems might, therefore, have considerable and lasting impacts on existing northern Australian prawn fisheries. Catches of prawns, barramundi and mud crabs are related to summer rainfall and may be adversely impacted through changes in rainfall patterns and abundance (Hobday et al. 2008). Sea level rise may reduce the area of mangroves, which are essential habitat for prawns and estuarine fish, in the Gulf of Carpentaria.

Abalone and rock lobster abundance is declining in areas of Tasmania where the NSW urchin, *Centrostephanus rodgersii*, is establishing barrens. The introduced shore crab *Carcinus maenas* preys extensively on, and largely eliminates, cockle clams from invaded areas: cockle clams support a small inshore fishery in Tasmania (Walton et al. 2002). The crab is also fundamentally altering the tropho-dynamics of shallow subtidal areas, with as yet unknown consequences for commercial species that use such areas, including seagrass habitats, as nurseries. Kelp beds, a major marine community once extensive along the coast of Tasmania and an important habitat for a wide range of commercially fished species, have disappeared in many locations along the coast (Johnson et al. 2011). These could well change as productivity or distribution change, with significant impacts on quotas and effort levels leading to a disruption of fishers' income.

The robustness of the west coast fishery sector may decline in the future if climate variability increases, as variation in catch between years will increase. The fluctuation in value of the rock lobster catch, which is related to environmental variation, indicates that socio-economic effects can be large. Interaction between the commercial and recreational sector and other marine users are also resulting in zoning that excludes fishing activities in some areas (e.g. recreational fishing zones, marine protected areas). As changes in fish distribution occur, commercial fishers may not be able to simply follow the stocks, as they may contract into different management regions.

The limited evidence of climate variability impacts in Australian waters, when coupled with the greater body of evidence elsewhere in the world on the same or related species, does suggest that the impacts will be expressed first in the distribution and abundance of the generally widely distributed and mobile pelagic species, such as tuna and billfish. Impacts that result in changes in the other three biological categories - phenology and physiology, composition and interactions within communities, and structure and dynamics of communities - are even more uncertain. Artisanal fishers, which are confined to harvest in a very limited geographical area and have few, if any, alternative sources of income, are likely be the most vulnerable to climate change as they will have least ability to adapt (Grafton 2010).

One example of an industry impact can be provided (Hobday et al. 2008). Southern bluefin tuna (*Thunnus maccoyii*, SBT) are restricted to the cooler waters south of the East Australian Current and range further north when the current contracts up the New South Wales coast (Hobday and Hartmann 2006). This response to climate variation has allowed real-time spatial management to be used to restrict catches of SBT by non-quota holders in the east coast fishery by restricting access to ocean regions believed to contain SBT habitat (Hobday and Hartmann 2006). This is the only Australian example where environmental information is incorporated into a management response. Changes in the future distribution of SBT (southward contraction) would allow fishers to operate without the particular SBT-restrictions, which may be an economic advantage.

Projected

If climate change leads to the decoupling of the link currently used to estimate future western rock lobster catch (e.g., the adult western rock lobster is no longer well predicted by larval settlement), then the current management regime may be compromised, and a valuable and high-profile industry impacted. Southeast Australia is also the region where climate models indicate rapid warming (Tasman Sea warming). This suggests that considerable social disruption would occur if key fisheries were affected (Hobday et al. 2008).

Rising temperatures are of great concern for Tasmania's valuable Atlantic salmon (*Salmo salar*) aquaculture industry. The projected warming of 2-3ºC by the 2070s (under a mid-range greenhouse gas emission scenario) may render salmon farming unviable at some current production sites in Tasmania. The occurrence of temperature-induced disease outbreaks is also expected to increase as global temperatures rise (Harvell et al. 2002). For example, large-scale mortalities of wild abalone in along the south Australian coastline and in California may have been aggravated by warmer temperatures, predisposing the abalone to infection (Goggin and Lester 1995; Hobday et al. 2008) and raising considerable concerns for the developing abalone aquaculture industry.

The projected decreases in rainfall over much of Australia will impact freshwater aquaculture industries that rely directly on rainfall to supply dams or ponds or to recharge groundwater supplies. Adequate supplies of freshwater are required to maintain the water quality in these systems. The projected increases in the intensity of storms and cyclones will increase flood risk, which is a threat to stock through overflows or damage to pond or dam walls. Both reduced freshwater supply and flood events are significant threats to pond aquaculture systems in brackish water areas, such as those used for prawn production. Rainfall affects the salinity of brackish water ponds, which can affect farm production significantly. An increase in storm activity may therefore initiate erosion. These and other effects can affect facilities outside the direct exposure to increased wind and wave activity. Any severe flooding event could result in mass mortalities of animals in aquaculture ponds, open-water rafts, and lines or cages in coastal and offshore areas. The result will be diminished production which may ultimately reduce fisher incomes.

RESPONSE(S)

Response 1: Retreat

A potential response to the projected warming would be to move the Tasmanian salmon grow-out cages offshore to deeper, cooler waters (Hobday et al. 2008). This would ameliorate the impacts of climate change, particularly for species at the limits to their thermal tolerance, and provide incentive to develop offshore aquaculture technology. As with the other fishery regions considered, information on the potential changes will enhance industry capability to adapt to climate change, and make sensible business and investment decisions. Additional work is needed to explore the socio-economic impacts in this region.

Response 2: Adaptive governance

Governance will need adaptive capacity to address climate change where adaptive capacity should reduce exposure to climate change, reduce sensitivity to climate change, and increase resilience and the ability to cope with climate change (McIlgorm et al. 2010). The effects of climate change will diminish the effectiveness of the existing approach to salmon fishery governance and will require new governance based on four key principles: planning for variability and uncertainty, broadening the information base, integrating management actions at the ecosystem level, and promoting flexibility. Governance will focus on mitigating for loss of habitat and new approaches for allocating increasingly limited yields (McIlgorm et al. 2010).

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FOOD SECURITY

SUMMARY

- Currently, Australia is considered food secure and is a net exporter of food.
- Nutritional insecurity, attributed to affordability of fruits and vegetables, has been reported in Australia.
- Climate variability is likely to affect food access through changes in food production and price shocks during periods of droughts and extreme weather events.

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Projected Impact

CATEGORY(S)

Human wellbeing, livelihoods

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Extreme Events

PRESSURE(S)

Australian food security is highly dependent on the climate and weather variability, and related environmental resources (Edwards et al. 2010; PMSEIC 2010). The combined and interacting influence of climate change and weather variability, mainly through temperature increase and related droughts, and extreme weather events (including cyclones), are likely to affect the availability of food and therefore consumer prices through repeated short and long term disruptions in agricultural production and productivity (Butler 2009; Sheales and Gunning-Trant 2009). The influences of these pressures vary between regions and farm production types. The increase in temperature across food production areas of Australia has made the impacts of droughts more severe (see further discussion in the “Agricultural Communities” fact).

Quiggin (2010) showed that temperature increases of 3°C will result in elevated global grain prices, resulting in high food prices of products such as bread. Pasture capacity for livestock production would decline by up to 40% for temperature increases above 2^{o}C resulting in permanently elevated prices for livestock products (Preston and Jones 2006; Quiggin 2010).

STATE(S)

Australia is a net exporter of food and is considered food secure with no immediate threat of food supply shortages (Edwards et al. 2010). However, Australia faces challenges, including climate variability and change, that may threaten food security in the long term through negative impacts on agricultural productivity (Sheales and Gunning-Trant 2009).

Climate variability is affecting the availability of nutritious food through food price changes particularly fruit and vegetables. For example, drought and other severe weather events induced price increases of 43%, 33%, 17%, 11 % and 4% for vegetables, fruit, eggs, milk and dairy products and meat and seafood respectively between 2005 and 2007 (Quiggin 2010). In Australia, nutritionally compromised diets have been reported in 15% of the young population, 23% of the unemployed and single households and 71% of Australian resident refugees (Friel 2010; Gallegos et al. 2008).

Australia experienced an 11% fall in farm and fisheries production in the 2006-07 season from 2005-2006 and, despite remaining a net exporter of food, experienced a 3% fall in exports (DAFF 2008). This fall in production was attributed to the 2006 drought, which resulted in a 47% drop in broadacre crop production to levels below average production. The fall in production also resulted in Australia being a net importer of grain in the 2007-08 season (Butler 2009). See details of the impacts on agriculture productivity in the “Agricultural Communities” fact and specific agricultural crops facts.

IMPACT(S)

While potential food shortages in Australia due to the adverse effects of climate variability and changes are noted in a number of publications (e.g., Edwards et al. 2010; Larsen et al. 2008 ; Quiggin 2010), there are no comprehensive studies providing evidence on the likely impacts of climate change and weather variability on food security in Australia. However, using 2004 as the base year, global modelling using the Global Track Analysis Project model (GTAP) has projected an increase in farmers prices by 4% and a fall in agricultural consumption volume by 2% due to the projected effects of crop productivity shocks resulting from climate change and weather variability by 2030 (Valenzuela and Anderson 2011).

With the projected increasing frequency and severity of droughts and extreme weather events, reduction in food quality and increases in the severity and frequency of food price shocks are highly likely (Edwards et al. 2010, Quiggin 2010). Price increases will affect food affordability negatively, which may result in food nutritional insecurity (Queensland Health 2009, Sheales and Gunning-Trant 2009).

RESPONSE(S)

Improvements in agricultural productivity lead in higher production, which lowers commodity prices and therefore improves accessibility to food and nutrition (Mallawaarachchi et al. 2009; Nossal and Sheng 2010). Responses related to agricultural productivity are further discussed in the “Agricultural Communities” and the specific crop productivity facts.

Edwards et al. (2010) suggests that changes in consumer shopping behaviour such as ‘one-stop’ shopping at major supermarkets and reduction in luxury expenditure are possible adaptation measures to food price shocks. Household growing of fruit and vegetables, subject to the availability of land and water, could provide nutritional security during price shocks (Edwards et al. 2010).

BACKGROUND

Food security is concerned with food quality, availability, access and affordability, and cultural acceptability of food (Sheales and Gunning-Trant 2009). The food processing industries source a significant amount of their ingredients from agriculture; therefore, agricultural productivity is important for the supply of competitively priced and high quality products (Mallawaarachchi et al. 2009). In addition to demand factors (e.g., population growth) declines in food production and hence food supply, increase food prices and therefore, limit access. Nutritional insecurity attributed to the affordability of fruits and vegetables has been reported in Australia (Queensland Health: Pollard et al. 2009 ; Sheales and Gunning-Trant 2009). Kettings et al. (2009) showed that the cost of matching diets with national health guidelines would require about 40% and 20% of the household budget for welfare dependent families and average income families respectively.

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FOOD BORNE DISEASE

SUMMARY

- Increased temperatures and rainfall associated with climate change are expected to increase *Salmonella* notifications.

- Climate change is projected to result in a 5% increase in *Salmonella* notifications per degree increase in the mean temperature of the previous month in all cities except Brisbane and Darwin. Actual rates may be as much as seven times higher due to underreporting.

- Increased temperature has been shown to increase the incidence of gastrointestinal infections; a 2.48% increased risk of gastroenteritis has been demonstrated for every 1°C above the mean of the previous month rise in temperature sustained over 8 days.

- Summer peaks in the incidence of gastrointestinal infections are projected to be higher and more prolonged with climate change, with associated increased economic costs of lost workdays and health and surveillance costs.

CONTEXT

This statement is compiled from scientific literature and published reports

EVIDENCE

Projected Impact

CATEGORY(S)

Human health: Food borne

REGION

Australia

DRIVER(S)

Temperature
Precipitation

PRESSURE(S)

Ambient temperature influences the development of *Salmonellae* at various stages in the food logistics chain, including raw food production, transport and storage ((Zhang et al. 2010). The optimum temperature for the growth of *Salmonellae* is between 35 °C and 37 °C

(Doyle and Mazzotta 2000 in (Zhang et al. 2010). Temperature is thought to affect the transmission of *Salmonella* infections via several causal pathways, either directly, such as by affecting the rate of bacterial proliferation, or indirectly, by changed eating behaviours in hot weather (for example, increased eating outdoors with suboptimal food storage and increased consumption of uncooked foods such as salads) (Britton et al. 2010).

The relationship of other bacterial pathogens with ambient temperature, however, differs from that of *Salmonella*. For example, Fleury et al. (2006) observed temperature effects on rates of notifications of *Campylobacter* to be twice as great as for *Salmonella*, and temperature effects on rates of notifications of *Escherichia coli* to be approximately four times as great as for *Salmonella* (Fleury et al. 2006).

Studies in Europe, North America and Asia noted by Zhang et al. (2010) reported positive associations between ambient temperature and salmonellosis, hepatitis A, campylobacteriosis and other enteric infections (Zhang et al. 2010). Laboratory studies have also demonstrated that that there is a direct relationship between temperature and the rate of multiplication of *Salmonella* organisms (Esler 2009; Jay et al. 2003).

Bambrick et al. (2008) cite evidence that gastrointestinal infection from all bacterial pathogens is positively associated with ambient temperature, as warmer temperatures facilitate more rapid reproduction (Meer et al. 1997; Fleury et al. 2006; Allan et al. 2004 in Bambrick et al. 2008). Hall et al. (2006) however, hold that understanding of the causal pathway associating gastroenteritis and the weather is still speculative (Hall et al. 2006a).

STATE(S)

In 2009, OzFoodNet sites reported 27,037 notifications of 9 diseases or conditions that are commonly transmitted by food. The most frequently reported organisms were *Campylobacter spp.* (15,973 notifications) and *Salmonella spp.* (9,533 notifications) (The OzFoodNet Working Group 2009). Underreporting, however, is a significant issue in foodborne disease surveillance; the under-reporting factor for salmonellosis has been estimated by Hall et al. (2006) as 6.9%, for campylobacteriosis as 9.6% and for shiga toxin-producing *Eschericia coli* (STEC) infection as 8.2% (Hall et al. 2006b). Based on five years' data from the National Notifiable Diseases Surveillance System between 2000 to 2004 and applying the under-reporting factors to these notification numbers gives an estimated yearly number of infections of 48,763 for *Salmonella,* 222,958 for *Campylobacter* and 3,765 cases of STEC in Australia each year (Hall et al. 2006b).

Data from the National Gastroenteritis Survey in 2001 and 2002 indicate that there are approximately 5.4 million cases of food-borne gastroenteritis in Australia every year, causing:

- 15,000 hospitalizations
- 120 deaths
- 42,000 episodes of long term effects (chronic sequelae)
- 2.1 million lost work days
- 1.2 million doctor consultations
- 300,000 prescriptions for antibiotics

(Abelson et al. 2006; Hall and Kirk 2005; Kirk et al. 2008).

The total cost of foodborne illness in Australia was estimated at $1,249 million per annum (based on data from 2001 and 2002), broken down as follows:

- productivity and lifestyle costs: $771.6 million (62%)
- premature mortality: $231.5 million (19%)
- health care services: $221.9 million (18%)

(Abelson et al. 2006)

IMPACT(S)

Impact 1: Salmonella

Observed

Zhang et al. (2008), using four regression models, found a positive association between temperature and the number of salmonellosis cases in Adelaide. They also found a negative association between rainfall and the number of salmonellosis cases in Adelaide (which has wet winters with lower temperatures and more rainfall, and dry summers) but were uncertain as to whether rainfall affected disease transmission independently or whether it interacted with other climatic variables such as temperature (Zhang et al. 2008). Zhang et al. (2010) applied Spearman correlation and timeseries adjusted Poisson regression (controlling for autoregression, lag effects, seasonal variation and long-term trend), and.found that maximum and minimum temperatures, relative humidity, and rainfall were all positively correlated with increases (5.8% to 11.9%) in the number of *Salmonella* cases in subtropical Brisbane and tropical Townsville. They suggested that temperature and rainfall may be used as meteorological predictors for the number of *Salmonella* cases in these regions (Zhang et al. 2010).

Britton et al. (2010) used a negative binomial regression model to investigate the relationship between monthly salmonellosis notifications and the monthly average temperature in New Zealand. They found that for a 1°C increase in monthly average ambient temperature there was a 15% increase in salmonellosis notifications. Based on these results, they concluded that climate change could increase salmonellosis notifications in New Zealand (Britton et al. 2010).

Projected

Bambrick et al. (2008), by fitting a 2nd order polynomial regression, estimated the size of the effect of climate change on salmonellosis notifications to be around a 5% increase in notifications per degree increase in the mean temperature of the previous month (4.1% in Perth to 5.6% in Sydney), for all cities except Brisbane and Darwin. Brisbane, the warmest city studied, showed a 10% increase in *Salmonella* notifications per degree increase in the mean temperature of the previous month (Bambrick et al. 2008).

Australia-wide, annual cases of salmonellosis are projected to increase by approximately 3% by 2020 and 14% by 2050 (Bambrick et al. 2008 in (Bambrick et al. 2011). This translates to around 1000 extra cases per year by 2050 under the U1[1] (unmitigated) scenario, or 580 under the M4[2] (mitigated) scenario, with an annual difference of approximately 1200 lost workdays and $120,000 in the cost of health care and surveillance by 2050 (Bambrick et al. 2008). It is important to note that since these estimates are based on notifications and do not take under-reporting into account, the actual impact of climate change on salmonella may be seven times higher (Bambrick et al. 2008).

Impact 2: Gastroenteritis

Observed

Hall et al. (2006), in a year-long national gastroenteritis survey, found that the likelihood of infectious gastroenteritis in Australia was significantly increased in the summer and in warmer regions, suggesting that climatic variation may influence gastroenteritis in Australia (Hall et al. 2006a). More recently, Hall et al. (2010), investigated the same data for an association with local weather variables. They found a statistically significant positive association between the probability of onset of gastroenteritis and local temperature, and suggested that projections of increased temperature and changing climate conditions are likely to affect the distribution and incidence of infectious gastrointestinal disease. For every 1°C rise in temperature sustained over 8 days there was a 2.48% increased risk of gastroenteritis and for a 5°C rise sustained over 8 days a 13% increased risk of gastroenteritis was reported (Hall et al. 2010).

Projected

Bambrick et al. (2008) maintain that climate change is likely to act on other bacterial enteric pathogens in a similar way to *Salmonella* (Bambrick et al. 2008). In general, summer peaks in the incidence of gastrointestinal infections are projected to be higher and more prolonged with climate change, and seasonal patterns of infection peaks may change (Bambrick et al. 2011). The annual health and economic costs of gastrointestinal infections are projected to rise to 335,000 new cases by 2050 under a U1 scenario, leading to more than 936,000 lost workdays, and $92 million in healthcare and surveillance costs. Under the M4 scenario, 205,000 new cases of gastroenteritis are anticipated, costing $56.5 million in healthcare and surveillance and resulting in 570,000 lost workdays (Bambrick et al. 2008 in (Bambrick et al. 2011).

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[1] **Unmitigated Scenario 1 (U1**)—Hot, dry scenario, using A1FI emissions path, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100. Source: Bambrick, H., Dear, K., Woodruff, R., Hanigan, I., McMichael, A., 2008. Garnaut Climate Change Review: The impacts of climate change on three health outcomes: temperature-related mortality and hospitalisations, salmonellosis and other bacterial gastroenteritis, and population at risk from dengue.

[2] **Mitigation Scenario 4 (M4)—**Best estimate (median) strong mitigation scenario where stabilisation of 450 ppm CO2 equivalent (CO2 stabilised at 420 ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~1.5°C in 2100. Source: Ibid.

BACKGROUND

Transmissible foodborne diseases are among the most serious health problems affecting public health and development worldwide. Industrialization, mass food production, decreasing trade barriers, and human migration have disseminated and increased the incidence and severity of foodborne diseases worldwide.

Transmissible foodborne illnesses are commonly caused by

- bacteria (e.g., *Salmonella typhimurium, Campylobacter jejuni*)
- viruses (e.g., rotavirus, hepatitis A virus)
- parasites (e.g., *Cryptosporidium, Giardia lamblia*)

In Australia it is estimated that viruses account for 49% of all notified gastroenteritis cases, bacteria for 36%, and parasites for 15% (Hall et al. 2005). Causes of non-transmissible foodborne illness include metabolites of moulds and fungi (e.g., aflatoxins in cereals and pulses), natural food toxins (e.g., ciguatera and histamines in fish) and by other nonliving pathogenic agents. This impact statement is limited principally to discussion of bacterial foodborne illnesses due to the paucity of information about other types of pathogens.

Transmissible foodborne illnesses have been categorised by Abelson et al. (2006) as

- gastroenteritis
- non-gastroenteritis illnesses (invasive listeriosis, toxoplasmosis, hepatitis A)
- chronic sequelae (e.g., haemolytic uraemic syndrome, irritable bowel syndrome, Guillain-Barré syndrome and reactive arthritis) (Abelson et al. 2006).

It has been estimated that there are approximately 42,000 such episodes of chronic illnesses following an initial acute infection of foodborne gastroenteritis in Australia each year (Hall and Kirk 2005).

The incidence of foodborne illness is also influenced by a range of non-climatic factors such as

- regulations governing food handling
- emerging pathogens
- changing agricultural and manufacturing practices
- changing trends in consumers' food choices and eating patterns (Abelson et al. 2006).

Two populations which may have a compounded risk of gastrointestinal infection in a warming climate are

- the ageing population (especially those living institutionally)
- indigenous populations (due to suboptimal food preparation and storage facilities and clean water availability)

(Bambrick et al. 2008).

Many microbial pathogens have seasonal peaks of infection, but patterns vary. For example, cases of gastroenteritis caused by the bacteria *Clostridium perfringens*, *Vibrio parahaemolyticus*, *Aeromonas spp.* and *Salmonella spp.* peak in summer, whilst *Campylobacter* infection rates peak in spring and norovirus and rotavirus infection rates peak in winter (Bambrick et al. 2008; Hall et al. 2010). The winter seasonal peak observed with rotavirus is thought to be primarily due to person-to-person contact (Bambrick et al. 2008; Hall et al. 2010) (D'Souza et al. 2008). Thus the mechanisms of seasonality vary for different pathogens –some may multiply faster in warmer conditions, while the proliferation of others may be influenced by seasonal fluctuations in animal reservoirs (Hall et al. 2006a) or increased availability of breeding media when rainfall is high.

It is important to note that the data on foodborne illnesses are subject to a significant degree of uncertainty; the incidence of foodborne illness is postulated to vary by 25% above or below the rates notified (Abelson et al. 2006).

Salmonellae

Salmonellae are common bacterial foodborne pathogens, accounting for approximately 30% of all notified gastroenteritis (Bambrick et al. 2008). *Salmonella* infections may be transmitted by contaminated food or water and affect the gastro-intestinal tract, causing diarrhoea, vomiting, fever, and other symptoms (Bambrick et al. 2008). More than 2000 serotypes of *Salmonellae* have been described, however they may be categorised simply as follows:

1. serotypes causing enteric fever, e.g., typhoid (*S. typhi, S. paratyphi*)
2. 'nontyphoidal *Salmonella*' serotypes *(S. typhimurium, S. enteritidis)* which cause gastroenteritis

(Darby and Sheorey 2008)

Although not all cases of *Salmonella* infections in Australia are food-borne, more than 70% of cases are believed to be transmitted by food (Haines et al. 2006). Notified cases of salmonellosis are estimated to account for approximately 30% of all notified gastroenteritis (Bambrick et al. 2008).

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HEAT STRESS

SUMMARY

- Climate change is expected to reduce temperature-related deaths in Australia in the first half of the century 1990 to 2090, but increase temperature-related deaths in the second half of the century.

- Heatwaves are projected to occur more frequently in the future due to climate change, and to be more intense and longer lasting

- Evidence exists that heatwaves result in increased overall mortality. In Queensland and the Northern Territory, however, deaths are expected to increase markedly, with 10 times as many deaths by the end of the century compared with a scenario of no climate change. In Western Australia twice as many deaths are projected compared with a scenario of no climate change.

- Evidence exists that heatwaves result in increased mortality for people with some mental illnesses and for people with cardiovascular conditions.

- There is evidence that heatwaves result in increased overall morbidity.

- Heatwaves have been shown to result in increased morbidity for people with mental, renal, and cardiovascular conditions.

CONTEXT

This statement is compiled from published scientific literature and reports

EVIDENCE

Projected Impact

CATEGORY(S)

Human health

REGION

Australia

DRIVER(S)

Temperature

PRESSURE(S)

Climate change is expected to result in substantial increases in extreme hot weather. Without climate change mitigation, the number of days over 35°C each year is projected to rise from 9 to 27 in Melbourne, 1 to 21 in Brisbane and most dramatically from 9 to 312 in Darwin by 2100 (Queensland Health 2004a).

Thus heatwaves are projected to occur more frequently in the future, and to be more intense and longer lasting (IPPC 2007; Reeves et al.2010). Weather projections for Adelaide, for example, suggest average summer temperatures will rise 0.4–1.3° C by 2030, and 0.8–4.0°C by 2070 (Suppiah et al. 2006 in (Nitschke et al. 2007). The average number of days per year above 35°C in Adelaide, currently 17, is projected to increase to 36 by 2070 under a median A1F1 scenario (CSIRO and Bureau of Meteorology 2007). Correspondingly, the annual number of temperature-related hospitalisations in South Australia under an unmitigated U1[1] scenario is expected to increase by 110% by the year 2100 (Bambrick et al. 2008).

[1] **Unmitigated Scenario 1**: Hot, dry scenario, using A1FI emissions path, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100. Source: Bambrick et al. (2008)

STATE(S)

It is estimated that more than 4,000 deaths have occurred over the past 200 years as a consequence of heatwaves in Australia (McMichael et al. 2002 in(Ibrahim and McInnes 2008). Since 1950, Australia’s average annual temperature has increased by 0.9°C. Whilst Southern Australian metropolitan regions have experienced heatwave events in the past (e.g. 1908 and 1939), events in the first decade of the 21st century have been unusually intense, long-lasting and extensive (Queensland University of Technology 2010). In January 2009, slow-changing synoptic conditions maintained a very hot air mass over south-eastern Australia, resulting in a record-breaking heatwave. Maximum daily temperatures were 12 to 15 °C above the seasonal average of 28–32 °C for many consecutive days. New daily maximum temperature extremes were observed for Adelaide (45.7 °C) and Melbourne (46.4 °C). Adelaide had eight consecutive days over 40 °C and Melbourne suffered an unprecedented run of three days above 43 °C. Night-time temperatures for both Adelaide and Melbourne were unusually high (Reeves et al. 2010). As many as 500 people died as a result of this extreme heat event in Adelaide and Melbourne. Financial losses, mainly as a consequence of power outages, transport service disruptions and response costs, have been estimated at $800 million Reeves et al. 2010).

IMPACT(S)

Bambrick et al. (2008), in modeling population, health and climate data, found that temperature-related mortality and morbidity are highly variable with different daily maximum temperature

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thresholds being estimated for different locations (Bambrick et al. 2008). When projected to 2100, the modeling results for temperature-related mortality and morbidity varied widely over place, time and climate change scenarios, with climate change reducing temperature-related deaths and hospitalisations (due to fewer cold weather-related deaths) in some parts of Australia, but increasing them in others (Bambrick et al. 2008).

Extreme heat events in south-eastern Australia in late January 2009, in which temperatures of 43°C and above were recorded in Melbourne on three consecutive days, resulted in excess mortality (DHS 2009). During the week from 26 January to 1 February 2009, there were 374 more deaths than would be expected normally, representing a 62% increase in total all-cause mortality; the total number of deaths during this period was 980, compared to a mean of 606 for the same period in the previous 5 years (DHS 2009).

Impact 1: Mortality

Observed

Tong et al. (2010), using a Poisson time series regression model, found a substantially increased number of deaths in the Brisbane heatwave of 2004, when the temperature ranged from 26°C to 42°C. There was a 23% increase in all deaths except injury and suicide, compared with those in the same (non-heatwave) periods of 2001-2003, when the temperature ranged from 22°C to 34°C (Tong et al. 2010).

Vaneckova et al. (2008) found that maximum temperature had a significant effect on mortality in temperate Sydney, with air pollutants (ozone and particulate matter) confounding the association. A generalized linear model assuming negative binomial distribution was used on daily mortality counts, together with daily maximum temperature and hourly maximum concentrations of ozone and particulate matter as covariates. The observed change in mortality was estimated to be between 4.5% and 12.1% for a 10ºC increase in maximum daily temperature with air pollutants included in the model. When air pollutants were removed from the model, these mortality percentages changed by -1.1% to 0.9% (Vaneckova et al. 2008)

Bi et al. (2008) used correlation, autoregressive integrated moving average regression analyses (ARIMA) and generalized least squares regression to assess the relationship between weather and mortality in the population in subtropical Brisbane. They found that in summer, a higher minimum temperature was associated with higher mortality in the elderly and those with cardiovascular disease. In winter, negative correlations were found between temperature and mortality for people with cardiovascular and respiratory diseases (Bi et al. 2008).

Projected

Climate change is projected to reduce temperature-related deaths in all states and territories except Queensland during the first half of the century 1990 to 2090 (due to reductions in the number of cold-related deaths). During the second half of the century increases in deaths are projected overall under scenarios of no mitigation (U1 and U2[2]). Unmitigated climate change may modestly reduce temperature-related deaths in Victoria, Tasmania, South Australia and New South Wales. In

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Queensland and the Northern Territory, however, deaths are expected to increase markedly, with 10 times as many deaths by the end of the century compared with a scenario of no climate change. In Western Australia twice as many deaths are projected compared with a scenario of no climate change. With mitigation, deaths in the second half of the century are projected to be considerably reduced (Bambrick et al. 2008).

By 2100 the annual heat-related death rate in Australia for people aged over 65 is projected to increase from the 1999 baseline of 82 per 100,000 to 131 per 100,000 for a scenario of stabilising the CO_2 concentration at 450 ppm, and 246 per 100,000 for a larger emissions scenario (resulting in a 3.8ºC warming by 2100 relative to 1990) (Woodruff et al. 2005).

Impact 2: Morbidity

Hughes and McMichael (2011) summarise documented impacts of extreme heat, and describe specific groups at greater risk, which include those with existing health conditions, children and people who are elderly, those who work in heat-exposed jobs and people with low incomes.

Observed

In Adelaide during a period of 13 years (1993-2006), the number of people requiring ambulance transport during heatwaves increased by 4% when compared with non-heatwave periods. A corresponding increase in total hospital admissions of 7% was observed during heatwaves (Nitschke et al. 2007).

Impact 3: Direct heat-related illness (heat rash, heat cramps, heat exhaustion, heat stroke)

Observed

In one New South Wales study, the association between emergency hospital admissions due to heat-related injuries, dehydration and other disorders of fluid, electrolyte and acid–base balance, increased significantly during periods of extreme heat (Khalaj et al. 2010)

Impact 4: Mental Illness

Total mental health admissions were shown to increase by 7.3% in metropolitan South Australia during heatwaves - the increased admission rate was observed across all age groups. A positive association between ambient temperature and hospital admissions for mental and behavioral disorders was observed above a threshold of 26.7°C. Mortalities attributed to mental and behavioral disorders increased during heat waves in the 65- to 74-year age group and in persons with schizophrenia, schizotypal, and delusional disorders. Dementia deaths increased in those up to 65 years of age in this study (Hansen et al. 2008a; Nitschke et al. 2007).

Impact 5: Renal disease

Observed

Patients with renal disease, especially renal failure, are more susceptible to an extreme heat event (Nitschke et al. 2007); (Khalaj et al. 2010); (Hansen et al. 2008b). A 13 year study in Adelaide, South Australia, ending in 2006 demonstrated that admissions for renal disease and acute renal failure were increased during heat waves compared with non-heat wave periods (Hansen et al. 2008b); (Nitschke et al. 2007).

Impact 6: Cardiovascular disease

Observed

Nitschke et al. (2007) observed an increase of 8% in admissions for ischaemic heart disease among people aged 65–74 years in heatwave conditions in their Adelaide study.   In contrast, a decrease in admissions for cardiovascular conditions was seen among people aged 75 years and older in heatwaves. Total and age-group specific cardiovascular admissions did not increase. The authors postulated that the positive outcome could be due to the high prevalence of air-conditioning (82%) in Adelaide, and suggested factors such as good care of the elderly and social cohesion could also have contributed (Nitschke et al. 2007). Tong et al. (2010) found that the 2004 Brisbane heatwave increased cardiovascular deaths by 20% when compared with the same (non-heatwave) periods of 2001-2003 (Tong et al. 2010). Loughnan et al. (2010) included socio-demographic and spatial information into analyses of admissions for acute myocardial infarction (AMI) and ambient temperature to present a more holistic picture of public health vulnerability to hot weather. They demonstrated a 10.8% increase in admissions for AMI on days exceeding a 30°C threshold in Melbourne, and a 37.3% increase in admissions for AMI during short episodes of heat (defined as when the 3-day average temperature was ≥ 27°C) (Loughnan et al. 2010).

RESPONSE(S)

Existing and potential adaptation measures include

Response 1: Health sector workforce education and training to attune to heatwave health risks

The Victorian government, as part of a strategy for educating health professionals on heat issues, produced a heatwave fact sheet for clinicians in 2010 (Government of Victoria 2010).

Response 2: Development of heatwave response plans, including development of regional definitions and indices

Queensland Health introduced a Heatwave Response Plan in 2004, which has now been incorporated into the Queensland Health Disaster Plan 2008(Queensland Health 2004b).

In 2009 the Victorian Government released the ‘ Heatwave Plan for Victoria 2009–2010’ (Government of Victoria 2009). The government has also prepared a comprehensive resource specifically for residential aged care services (Victorian Government 2010). As part of multifaceted Heatwave Strategy, the government funded 22 local government pilot heatwave plans (total cost $600,000) and established a heat alert system for metropolitan Melbourne (Hoy and Garoni 2009). Studies to develop heatwave thresholds for regional Victorian areas have also commenced (Government of Victoria 2008).

Western Australia’s Department of Health introduced a heat wave policy in 2010 for the Perth metropolitan area (Government of Western Australia 2010).

Response 3: Surveillance and monitoring, including early-warning systems for impending heatwaves

The Victorian government's Department of Health has further developed its Heat Health Intelligence Surveillance System in order to track and report on the health impact of heatwaves (Reeves et al. 2010).

Response 4: Community education and mass media campaigns to reduce and prevent weather-related health risks

Since the 2009 heatwave, the Victorian government is delivering public health messages and communications delivered through a range of community-based organisations, such as heatwave advice for Home and Community care organisations (Reeves et al. 2010).

Response 5: Technological/engineering and infrastructure development solutions such as climate-proofed housing design (shade, insulation, ventilation), or enhanced urban planning for green spaces and shade

Response 6: Community-based initiatives such as development of neighbourhood watch schemes or other support networks to assist those who are most vulnerable

The Victorian government's Department of Health is working with Personal Alert Victoria to provide additional support during a heat event to over 22 000 vulnerable clients. It is also expanding the 'Keeping in Touch' weekly telephone program to include all 7000 public housing tenants aged 75 years or over (Reeves et al. 2010).

BACKGROUND

Exposure to prolonged ambient heat causes conditions such as heat cramps, heat exhaustion and heat stroke. People most likely to be affected are those with chronic disease (e.g., cardiovascular disease, diabetes). Exposure to prolonged ambient heat may also exacerbate chronic conditions and increase the propensity for catastrophic events such as heart attack and stroke (Bambrick et al. 2008). Deaths and illness occurring during heatwaves are often not clinically apparent as being due to heat, so it is likely that existing data underestimate the effects of heatwaves on human health (Bambrick et al. 2008).

During heatwaves other related factors may increase the propensity for people to succumb to direct or indirect heat-related illness. For example, power outages may stop people using air conditioners, bushfires may reduce air quality and public transport disruptions may prevent people reaching cooler locations (Government of Victoria 2010).

The magnitude of health effects caused by extreme heat events depends on the intensity and duration of high temperatures, and also population acclimatisation and adaptation (Fouillet et al. 2006; Hansen et al. 2008a; Kovats and Hajat 2008; Kovats and Kristie 2006).

The factors that contribute to a heatwave are:

- the maximum day time temperature and the minimum night time temperature
- the duration of the high temperatures
- humidity and air quality

- the availability of cooling facilities and power to operate the cooling facilities
- urban and rural design
- local acclimatisation

(Government of Western Australia 2010).

Heatwave definition

Numerous climatic zones exist in Australia and heatwave definitions vary across regions.

The heatwave threshold for the Perth metropolitan area is a mean temperature of 32°C (the mean temperature is the average of the forecast daily maximum temperature and overnight minimum temperature) (Government of Western Australia 2010). Victoria has established a heatwave threshold for metropolitan Melbourne of a daily average of 30˚C (mean of daytime maximum and overnight minimum temperature). In these conditions, mortality rates in people aged 65 years or more increase by 15-17% (Nicholls et al. 2008). The authors of studies of heat-related morbidity and mortality in Adelaide, South Australia, defined heat waves as greater than or equal to three consecutive days when the daily maximum temperature reached or exceeded 35°C (Hansen et al. 2008a; Nitschke et al. 2007). Tong et al. (2010) were able to demonstrate a strong association between heatwaves and health, but the strength of the association was variable and depended on the heatwave definition used (Gage et al. 2008).

Pathophysiology of specific heat-health impacts

Mental illnesses: People with underlying mental and behavioural disorders appear to be more susceptible to extreme heat events. There are likely to be multiple causes behind the observed effect of heat on these conditions, including impaired coping skills. These patients may also be taking psychotropic medications (e.g., anticholinergic, anxiolytic, antidepressant and neuroleptic drug classes), which exacerbate the impact of heat on the health of those using them, by impairing thermoregulation due to their effects on the autonomic nervous system. It is also known that thirst sensation is decreased by selective serotonin re-uptake inhibitors (SSRIs), dopamine D1 and D2 agonists and antagonists and atypical neuroleptic drugs, like clozapine or risperidone (Stollberger and Finsterer 2007).

Renal disease: Susceptibility to extreme heat events is primarily due to the effects of hyperthermia and dehydration on already-compromised kidneys. Additionally acute renal failure (ARF), is often associated with exposure to extreme heat. Studies of heat wave morbidity and mortality have provided evidence of renal impairment directly attributable to heat exhaustion and heat stroke. As a consequence of hyperthermia and dehydration, the body's physiological mechanisms attempt to regulate electrolyte and water imbalance, and as glomerular filtration rates fall, renal failure can occur. The elderly are more vulnerable to the development of heat-related renal disease due to lowered thermotolerance, impaired thirst sensation, diminished conservation of sodium and water during dehydration, and reduced glomerular filtration rates (Hansen et al. 2008b).

Cardiovascular disease: Excessive heat exposure is a major stress for the cardiovascular system. When environmental heat rises, skin blood flow increases and sweating is initiated. Cutaneous vasodilatation results in marked increases in blood flow to the skin and cardiac output, at the expense of other major blood supplies. These cardiovascular adjustments to accelerate the transport of heat from the core to the periphery for dissipation to the surroundings represent a major load on the cardiovascular system. Accordingly, thermoregulation during severe heat stress requires a healthy cardiovascular system. In addition, sweating results in the production of up to 2 litres per hour of sweat rich in sodium and potassium, producing additional stress on the cardiovascular system if the plasma volume is not properly restored (WHO Regional Office for Europe 2009).

Diabetes: The reasons for increased susceptibility in people with diabetes are unclear, however it is known that diabetes is associated with impaired autonomic control and endothelial function. During periods of high temperatures blood viscosity and cholesterol in all people increase, and the body attempts to adapt to heat by increasing cardiac output, which increases skin surface blood circulation and heat loss (Schwartz 2005). Moreover, people with diabetes are thought to be at greater risk during periods of extreme heat because fluid and electrolyte disturbances may exacerbate poorly controlled glucose. Furthermore, a decreased sweating response due to peripheral neuropathy and structural impairment of blood flow to the periphery due to vascular disease might be responsible for the poor thermoregulation associated with diabetes (Oberlin et al. 2010).

Medications: Many therapeutic drugs can be risk factors for heat-related illness, due to their ability to inhibit thermoregulation in various ways (e.g. altered sweat production, dehydration, increased heat production, impaired thirst recognition or inhibited heat loss). These include many psychotropic drugs as well as anti-hypertensives (including b-blockers), diuretics, barbiturates and anti-histamines (Hansen et al. 2008b). Anticholinergic drugs inhibit sweating and therefore reduce heat elimination from the body. Some drugs such as narcoleptics and some antipsychotics have combined anticholinergic and central thermoregulatory effects. In addition overdoses of recreational drugs may also be linked to heat related mortality and morbidity. Amphetamines and cocaine increase metabolic heat production and increase the risk of heat stress, and excess intake of alcohol can lead to diuresis, dehydration, sedation and altered states of consciousness (Loughnan et al. 2009).

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MENTAL HEALTH

SUMMARY

- Evidence exists that increases in the number of people exposed to bushfires will lead to an increase in the number of people developing post traumatic stress disorder (McFarlane and Van Hooff 2009; Parslow et al. 2006; Yelland et al. 2010)
- Evidence exists that increases in hospital admissions for mental and behavioural disorders occur during heatwaves (Khalaj et al. 2010; Nitschke et al. 2007)
- Deaths attributed to mental and behavioural disorders have been shown to at least double during heatwaves (Hansen et al. 2008)
- Environmental degradation associated with climate change has been shown to contribute to mental ill-health (Sartore et al. 2008; Speldewinde et al. 2009)
- Suicide rates in male farmers are approximately triple the rates of urban males (Bennett and McMichael 2010) and an inverse relationship has been found to exist between precipitation and suicide rates in New South Wales (Nicholls et al. 2006)

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Human wellbeing, livelihoods

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Extreme Events

PRESSURE(S)

Pressure 1: Disasters

Natural disaster events are projected, in general, to be more severe and more frequent as a result of climate change (Hennessy et al. 2008; International Federation of the Red Cross and Red Crescent Societies 2009); the Centre for Research on the Epidemiology of Disasters identifies that the number of weather-related disasters globally has doubled since the mid-1990s (Morrissey and Reser 2007).

In Australia, recent significant disasters include

- the Thredbo landslide (1997);
- bushfires in Canberra (2004);
- bushfires in South Australia (2005);
- Cyclone Larry (2005);
- Bushfires in Victoria (2007);
- Black Saturday (2009);
- Cyclone Yasi (2011);
- Lockyer Valley flood (2011);
- Brisbane floods (2011) (Morrissey and Reser 2007).

Floods

Rafter and Abbs (2009) in Keenan et al. (2011) examined changes in the intensity of extreme daily rainfall, and found a tendency for increases in all regions for 2055 and 2090, for most of the 11 global circulation models considered. Consistent with previous studies, their analysis predicted smaller increases in the south of Australia and larger increases in the north. Regional climate modelling suggests increases in daily precipitation extremes on average, although with significant variability (Keenan et al. 2011).

There is projected to be an increased risk of coastal flooding especially in low-lying areas exposed to cyclones and storm surges. The severity and frequency of coastal flooding of infrastructure is projected to increase, partly due to continued development and population growth in Australia’s coastal regions, and also to sea-level rise associated with climate change (Department of Climate Change 2009; Hennessy et al. 2007) . With a sea-level rise of 0.5 m in the 21st century, events that now happen every ten years would happen about every ten days in 2100. The current 1-in-100 year event could occur several times a year (Department of Climate Change 2009).

Fires

Lucas et al. (2007) in Keenan et al. (2011) examined fire-weather risk in Australia using various climate model results. Simulations showed that the number of days with very high fire danger ratings is likely to increase by 2% to 30% by 2020 and by 5% to 100% by 2050. The number of days with extreme fire danger ratings is projected to increase between 5% and 65% by 2020 and between 10% and 300% by 2050. For example, Canberra is projected to have an annual average of 19 to 25 very high or extreme fire danger days by 2020 and 22 to 38 days by 2050 compared with a present average of 17 days. They also concluded that it is likely that the fire season will become significantly longer (Keenan et al. 2011).

Cyclones

The IPCC (2007), reporting on recent regional modelled studies of tropical cyclone behaviour and characteristics, states there is no clear picture with respect to regional changes in frequency and movement of tropical cyclones. Keenan et al. (2011) corroborate the view that trends in tropical cyclone activity and intensity are difficult to identify (Keenan et al. 2011). However, increases in tropical cyclone intensity are indicated. Walsh et al. (2004) cited in Solomon et al. (2007) obtained a 56% increase in storms with a maximum wind speed greater than 30 m/s under tripled CO2 conditions (Solomon et al. 2007). Regional climate model outputs showed a larger percentage of tropical cyclones producing higher wind speeds in the 2070 climate than either the 1980 or 2030 climates, and an average increase of 17% in tropical cyclone-related rainfall occurring within 300 km of the cyclone centre (Abbs 2009 cited in Keenan et al. 2011).

Pressure 2: Temperature

Keenan et al. (2011) report that the decade ending in 2010 has been Australia's warmest decade in recorded history, continuing a trend of each decade being warmer than the previous for the last 70 years. In 2010 the annual mean temperature across Australia was +0.19 °C above the 1961-1990 average of 21.81°C. 2009 was the second warmest year on record based on the mean annual temperature across Australia (Keenan et al. 2011). Alexander and Arblaster (2009) in Keenan et al. (2011) project more warm nights, fewer frosts (below 0ºC), and longer heatwave duration (period of at least five consecutive days with the maximum temperature at least 5ºC above the 1961-90 mean) as being likely throughout Australia in the future. Perkins and Pitman (2009) cited in Keenan et al. (2011) project more extremely high temperatures (1 in 20 annual daily events) and fewer extremely low temperatures for the future climate in Australia (Keenan et al. 2011)

Presure 3: Environmental degradation

Precipitation

Precipitation and temperature patterns associated with climate change are projected to vary throughout Australia. For example, since 1950, parts of south-western and eastern Australia have received declining rainfall. In contrast, parts of north-east Australia have been wetter during summer over the same period. Best-estimate predictions for Australian annual precipitation patterns by 2030 note 'little change in the far north and decreases of 2% to 5% elsewhere' (Saniotis and Irvine 2010). The CSIROMk2 simulation predicts wetter conditions in central Australia and the Top End, but drier conditions elsewhere, while the ECHAM4 from the Max Planck Institute for Meteorology, Hamburg shows wetter conditions north of a diagonal line from Broome to Hobart, and much drier conditions in the west (Bi and Parton 2008).

Drought

Much of rural Australia, especially the south, south-east and parts of eastern Australia experienced a severe and prolonged drought during the period 2001-2007 (Berry et al. 2008). The Bureau of Meteorology concluded that the severity of this drought (2001-2007) was due in part to the underlying warmer temperatures caused by climate change (Nicholls and Collins 2006 cited in Berry et al. 2008). In their climate science update for the 2011 Garnaut Review, Keenan et al. (2011), project that the areas of Australia experiencing exceptionally hot years are likely to increase to 60-80 per cent on average up to 2030. Exceptionally dry years are likely to occur more often and over larger areas in the south and south-west (i.e., south-west of Western Australia and Victoria and Tasmania regions) with little detectable change in other regions for 2010-2040. Moreover, years with exceptionally low soil moisture are likely to occur more often, particularly in these same regions. They caution, however that considerable uncertainty remains regarding the projection of droughts in the future (Keenan et al. 2011).

STATE(S)

The 2007 second National Survey of Mental Health and Wellbeing estimated that 1 in 5 Australians aged between 16 and 85 years experienced one or more of the common mental disorders in the 12 months before the survey. These were mood disorders (such as depression), anxiety disorders and substance use disorders. An additional one-quarter of those surveyed, while not experiencing one of these disorders in the 12 months beforehand, had done so at some time in the past. Thus, 45% of respondents had experienced a mental disorder in their lifetime. This equates to 7,286,600 Australians aged 16 to 85 (Australian Institute of Health and Welfare 2010).

Many people with mental health problems are effectively disabled in their day-to-day functions. According to the 2007 Survey of Mental Health and Wellbeing, people with no physical or medical conditions normally experience, on average, 1 day out of their usual role in the previous 30, whereas people with a mental disorder experienced 3 days out of their normal role in the previous 30 (Australian Institute of Health and Welfare 2010). Based on the 2003 Australian Bureau of Statistics' Survey of Disability, Ageing and Carers, the prevalence of psychiatric disabling conditions was estimated at 5.2% of the Australian population in 2003, around 1 million people. Of the 714,156 Australians receiving the disability support pension as at June 2007, over a quarter (27.3%) had a psychological or psychiatric condition. In line with this, in 2006–07, nearly one in four new claims for disability support pension approved (24% of 62,608) were from those with a psychological or psychiatric condition. It is clear that mental health problems are a leading cause of disability in Australia (Department of Families, Housing, Community Services and Indigenous Affairs, 2009 cited in Australian Institute of Health and Welfare 2010).

Mental health service costs in Australia accounted for $3 billion (6%) of Australia's total health care expenditure in 2001 (Australian Bureau of Statistics, 2005 cited in Berry et al. 2008). In addition to direct service costs, mental health problems account for significant productivity losses among people in paid employment, particularly in terms of reduced effectiveness on the job, and also in terms of sick days (Lim, Sanderon, & Andrews, 2000 cited in Berry et al. 2008).

Mortality

A mental or behavioural disorder was recorded as the underlying cause of death for 667 deaths in 2007, representing 0.5% of all deaths in that year, excluding suicide and dementia. Most of these deaths were due to the use of psychoactive substances such as alcohol and heroin (Australian Institute of Health and Welfare 2010).

Currently, six Australians end their own lives every day (Berry et al. 2008). There were 2,191 deaths from suicide registered in Australia in 2008 (1.5% of all deaths), equating to 10.2 per 100,000 (Australian Bureau of Statistics 2010).

IMPACT(S)

Impact 1: Natural disasters

Bushfires

Parslow et al. (2006) collected data from a community-based survey of 2085 young adults before and after a major bushfire disaster to ascertain the prevalence of post-traumatic stress disorder (PTSD). They found that 5% of all survey participants met the criteria for PTSD, confirming that the mental health impact of such disasters on a local community can be substantial (Parslow et al. 2006).

McFarlane et al. (2009) undertook a 20-year longitudinal follow-up study to determine the adult psychiatric outcomes of childhood exposure to a major Australian natural disaster (bushfire). Seventy-five per cent of the bushfire-exposed group still reported some degree of distress in relation to the bushfires 20 years on. Six of the bushfire survivors (1.7% of those questioned in relation to the bushfire, 1.1% of the entire sample) met full diagnostic criteria for lifetime PTSD in relation to the fires. This finding contrasted with other longitudinal studies, which have reported lifetime rates of PTSD in disaster survivors that have ranged from 34.0 to 51.5%. Despite the major losses to the community, this disaster appeared to have had only a small long-term effect on anxiety levels (McFarlane and Van Hooff 2009).

Yelland et al (2010) examined the association between living through a bushfire and posttraumatic stress disorder (PTSD) in South Australian youth following a fire in January 2005, in which 9 people died and 83,000 hectares of land, including 100 homes were burned. A significant number of young people (27%) reported moderate to severe levels of PTSD symptoms 11 to 15 months after the disaster. Younger children reported greater PTSD symptom severity than the older youth (Yelland et al. 2010).

Floods

There is little empirical research available about the effects of floods on mental health. A qualitative study by Carroll et al. (2010) after severe floods in Carlisle, northwest England, in 2005, revealed that every respondent (n=40) reported varying degrees of anxiety and stress. Symptoms were attributed directly, to primary factors related to the floods themselves such as dangers posed by the floodwaters, damage to property and possessions, evacuation, displacement issues and living conditions or, indirectly, to secondary factors such as disputes with insurance companies or building contractors. Many respondents reported suffering from depression, panic attacks, flashbacks, sleeplessness, a lack of motivation, and unsettled or obsessive behaviour related to the floods. All of the latter are potential symptoms of PTSD (NICE, 2005 cited in Carroll et al. 2010). People who have experienced a flood have been shown to have a fourfold higher risk of psychological distress than do those not exposed to flood, and a suicide rate 13.8% higher than pre-disaster rates (Du et al. 2010).

Impact 2: Temperature

Morbidity

Two Australian studies have demonstrated a significant increase in hospital admissions for mental health disorders during hot weather. Nitschke et al. (2007) found that during heatwaves (>=35°C over 3 or more days) in Adelaide, South Australia in the period 1993-2006, total mental health admissions increased by 7%. There was a small increase in mental health-related mortality (incidence rate ratio = 2.58 = daily mean incidence of deaths during heatwaves over incidence in non-heatwave periods) in people aged 65–74 years (Nitschke et al. 2007). Khalaj et al. (2010) estimated a relative increase in emergency hospital admissions for mental disorders of 7% during periods of extreme heat in five regions of New South Wales in the period 1998-2006 (Khalaj et al. 2010).

Hansen et al. (2008), building on the study by Nitschke et al. (2007), characterized the specific mental and behavioral disorders (MBDs) that may be exacerbated by high temperatures (Hansen et al. 2008). They noted that the 7.3% increase observed in hospital admissions in Adelaide for mental and behavioural disorders during heatwaves occurred above a threshold of 26.7°C. They also elicited the specific disorders contributing to increased psychiatric morbidity and mortality during heatwaves (Hansen et al. 2008). During these periods there were significant increases in admissions for:

- organic illnesses (dementia, cerebral disease, brain injury);
- mood affective disorders (depression, dysthymia, mania, and bipolar affective disorders);
- neurotic, stress related, and somatoform disorders (anxiety disorders, panic disorder, agoraphobia, obsessive compulsive disorder, and posttraumatic stress disorder),
- disorders of psychological development (autism and developmental disorders of speech and language);
- behavioral syndromes associated with physiological disturbances and physical factors (including eating and sleep disorders), and
- senility (including senescence, asthenia and debility relating to mental infirmity).

Mortality

Australian authors Hansen et al. (2008) used regression analysis to demonstrate that mortalities attributed to all mental and behavioral disorders increased by a factor of 2.4 during heat waves in the 65 to 74 year age group. More specifically, deaths in persons with schizophrenia, schizotypal, and delusional disorders increased more than 2-fold during heat wave periods, and dementia deaths increased by a factor of 5 in the 15 to 64 years age group (Hansen et al. 2008).

Impact 3: Environmental degradation

Morbidity

Phillips (2009), cites evidence from the National Health Survey (Australian Institute of Health and Welfare 2008) which suggests that for men, the prevalence of high psychological distress in outer regional areas is 1.2 times higher than in major cities. Additionally, for 45 to 64 year-old men in regional areas, the prevalence of high psychological distress and depression appears to be 1.4 times higher than in major cities (Australian Institute of Health and Welfare 2008; Phillips 2009). Sartore et al. (2008), in a exploratory, qualitative study of the impact of drought on an Australian rural community, documented impacts such as community stress and social isolation as well as individuals' feelings of loss, grief and hopelessness (Sartore et al. 2008). Jardine et al. (2007) discuss the mental health consequences of dryland salinity with resultant environmental degradation, which is partly attributed to climate change. The authors describe a consequential pathway for mental ill-health, which includes reduced productivity, financial stresses, social isolation and solastalgia (Jardine et al. 2007). Speldewinde et al. (2009) found evidence indicating that the environmental degradation of dryland salinity may be driving the degree of psychological ill-health in a rural Australian region. They found the optimal predictive model for the relative risk of depression in the agricultural regions of south-western Western Australia incorporated the following variables: socio-economic status, percentage of the population identified as Aboriginal, and presence of dryland salinity. It is interesting to note that dryland salinity contributed to the relative risk of depression independently of the other variables (Speldewinde et al. 2009). Eckert et al. (2006) determined that psychosocial factors, rather than remoteness or rural location heightens the risk of mental illness in rural populations (Eckert et al. 2006).

Cost

The dollar cost of the psychological impact of drought has been estimated as equivalent to an annual reduction in mean rural household income of $18,000 (Carroll, Fritjers, & Shields 2007 cited in Berry et al. 2008). Flow-on mental health effects (e.g., the erosion of family relationships due to climate-related business stress) are difficult to quantify.

Suicides

Suicide mortality has been identified as one consequence of mental ill-health, especially depression. Rates of suicide for men are higher in regional and especially remote areas in all age groups from 15 to 64 years, with rates for men increasing (from 1.3 to 2.6 times the rates in major cities) with remoteness (Australian Institute of Health and Welfare 2006 cited in Phillips 2009). The suicide rate in Australian male farmers is approximately triple the rate of suicide in urban males and 4-5 times the rate of suicide in women (Bennett and McMichael 2010). The suicide rate in New South Wales has been shown to be related to annual precipitation (Nicholls et al. 2006), supporting the belief that drought in Australia increases the likelihood of suicide. Nicholls et al. (2006) found a decrease in precipitation of about 300 mm would lead to an increase in the suicide rate of approximately 8% of the long-term mean suicide rate. The researchers made the point that although the relationship was weak, suicide, as an extreme psychological event, was an indicator of a much larger, but less quantifiable, degree of human suffering (Nicholls et al. 2006).

BACKGROUND

The World Health Organisation has predicted that mental health problems will be the second leading cause of disease burden worldwide by 2020 (Berry et al. 2008). In Australia, mental illness accounts for an estimated 13% of the national health burden, and is among the 10 leading causes of health issues and has been declared a National Health Priority Area (AIHW 2006 cited in Hansen et al. 2008). Mental ill-health may be precipitated by chronic stress and uncertainty and feelings of helplessness and lack of control (Sartore et al. 2008). It is characterized by alterations in thinking, mood or behavior, and associated distress or impaired functioning. Common mental health problems include

- depression;
- anxiety;
- psychological distress (such as acute traumatic stress or post traumatic stress disorder);
- substance abuse;
- eating disorders;
- dementia.

Less commonly, mental illness manifests as

- schizophrenia;
- bipolar disorder;
- personality disorders.

All mental health problems may be severe and/or enduring (Berry et al. 2010). The individual manifestations of mental health problems are diverse; thus, the exact burden of mental health problems is difficult to quantify (Berry et al. 2008).

Adverse mental health outcomes associated with climate change have been directly attributed to

1. the effects of natural disasters such as floods, cyclones and bushfires (McFarlane and Van Hooff 2009; Parslow et al. 2006; Yelland et al. 2010) on mental health (Page and Howard 2010);
2. the effects of higher ambient temperatures (Hansen et al. 2008; Khalaj et al. 2010; Nitschke et al. 2007) ;
3. the effects of environmental degradation (Sartore et al. 2008; Speldewinde et al. 2009), particularly in rural areas (Bennett and McMichael 2010; Nicholls et al. 2006).

Worsening economic conditions, **indirectly** attributable to climate change, may increase stress and predispose more people to mental ill-health (Page and Howard 2010). Widespread financial hardship related to climate change may result from

- reduced income and employment in climate sensitive industries, such as agriculture and tourism;

- loss of assets and recovery costs from extreme weather events or relocation;
- increases to the cost of essential goods and services, such as energy, water and communications;
- rapid restructuring of emissions-intensive industries including power generation, agriculture and heavy industry;
- reduced food security through disruptions to the global food supply from extreme weather events;
- relatively rapid changes to the viability of agricultural land; and
- increased insurance costs due to increased risk within the insurance industry.

(Fritze et al. 2008).

Other indirect contributors to mental ill-health associated with climate change include migration/displacement, conflict and urbanisation (Page and Howard 2010).

1. THE EFFECTS OF NATURAL DISASTERS, SUCH AS FLOODS, CYCLONES AND BUSHFIRES, ON MENTAL HEALTH

The shock and aftermath of extreme events are significant precursors to mental health problems, including

- acute traumatic stress in the immediate wake of the event;
- post traumatic stress disorder;
- complicated grief;
- depression or anxiety disorders;
- somatoform disorders;
- drug and alcohol abuse;
- domestic violence;
- child abuse, and
- suicide completion and attempts (Fritze et al. 2008).

In studies in Western countries, post traumatic stress disorder (PTSD) occurs in between 10 to 20% of those exposed to common traumas such as motor vehicle and other accidents, assault and natural disasters (Silove and Steel 2006). However, PTSD is only one of several psychological reactions to trauma and disaster, with exposed populations being at risk of a range of other stress-related problems, such as complicated grief, depression, other anxiety disorders, somatoform disorders and drug and alcohol abuse (Silove and Steel 2006). There is also a subgroup with established mental illnesses (e.g., psychosis, mood disorders) who are especially vulnerable and may need urgent care following exposure to the trauma of a natural disaster (Fritze et al. 2008; Silove and Steel 2006).

Floods

Du et al. (2010) maintain major life stressors, such as disasters, increase susceptibility to poor mental health, and mental health problems are a common sequelae of floods. People who experience a flood had a fourfold higher risk of psychological distress than those not exposed to flood (Reacher et al. 2004 cited in Du et al. 2010) and those who had experienced a flood had a suicide rate 13.8% higher than pre-disaster rates (Axelrod et al. 1994 cited in Du et al. 2010) . These mental health problems may derive from physical health problems or from personal losses, social disruption, and economic hardship (Du et al. 2010).

Paranjothy et al. (2011) maintain that the psychosocial and mental health impact of flooding is a growing public health concern. They found the prevalence of all mental health symptoms was two to five-fold higher among individuals affected by flood water in the home. People who perceived negative impact on finances were more likely to report psychological distress, anxiety, depression and PTSD. Disruption to essential services increased adverse psychological outcomes by two to three-fold and evacuation was associated with some increase in psychological distress although it was not significant (Paranjothy et al. 2011).

2. THE EFFECTS OF HIGHER AMBIENT TEMPERATURES ON MENTAL HEALTH

The interaction of heat and psychiatric illness is a multifaceted phenomenon:

1. the psychiatric condition itself can be a risk factor for heat-related morbidity and mortality (Hansen et al. 2008; Schifano et al. 2009; Shiloh et al. 2005; Stafoggia and Forastiere 2006);
2. psychotropic medication use is a risk factors for heat-related death (Martin-Latry et al. 2007; Stollberger and Finsterer 2007; Stollberger et al. 2009), as is substance (e.g., alcohol) misuse (both are prevalent in those with mental disorders);
3. people with mental health problems may be more likely to have maladaptive coping mechanisms and poor quality housing (Page and Howard 2010).

Stafoggia and Forastiere (2006) and Schifano et al. (2009) found evidence of a significant effect of high summer temperatures on mortality in people with preexisting psychiatric illness and depression (Stafoggia and Forastiere 2006; Stollberger et al. 2009). A meta-analysis aimed at identifying prognostic factors in heat wave-related deaths was conducted by Bouchama et al. (2007), who concluded that pre-existing mental health problems tripled the risk of any-cause mortality during a heat wave (Bouchama et al. 2007).

There is also some evidence from studies in other countries suggesting that the incidence of suicides increases with higher ambient temperatures (Lee et al. 2006; Page et al. 2007; Toro et al. 2009). The postulated mechanisms of the observed effect of higher ambient temperatures on the incidence of suicide include:

- Excess alcohol use in hotter weather (Page et al. 2007);
- Reduction in levels of neurotransmitters, such as serotonin (Page et al. 2007) or L-tryptophan (Lee et al. 2006) in hot weather (suicidality, aggression, disinhibition and impulsivity are negatively correlated with higher levels).

3. THE EFFECTS OF ENVIRONMENTAL DEGRADATION, PARTICULARLY IN RURAL AREAS, ON MENTAL HEALTH

Australia is a leading exporter of pastoral products such as wool, lamb, beef, wheat, cotton and canola, and climatic conditions are a major influence on the growth of grassland, subsequent growth of livestock and on other agricultural productivity (Bi and Parton 2008). Changed climatic conditions may contribute to loss of farmland, scarcity of fresh water for irrigation, soil erosion, diminishing fertiliser response, problems associated with pests and the emergence of new types and combinations of food parasites, declining genetic diversity of crops, yield losses or increases and damaging heat stress to temperate crops and livestock (Bi and Parton 2008).

Climate change in Australia is projected to result in drier OR wetter conditions, manifesting differently in different regions; some of which might experience an improvement in climate-related conditions. Specific mental health impacts will depend on

- existing climatic conditions in each region;
- how important agriculture is to the economic base of the region, and what is being farmed, and
- underlying socio-economic vulnerability (Berry et al. 2008).

The mental health of people in Australian rural communities, and the agricultural sector in particular, is considered to be at increased risk due to the effects of climate change (Horton et al. 2010) for the following reasons

1. Living in a rural setting in Australia substantially increases the risk of experiencing one or more natural disasters, and living with the threat of natural disasters on a more or less continuous basis (Morrissey and Reser 2007);
2. Agricultural communities are vulnerable to chronic disasters, such as drought, related to a changing climate; for example, diseases of livestock, exacerbation of salination, soil erosion and pest infestations are associated with flow-on effects such as occupational deprivation, economic impacts, social isolation and displacement (Sartore et al. 2008; Berry 2009; Fritze et al. 2008). Such slow-onset disasters are commonly associated with helplessness-induced depression, ongoing emotional distress and generalised anxiety (Berry et al. 2008);
3. Rural communities also face a rapidly changing demographic and service infrastructure;
4. Rural residents are particularly vulnerable to the effects of solastalgia[1] (Albrecht et al. 2007; Pereira 2008);
5. As Aboriginal and Torres Strait Islander Australians represent a greater proportion of the population residing in rural and remote Australia, with a background of pre-existing health and social disadvantage, they are likely to be disproportionately affected by the social and economic effects of climate change.

Psychological distress is not confined to the farming sector, but also extends to businesses (e.g., agricultural suppliers) and support networks (e.g., seasonal workers) in the rural community (Sartore et al. 2008).

Some authors postulate that the challenges brought about by climate change may result in opportunities for adaptation and resilience which have positive mental health consequences (Berry 2009; Hunter 2009). While health states associated with the social and economic changes resulting from climate change are difficult to study, there appears to be abundant informal evidence that well-being, morale and mental health are affected by changes to the environment (Woodruff et al. 2006).

[1] ‘the distress that is produced by environmental change impacting on people while they are directly connected to their home environment’ (Albrecht et al. 2007)

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RURAL SERVICES

SUMMARY

- A preliminary analysis of the location of infrastructure and community services reveals a large number of facilities within 200m and 500m of the coastline, therefore at risk from inundation under a changing climate.

- A general increase in fire risk over Australia is projected as the climate warns. Of concern is the number of hospitals, police, fire and ambulance stations very close to the coast. Compromised functioning of these services during an extreme weather event can result in significantly greater impacts than might otherwise occur and could have life and death consequences.

- Coastal communities, families and individuals are thus likely to bear the brunt of the early stages of climate change. In many areas, those communities are encountering increasing stresses from water shortages, warmer average temperatures, and more extreme bushfires.

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Human Settlements, Industry, and Infrastructure/key economic sectors and services

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Sea level rise
Extreme events

PRESSURE(S)

Pressure 1

A consistent increase in regional-scale fire risk over Australia is projected driven principally by warming and reductions in relative humidity in all simulations, under all emission scenarios and all time periods (two future emission scenarios (relatively high and relatively low) are used for 2050 and 2100 and four realizations for each time period and each emission scenario were run under Regional Atmospheric Modelling System (RAMS)). Fire risk for a single point in New South Wales shows that the probability of extreme fire risk increases by around 25% in 2050 compared to the present, under both low and high emission scenarios, and that this risk increases by at least further 20% by 2100 (under the low emission scenario). The likelihood of a significant increase in fire risk over Australia resulting from climate change is very high. While there is already substantial investment in fire-related management in Australia, results indicate that this investment is likely to have to increase to maintain the fire-related losses in Australia at present levels (Pitman et al. 2007).

Pressure 2

The drivers of regional development and regional decline are critical considerations for health service planners both in the present and in the future. The sustainability of many small rural and remote communities in Australia is in question. The impacts of changing rainfall patterns and water availability and rising fuel costs has been profound on many agricultural communities. Erosion of their traditional economic base and de-population calls into question the viability of these communities (Humphreys and Wakerman 2009).

STATE(S)

There are many facilities supporting the delivery of community services in close proximity to the coastline there at risk from rising sea-levels (DCC 2009). They include 258 police, fire and ambulance stations, 5 power stations/sub stations, 75 hospitals and health services, 41 landfill sites, 3 water treatment plants, and 11 emergency services facilities within 200m of the shoreline (Table 1).

Table 1 Services and facilities within 200m and 500m of the Australian coastline (source: Geoscience Australia 2009. NEXIS database; cited in DCC 2009).

Services and facilities	Within 200m of the coastline	Within 500m of the coastline
Police, fire and ambulance stations	258	702
Hospitals and health services	75	199
Government administration facilities	46	107
Universities, colleges and schools	360	992
Retirement/nursing homes	102	296
Emergency services facilities	11	35
Waste disposal facilities	41	92

The rate of growth in coastal areas outside the capital cities is consistently higher than the national average. In just over a decade from 1997 to 2008 the population of non-metro coastal areas increased from 4.9m to 6.4m at an average rate of 131,000 people a year. This population now represents 83% of Australia's regional population and 30% of the nation's entire population (NSCTI 2010). The delivery of essential services such as electricity generation and wastewater management will increasingly be affected by inundation, erosion, the effects of sea water intrusion into coastal freshwater systems and drainage systems, and increased corrosion (DCC 2009).

About 3 % of Australia's total population live in areas characterised as remote or very remote. This is about 650,000 people – the equivalent of the combined populations of Darwin, Hobart, Townsville, Toowoomba and Bendigo. Given the critical mass required for the provision of certain services and the results likely to be delivered to small populations by an unfettered market, one of Australia's current challenges is how to deal with communities that are small and/or isolated. Compounding the urgent need for local and affordable services is that more than half the areas classified as Very Remote are in the bottom quarter of socio-economic areas in Australia (NRHA 2009).

IMPACT(S)

Observed:

IO1: Health service-In the future, climatic events such as tropical cyclones, storm surges, drought and wildfires, will bring a host of health effects from injuries to nutritional deficiencies to mental health conditions as more people, particularly indigenous peoples, experience food security issues and displacement (Bell 2009). A particular challenge of providing primary health care service will be to support communities most vulnerable to climate change such as those in rural and regional areas (Blashki et al 2007). Already the impact of extended drought on the economic base and viability of many rural and remote communities and the livelihood of their residents is evident, while the deleterious affects on the mental health of farming families are all too obvious (Humphreys and Wakerman 2009).

Projected:

IP1: Water and wastewater service- Securing a reliable water supply for Australia's coastal residents outside of the capital cities is not only crucial for the survival of those communities but is also important for the Australian economy and society (DCC 2009). With much of Australia's population living within the coastal zone, significant water and wastewater infrastructure has been built to accommodate coastal cities and communities, with some assets located in very close proximity to the coast (Table 1). A survey of coastal councils in 2005 noted the ability to provide good quality water to the community as a significant concern (ALGA 2005). A number of coastal freshwater aquifers will be increasingly exposed to saline groundwater intrusion with rising sea levels. Freshwater contaminated by seawater at the level of only 5% renders it unsuitable for domestic water consumption and for some irrigation and industrial uses. Increasing maintenance and renewal costs of drainage assets and an increased risk of local flash flooding are likely to result. Saltwater may increasingly enter because of factors such as cracks in pipes caused by ageing or movement, and the presence of seawater reduces system capacity and increases operational costs.

IP2: Waste – landfill service- There is a large legacy of many 'tips' and 'dumps' long closed, but located in areas vulnerable to the future impacts of climate change and sea-level rise. For example large, multi-million dollar landfills in Cairns and Brisbane are located in low-lying areas (DCC 2009). Many old dumps are sited in or adjoining flood prone and low-lying lands. The Cairns landfill, for example, is in the final stages of its life and is located adjoining low-lying mangroves. It is known however that most landfills contain quantities of oil, demolition waste, asbestos, pesticides, plastic and heavy metals fixed into the soil/waste matrix. If this were released back to the environment it would constitute a significant environmental hazard. The cost of relocation would range from thousands of dollars, to many millions depending upon the size of the landfill (DCC 2009).

IP3: Energy supply- At least 11 power plants/substations are located within 500m of the coastline (DCC 2009). For power stations located very close to the coast storm surge and resultant flooding will obviously pose a great risk as will damage to powerlines from destructive winds. Generation facilities may cease operation in preparation for a flood and if infrastructure is flooded, delays in restarting generation will occur (DCC 2009). If storm surge travels a long way inland, storm surge protection may be lacking for more inland substations and generators, as occurred for Hurricane Katrina in the US, which reached 24 kilometres inland and resulted in the replacement of over a million powerlines (Yates & Mendis 2009; cited in DCC 2009). Destructive winds can also increase salt aerosols deposits on electricity conductors, leading to flashovers and corrosion. Many power stations are subject to an upper temperature limit for discharged cooling water. On hot summer days, the temperature of cooling water can be close to this specified limit and the power station will have to operate at a reduced level to accommodate water temperature requirements, and hot summer days are often times of peak energy demand (DCC 2009).

IP4: Fire management service-By using two climate change projections as lateral boundary conditions to explore how forest and grassland fire risk might change over Australia for 2050 and 2100, it is found that there is a general increase in fire risk over Australia as the climate warms (Pitman et al. 2007). This was common to both emission scenarios for both 2050 and 2100. However, the impact of the higher emissions in the A2 scenario led to a very much higher risk of forest and grassland fires by 2100 than the B2 scenario (Pitman et al. 2007). Australia will be significantly more exposed to forest and grassland fire risk in the future (Pitman et al. 2007). In reference to the result of using the McArthur forest fire danger index (FDI) by Beer and Williams 1995; cited in Pitman et al. 2007, it is found an increase in fire danger over Australia due to a doubling of CO_2. The projections agree for Perth (10–25% increase) and Melbourne (no change). However, the higher emission scenarios under A2, and the higher warming and stronger decreases in relative humidity has a major impact on forest fire danger index (FDI) and grassland fire danger index (GDI) for Canberra, Sydney and Brisbane. Under B2, Canberra is projected to increase by 10–25% while Brisbane and Sydney are projected to increase by 25–50%. Under the A2 scenario these increase to at least 50–100% in Brisbane and Sydney. A change in the frequency or intensity of fire in Australia would likely have severe consequences increasing economic losses and the costs of fire management strategies (Pitman et al. 2007). A change in the frequency or intensity of fire in Australia would also dramatically affect plant population dynamics and plant community composition (Gill 1997) placing species near an extinction threshold at risk (Cary 2002; cited in Pitman et al. 2007

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TOURISM

SUMMARY

- The Australian tourism industry is strongly dependent on natural ecosystems and their extent and quality, and the industry will be affected by climate change (Turton et al. 2010) through additional pressures on major ecological sites, tourism infrastructure, and changes in weather including more frequent severe weather events.

- Many of Australia's areas which area vulnerable to climate change, such as the Great Barrier Reef, Queensland's Wet Tropics and Kakadu are also major tourism destinations (DRET 2008).

- A large part of the industry consists of small operators who are therefore more vulnerable to significant economic losses (DCC 2009). The tourism sector is in reluctant to invest in climate change adaptation because of the perceived uncertainties (Turton et al. 2010).

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Projected Impact

CATEGORY(S)

Tourism

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Water CO_2
Solar radiation
Ocean currents
Extreme events
Sea level

PRESSURE(S)

Australia's tourism industry is particularly vulnerable to the effects of climate change and sea-level rise. Many of the tourist icons, such as the Great Barrier Reef and coastal islands and beaches, are in regions that are likely to be affected by storm surge, sea-level rise or increased cyclone intensity (DCC 2009). Due to the risk of increased cyclone intensity, increased sea surface temperatures leading to coral bleaching, and increased ocean acidification resulting in reduced coral formation, tropical north Queensland is probably the most threatened tourism region in Australia in terms of absolute numbers of holiday visitors exposed to the effects of climate change (DCC 2009).

Climate projections at the national scale suggest significant increases in mean annual temperatures, coupled with reduced annual rainfall in most regions. This will stress natural resources and the many industries dependent on these resources for their livelihood, notably agriculture and tourism (Turton et al. 2010).

Climate change will directly affect Australian tourism through loss or degradation of attractions, the costs of adaptation and replacement of infrastructure (STCRC 2007). Extreme weather events, such as cyclones and storm surges, can affect infrastructure, such as buildings and roads, thus affecting tourism access (NT Tourism 2009). Attractiveness of destinations is likely to decline where weather events become more extreme.

STATE(S)

Tourism provides employment for almost half a million Australians, and is the lifeblood of many regional communities. It is Australia's leading services export: contributing $24 billion or just over 10% of total export earnings (DRET 2010), employing 853,000 Australians (directly and indirectly) or 8.3% of total employment (Australian Department of Resources, Energy and Tourism, 2009; cited in Pham et al. 2010). In 2003–04, an estimated $20 billion was spent on recreation and tourist activities directly involving coastal and ocean ecosystems (Haines and Thom 2007; cited in DCC 2009). Coral reefs are critical to Australia's economic wellbeing: they are the basis for much of Australia's tourist industry, generating an estimated $6.1 billion in revenue from tourism each year (DCC 2009). Around 5.8 million visitor nights (35 % of total inbound tourism) are spent in tourism regions regarded as 'extremely vulnerable' to the effects of climate change (DCC 2009).

IMPACT(S)

Since Australia relies heavily on nature-based tourism, which is most at risk from direct climate change impacts, Australia is likely to be a net loser from changing international patterns of tourism as a result of climate change (STCRC 2007). Some strategic drivers associated with climate change that are likely to directly influence tourist destination choice include increased temperatures; increased demand and competition for water; increased demand for energy; increased sensitivity and interest in the environment; and changing attitudes affecting consumer preferences for types of products purchased and transport systems (Miles 2005; cited in STCRC 2007).

Observed:

The disrupting effect of severe weather events on tourism business is exemplified by the collapse of a large section of the Barkly Highway in the Northern Territory of Australia due to extraordinary flooding in January 2009, which cut off northern access between Queensland and the Northern Territory for a number of weeks. Cyclone Monica (April 2006) and Tropical Low George (March 2007) both resulted in substantial flooding in the Kakadu region. The accommodation at Gagudju Lodge Cooinda was inundated on both occasions and during the 2007 event a culvert on the Arnhem Highway was destroyed, which rendered the Arnhem Highway inaccessible for a month. Events such as these have significant flow-on effects. They increase the threat to visitor safety, costs are involved in evacuation of visitors, tourism businesses lose revenue from booking cancellations, infrastructure is damaged, and the cost of insurance increases (on top of the already high insurance premiums in the Northern Territory) for businesses directly affected by these extreme weather events (NT Tourism 2009).

Projected:

IP1: The value of the Great Barrier Reef to the Australian economy was calculated to be 4.7% of annual GDP (Oxford Economics 2009). The present value of the Great Barrier Reef to the Australian economy was $51 billion; the cost of coral bleaching could erode $38 billion of that value (Oxford Economics 2009, DCC 2009).

IP2: Kakadu, Northern Territory, is vulnerable to sea-level rise. Kakadu's unique freshwater wetlands are highly vulnerable to saltwater intrusion. A loss of wetlands, together with the birds, reptiles and other animals it supports, would result in a rapid decline in tourist numbers (DCC 2009). It is also likely that the impact of loss of wetland areas, increased extreme weather events and increased heat-related, vector-borne and water-borne illness will have a negative impact upon Aboriginal communities in the region. This may further restrict opportunities for cultural tourism within the Park and increase pressure on existing indigenous tourism enterprises. The CSIRO models of the predicted impacts of climate change suggest that 80% of Kakadu's freshwater wetlands would be lost under a 2^{o}C temperature rise scenario (Preston and Jones 2006; cited in STCRC 2007).

IP3: Increased temperatures will also reduce visitor comfort and increase the incidence of heat stress or heatstroke. Similarly, increased rainfall as a result of climate change will also extend periods of inaccessibility of park features, reduce visitor enjoyment and increase damage to tourism infrastructure (DCC 2009).

IP4: Highly developed tourism areas, such as the Gold Coast and Sunshine Coast, also depend on tourism to support regional economies and are vulnerable to sea-level rise, erosion and storm surges. The low-lying nature of many of the tourism and housing developments, particularly canal estates and coastal housing, leave these areas vulnerable to storm inundation and beach erosion (DCC 2009).

IP5: The economic benefits of tourism may be reduced by climate change impacts on income earners. As tourism is relatively labour-intensive, a reduction in tourism demand will result in job losses and lower wage incomes, potentially increasing inequality and imposing additional wages costs on the society (Pham et al. 2010).

RESPONSE(S)

R1: Tourism Australia's *Brand Health Monitor Survey - Attitudes to Climate Change and Environmental Degradation, 30 March 2009* indicates that consumers in key Australian tourism markets are increasingly focusing on climate change and environmental sustainability when making purchasing decisions. Through enhancing awareness of environmental protection and sustainability, and ensuring proper management of natural assets, Australia has the opportunity to counteract negative consumer perceptions and purchasing behaviours, and to gain significant economic, social and cultural benefits from sustainable tourism (DRET 2009).

R2: In the short to medium-term, government climate change policy reforms will have associated flow through costs that will affect the tourism industry and broader service sectors. Governments can provide a framework to help businesses prepare for a carbon-constrained future and move to a low-pollution economy, but for this to be effective, industry must take advantage of Commonwealth Government programs, such as the Climate Change Action Fund (funded from 2009 to 2015) (DRET 2009).

R3: Many Australian tourism operators have developed clean green tourism products, but the industry must continue to focus on developing and implementing innovative practices that will enhance Australia's status as a green destination (DRET 2009).

R4: the Climate Futures Adaptation Plan is a planning package developed by CSIRO and Tourism Queensland specifically for coastal tourism operators in the Cairns and Airlie regions (Thomas 2011). The Climate Futures Tool is designed to be used in a workshop setting where tourism operators meet with local councils, tourism bodies, scietists and others to learn and share about how to prepare for climate change (www.tq.com.au/tqcorp_06/fms/tq_corporate/industrydevelopment/Climate%20Futures%20Industry%20Tool.PDF).

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VECTOR BORNE DISEASE

SUMMARY

- Outbreaks of dengue fever have become more frequent and more severe in Australia, consistent with global trends.
- The annual cost of dengue fever is currently estimated to be $1.2 million.
- Under predicted climate change scenarios, substantial geographic expansion of the dengue risk region is expected to occur.

CONTEXT

This statement is compiled from scientific literature and published reports

EVIDENCE

Observed Impact; Projected Impact

CATEGORY(S)

Human health: Vector borne and zoonotic

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Humidity
Sea level rise
Ocean salinity

PRESSURE(S)

There is evidence indicating that global climate change is affecting the seasonal and geographical distribution of dengue fever in the Asia-Pacific region; however, the empirical evidence linking dengue to climate change is considered inconsistent across geographical locations (Banu et al. 2011). The adult dengue vector *Aedes aegypti* has been found to be more abundant in times of higher humidity and temperature (Azil et al. 2010). Humidity has also been found to be the climate variable that explains the highest proportion of the variability in dengue outbreaks. Other climate variables such as ambient temperature have been found to influence the life cycle rate and geographic distribution of mosquitoes (Bambrick et al. 2008).

Kearney et al (2009) used biophysical models to predict the direct impact of climate change on the distribution and abundance of *Ae. aegypti*, concluding that although climate change will directly increase habitat suitability throughout much of Australia, the potential indirect impact of changed water storage practices by humans in response to drought may have a greater effect (Kearney et al. 2009). In a similar vein Beebe et al. (2009) concluded that the future risk of increased *Ae. aegypti* range expansion in Australia would not be due directly to climate change, but rather to human adaptation to drier conditions through the installation of large water storage containers (Beebe et al. 2009).

The following additional factors are expected to compound the impact of climate change on the incidence of vector-borne diseases:

- increasing international travel and trade
- changes in land use and deforestation
- increasing population size, particularly in coastal regions
- adaptations to water shortages, such as increased use of domestic water tanks
- increasing urbanisation

(Bambrick et al. 2008; Kearney et al. 2009; Leisnham et al. 2006; Tatem et al. 2006)

STATE(S)

Numerous climatic zones exist in Australia but dengue virus vectors flourish in warm wet conditions (e.g., the tropics). Queensland, the focus region of concern for dengue outbreaks, has both tropical and sub-tropical climates with average temperatures of 25°C in summer and 15°C in winter. Monthly rainfall varies regionally and seasonally, ranging from 0 mm to 1149 mm by local government areas between January 1993 and December 2005. Most of the state receives over 50% of its rainfall during summer (Hu et al. 2010b). As a consequence of this climatic regime, the north and central areas of Queensland and the Northern Territory are considered potentially receptive to the establishment of dengue (Bambrick et al. 2008) p. 39). Local transmission now occurs in most years in northern Queensland where the main dengue vector, *Ae. aegypti*, is active year-round, however its distribution also extends into sub-tropical coastal central Qld, and some arid inland areas (Mottram et al. 2009, in (Williams et al. 2010). Areas of northern Australia where *Ae. aegypti* has not been recently reported (e.g., Darwin, Northern Territory) are considered vulnerable to re-establishment of the species, as evidenced by recent infestations at Tennant Creek and Groote Eylandt (Northern Territory) (Williams et al. 2010).

The population at risk of contracting dengue fever in North Queensland (Cairns, Townsville and the Torres Strait) in the 2006 census was estimated by Bambrick et al. (2008) to be 430,000. Based on data from 1991 to 2008, the annual average number of confirmed indigenous (i.e., not imported) cases - incidence - of dengue fever is 47 per 100,000 (200 cases) (Bambrick et al. 2008).

IMPACT(S)

Observed

Impact 1

Consistent with global trends, outbreaks of dengue have become more frequent and severe in Australia, occurring predominantly in Cairns, Townsville and the Torres Strait islands, with cases also reported in Kuranda, Mareeba, Mossman, Port Douglas, Innisfail and Tully (Queensland Health 2010; Vazques-Prokopec et al. 2010; Hu et al. 2010a). Five major epidemics (three affecting the Torres Strait) and many smaller epidemics occurred between 1992 and 2004, whereas the five previous epidemics occurred over a 90 year time span (Bambrick et al. 2008).

Impact 2

The annual estimated cost of dengue has been estimated to be $1.2 million, based on costs from 2006 to 2008. This includes the costs of surveillance and control, diagnosis, treatment and hospitalisation. Surveillance and control comprise over 90% of the health-related costs of dengue. The number of work days lost per year due to dengue, based on confirmed as well as subclinical cases is estimated to be 2,117 (Bambrick et al. 2008).

Projected

Impact 3

Under current socio-epidemiological and predicted climate change scenarios, substantial geographic expansion of the dengue risk region is expected to occur. For example, an empirical model based on regression of climate parameters from dengue epidemics around world shows that under the warmer, wetter U3[1] scenario, people in areas as far south as northern New South Wales could be affected by dengue fever by 2100 (Bambrick et al. 2008). Barbazan et al. (2010) used a simulation model which included biological parameters of the vector population to estimate the effect of temperature on the transmission of dengue. They concluded that global warming will increase the probability of virus transmission by dengue vectors and permit the colonization of new areas by the main dengue vectors, *Ae. aegypti* and *Ae. (Stg.) albopictus* (Barbazan et al. 2010). A decrease in the average Southern Oscillation Index (SOI) during the preceding three to twelve months has been significantly associated with an increase in the monthly numbers of postcode areas with dengue fever cases (i.e., widened geographic distribution of dengue) (Hu et al. 2010b). Hu et al. (2010a) suggest that the geographic range of dengue transmission had already begun to extend south-easternwards in Queensland between 1993 and 2004 (Hu et al. 2010a).

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[1] **Unmitigated Scenario 3:** Warm, wet scenario using A1FI emissions path, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100. Source: Bambrick et al. (2008)

Impact 4

By 2100, under an unmitigated (U3)[1] scenario, it is anticipated that 8,000,000 people will be living in a region suitable for the transmission of dengue fever, as climatic conditions become more conducive to range expansion of the dengue vector (Bambrick et al. 2008). The percentage change in the number of people exposed to dengue in Australia from 2000 to 2100 under a warmer, wetter unmitigated scenario (U3) is estimated to be +2500%. This translates to a projected total of 7.93 million people exposed to dengue in 2100, with associated health costs estimated as $22,360,000. Total work days lost due to dengue in 2100 under this scenario are expected to reach 39,700 (Bambrick et al. 2008).

RESPONSE(S)

Response 1: Chemical control

Larval control and interior spraying undertaken by the Dengue Action Response Team (DART) of Queensland Health, under the auspices of the state Dengue Fever Management Plan for North Queensland reportedly led to the suppression of dengue transmission and elimination of the virus in four outbreaks from 2004 to 2008. (Queensland Health 2004; Rapley et al. 2009)

Response 2: Mosquito traps

Lure and kill traps reportedly do not increase the mortality rate in mosquito populations nearly as effectively as conventional pesticides can; however an incremental reduction in the older individuals in a population can be achieved, reducing the probability that a mosquito will live long enough to transmit a pathogen (Rapley et al. 2009). Moreover trap advantages include reduced pesticide use, (reduced environmental impact and cost), and improved efficiency of the vector control teams. The traps have proven to be a valuable adjunctive method of vector control (Ritchie).

Response 3: Early detection monitoring

The Vector-borne Disease Early Detection and Surveillance (VEDS) System provides timely access to disease data for Ross River virus and Barmah Forest virus in Queensland. Data from the Notifiable Diseases Database managed by Queensland Health is transferred to the VEDS System weekly. Notifications are mapped to the Local Government Area (LGA) and an outbreak detection algorithm is applied to help inform local government and public health officials of current disease levels (Queensland Institute of Medical Research 2011).

Response 4: Outbreak prediction modelling

Research shows that meteorological variables can be used prospectively to predict short-term changes in dengue vector abundance and prevent or ameliorate disease outbreaks (Hu et al. 2010b), (Azil et al. 2010), (Hu et al. 2010a). It has also been demonstrated that climate data can be used to predict mosquito-borne diseases such as Ross River virus disease epidemics in south-eastern Australia, with sufficient lead-time to be of use for planning public health responses (Woodruff et al. 2006).

Hu et al. (2006) developed an epidemic forecasting model using local data on rainfall and mosquito density to predict outbreaks of Ross River virus disease in Brisbane. They were able to show that both rainfall and mosquito density were strong predictors of the RRV transmission in simple models, with 85% and 95% of the variance in the Ross River virus transmission being accounted for by rainfall and mosquito density, respectively (Hu et al. 2006). Similarly Woodruff et al. (2006) demonstrated that climate data (tide height, rainfall, sea surface temperature) when combined with mosquito counts produced an early warning model for Ross River virus with a sensitivity of 90% (Woodruff et al. 2006).

Response 5: Airport screening

Thermal scanning in airports may be useful to detect fever in incoming travellers however the efficacy of this measure is dependent upon quarantine laws mandating assessment of febrile travellers following detection. (McBride 2010)

Response 6: Vaccine development

Significant progress is being made with vaccine candidates, some of which have advanced to evaluation in human subjects in countries with endemic disease. (McBride 2010), (Organization 2009; Williams et al. 2010)

Response 7: Biological control

The bacterium *Wolbachia*, a parasite of *Ae. aegypti*, is currently being investigated as a biological control agent to prevent transmission of viruses such as dengue. Since the majority of dengue virus transmission is accomplished by older mosquitos, infection of mosquitoes with *Wolbachia* halves the life span of the vector, reducing the proportion of infectious mosquitoes and subsequently, transmission. This bacterium has also been shown to interfere with the replication of the dengue virus in the mosquito. This approach is currently undergoing open field testing near Cairns, North Queensland (Popovici et al. 2010).

Response 8: Regulation of water storage behaviour to minimise mosquito breeding

Under Queensland's Public Health Regulation 2005, all rainwater tank openings (for example inlet and overflow pipes) must have mosquito proof screens and flap valves that, when closed, must stop mosquitoes passing through the openings (Government of Queensland 2005). Another example of this type of response is Cairns Regional Council’s introduction in 2009 of a $400 on-the-spot fine for residents found to have live mosquito larvae on their properties (Cairns Regional Council 2009).

Response 9: Genetic modification of vectors

The goal of genetic modification of vectors is to release genetically modified mosquitoes (e.g., sterile) to reduce population densities, or to replace the wild population with a disease-resistant one. Oxitec announced that it had released the world’s first sterile male mosquitoes on Grand Cayman island in November 2010. These releases reportedly reduced the local population of *Ae. aegypti* by 80% (Oxitec 2011).

Response 10: Education campaigns on decreasing exposure

An important element of dengue management is the education of members of the public about their role in eliminating dengue mosquito breeding at home and protecting themselves from dengue. Education programs in Queensland use media releases, public relations, advertising, promotional materials (brochures, posters), training sessions and information sheets. Programs are either targeted at the general community or specific community settings such as schools, work sites and travellers' hostels (Queensland Health 2008).

BACKGROUND

Vector-borne diseases are those which are carried and transmitted by an intermediary organism, usually arthropods. Mosquitoes, ticks and sandflies are the most notable disease vectors in humans. In Australia, mosquito-borne diseases of importance include

- Dengue fever
- Ross River virus
- Barmah Forest virus
- Murray Valley encephalitis
- Japanese encephalitis
- Kunjin virus
- Malaria
- Chikungunya virus
- West Nile virus

(Department of Health and Ageing 2010).

Key determinants of vector-borne disease prevalence include

1. the abundance of vectors and hosts
2. the prevalence of disease-causing pathogens
3. the local environmental conditions, especially temperature and humidity
4. the resilience behaviour and immune status of the human population.

The factors contributing to the effects of climate change on vector-borne diseases include

1. Vector, host and reservoir ecology
2. Human culture and behaviour, e.g., variations in agricultural practice and demographic movements
3. Land use
4. Abiotic factors: temperature, precipitation, relative humidity, wind, solar radiation, water systems, topography
5. Biotic factors: vegetation, hosts, natural predators, parasites, and pathogens of the vector

A key point to note is that the effect of any climate changes will affect different vectors and the pathogens they transmit differently, because of their different ecologies.
The effects of climate change on disease organisms and their vectors can be categorized as

- effects on physiology (e.g., metabolic or development rates)
- effects on distribution
- effects on phenology (i.e., timing of life-cycle events)

- effects on adaptation of vectors and disease organisms

(Hughes 2000).

Ross River fever

Ross River virus infection is the most prevalent vector-borne disease in Australia (Harley et al. 2001, Russell 2002 and Gatton et al. 2004 in Hu 2006), with about 5000 cases occurring in Australia annually (Woodruff et al. 2006). This infection is characterized by muscle and joint pain, lethargy, headache, fever and rash. The arthritic symptoms can be severe and debilitating and may persist for months. There is no treatment. The yearly cost is conservatively estimated to be $2.7–5.6 million (Hu et al. 2006).

More than thirty mosquito species from a variety of habitats have been implicated as vectors of Ross River virus (Mackenzie et al. 1994 and Russell 1994 in Tong 2008). Included are *Ochlerotatus vigilax* and *Ochlerotatus camptorhynchus*, which breed in intertidal wetlands, and *Aedes* species which breed in flooded inland areas. *Culex annulirostris*, which breeds in vegetated fresh water, is also found in irrigated areas or those subject to flooding. Species such as *Ochlerotatus notoscriptus* may be important disease vectors in semirural and urban areas (Tong et al. 2008). Transmission cycles of Ross River virus disease appear to be sensitive to climate and tidal variability (Tong et al. 2008).

Dengue fever

Dengue fever is the principal focus of this impact statement, as it is the most rapidly spreading vector-borne disease in the world (WHO 2006). In terms of morbidity, mortality and economic costs, it is the most important mosquito-borne viral disease of humans (Queensland Health 2004). Moreover, once established in a country, dengue virus can be extremely difficult to eradicate (Bambrick et al. 2008).

The main vector for dengue fever, the mosquito *Aedes (Stegomyia) aegypti*, prefers to breed in the urban environment and to feed on humans. The female lays her eggs in water lying in buckets, tarpaulins, tyres, pot plant bases, vases, boats and coconut shells. Roof guttering, rainwater tanks and palm fronds are also potential breeding sites. The adult female hides in and around urban dwellings, resting on dark surfaces such as behind and under furniture or on clothing in cupboards, and bites during the day.

Clinical manifestations of dengue fever vary from asymptomatic infection to serious disease. Most commonly, dengue fever manifests as a debilitating flu-like illness lasting around seven days. Symptoms include fever, headache, muscle and joint pains, fatigue and rash. Dengue haemorrhagic fever is a severe immune-mediated complication of dengue virus infection occurring in up to 1% of cases, with a mortality rate of 10–20%. There is no specific treatment for dengue fever (Esler 2009).

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WATERBORNE DISEASE

SUMMARY

- Climate change will increase the risk of exposure to waterborne pathogens during, particularly in the aftermath of storm surges and inundation events associated with extreme weather events (tropical cyclones, intense precipitation) and projected sea level rise.
- Climate change will increase the risk of water scarcity during prolonged droughts
- There is evidence of increased risk of waterborne disease in the event of catastrophic failure of water supply and sanitation infrastructure

CONTEXT

This statement is based on a synthesis of peer-reviewed journal articles

EVIDENCE

Projected Impact

CATEGORY(S)

Human health, well-being and security

REGION

Australia

DRIVER(S)

Temperature
Precipitation
Extreme weather events
Sea level rise

PRESSURE(S)

The key climatic variables influencing waterborne disease outbreaks are temperature, precipitation, sea level and extreme weather patterns.

Higher temperatures are known to favour the growth of naturally occurring pathogens and harmful organisms such as *Naegleria fowleri, Legionella*, Cyanobacteria (Cunliffe (2011) (Bambrick et al. 2008). Cunliffe (2011) refers to cases of primary amoebic meningitis, a rare but almost always fatal condition, caused by *Naegleria fowleri.* This amoeba grows in warm fresh water ranging in temperature from 25-44°C but prefers >30°C. Cysts change into infective flagellate forms which can enter the brain through the olfactory neuro-epithelium. Situations where *Naegleria fowleri* was detected in piped water supplies (classified as non-potable but used for domestic purposes) in South Australia, were associated with extended periods of elevated air temperatures (exceeding 35°C) (Cunliffe 2011).

Australia has the lowest percentage of rainfall captured as runoff as well as the lowest runoff volume of any inhabited continent. Goater et al. (2011) assert that the security of freshwater resources in Australia is likely to be eroded further under different projected climate regimes and that these impacts will vary regionally. Ongoing water security problems are very likely to increase in southern and eastern Australia (e.g., a 0–45% decline in runoff in Victoria by 2030 and a 10–25% reduction in river flow in Australia's Murray-Darling Basin by 2050) and in Northland and some eastern regions of New Zealand (IPCC 2008). The same report maintains the risk of flooding of Australian coastal towns near rivers, is likely to increase due to climate change, leading to a higher probability of damage to major infrastructure such as floodplain levees and urban drainage systems. Design criteria for extreme events are very likely to be exceeded more frequently by 2030 (IPCC 2008).

The projected changes in temperature, precipitation, sea level rise and frequency and severity of extreme events are expected to lead to a range of water supply and quality challenges due to the following:

- Sea level rise leading to salinisation of coastal aquifers (Goater et al. 2011);
- Alternating periods of aridity and precipitation tending to increase pollutant and turbidity concentrations (Goater et al. 2011);
- Increasing evaporation, resulting from a combination of decreasing rainfall, increasing solar radiation, decreasing cloud cover and increasing temperatures (Goater et al. 2011);
- Flooding, resulting from more frequent heavy rainfall events (Soh et al. 2008);
- Large-scale bushfires, contributing to the concentration of air pollutants and increasing the organic matter constituents in the surface runoff of fire-affected regions;
- Increasing or decreasing quantity of surface runoff in various regions;
- Water shortages, particularly in winter rain-fed systems that are already under stress; and
- Earlier onset of stratification and later turnover (natural mixing) in large water reservoirs, as a result of increased ambient temperatures, which may magnify the problems associated with stratification such as algal blooms, anoxic water, excessive dissolved metals, foul odour and taste (Soh et al. 2008).

STATE(S)

Potable water quality in Australia is generally of a very high standard and contamination is rare, especially for major population centres. In 2007–08, 82% of all water utilities reported full compliance with microbiological and chemical contamination standards (National Water Commission 2009 cited in (Australian Institute of Health and Welfare 2011). However Hanna and Spickett (2011) maintain that under current climate change projections the capacity to provide safe drinking water to Australian communities will be a major problem.

Fifty-four of 6,515 gastroenteritis outbreaks (0.83%) reported to OzFoodNet from 2001 to 2007 were classified as either 'waterborne' or 'suspected waterborne'. Drinking water was the suspected source for 19% (10/54) of the outbreaks and 78% (42/54) were attributed to recreational water. Most outbreaks occurred during the summer months. Of the 10 gastroenteritis outbreaks attributed to drinking water, six occurred at camps, three in aged care facilities and one in a public rural bore water supply. *Salmonella* sp. was implicated in five outbreaks, *Campylobacter jejuni* in three, *Giardia* in one, and one was due to an unknown pathogen. Of the 42 outbreaks attributed to recreational water, 41 were reported to be due to *Cryptosporidium* contamination in swimming pools, and *Salmonella litchfield* was implicated in the other. The authors of an article based on these data (Dale et al. 2010) concluded that, among reported water-associated gastroenteritis outbreaks in Australia, recreational exposure is currently more common than a drinking water source. However, the authors maintained that ongoing surveillance for all waterborne outbreaks is important, especially as drought conditions may necessitate replacement of conventional drinking water supplies with alternative water sources, which could increase health risks.

Bambrick et al. (2008) note that for Australia as a whole, bacteria account for 36% of all notified gastroenteritis cases, viruses for 49% and parasites (*Cryptosporidium* and *Giardia*) for 15%. Between 1998[1] and 2005, there were 2,204 occurrences of cryptosporidosis recorded, representing an 8.8% relative contribution to a total of 24,950 notified pathogenic causes of gastroenteritis in Australia. It was suggested that the observed spring and summer excess for cryptosporidiosis notifications may be largely due to recreational factors (i.e., more outdoor activity) and rainfall runoff rather than ambient temperature (Bambrick et al. 2008). The projected higher temperatures associated with climate change may therefore lead to an increase in exposure to waterborne hazards such as *Cryptosporidium* in recreational settings.

A study by Snel et al. (2009) revealed that New Zealand has a higher reported incidence of cryptosporidiosis and giardiasis than most other developed countries (Snel et al. 2009). Snel et al. (2009) demonstrated that cryptosporidiosis showed marked seasonality with 55% of notified cases occurring over the spring period (September–November in New Zealand) and only 11% occurring in summer (December–February).

In 2008, 2,005 notifications of cryptosporidiosis were reported to Australia's National Notifiable Diseases Surveillance System, with a national notification rate of 9.4 per 100,000 population. The highest notification rates of cryptosporidiosis were reported in the Northern Territory (46.4 per 100,000 population) and Queensland (16.2 per 100,000 population). Fifty-three per cent of all cryptosporidiosis notifications in 2008 were in children aged under 10 years (National Notifiable Diseases Surveillance System Annual Report Writing Group 2009). The national rate doubled to 20.7 per 100,000 in 2009, (the highest rate in 10 years) and fell

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[1] Collection of National Notification data for Cryptosporidosis did not begin until 2001 Bambrick, H.J., Dear, K., Woodruff, R., Hanigan, I., McMichael, A., 2008. Garnaut Climate Change Review The impacts of climate change on three health outcomes: temperature-related mortality and hospitalisations, salmonellosis and other bacterial gastroenteritis, and population at risk from dengue.

again to 6.6 per 100,000 in 2010 (Australian Government Department of Health and Ageing 2011).

Campylobacteriosis is notifiable in all Australian jurisdictions, except New South Wales.

In 2008, there were 15,535 notifications of campylobacteriosis (national rate of 107.5 per 100,000 population). The lowest and highest rates of *Campylobacter* notification were in Western Australia (84.2 per 100,000 population) and in South Australia (124.2 per 100,000 population) respectively (National Notifiable Diseases Surveillance System Annual Report Writing Group 2009). The national rate has stayed relatively constant with 106.5 and 112.3 per 100,000 notified in 2009 and 2010 respectively (Australian Government Department of Health and Ageing 2011).

IMPACT(S)

Observed impacts

While no published articles attribute a higher incidence of waterborne disease in Australia to climate change specifically, a higher incidence of waterborne diseases has been recorded in relation to particular seasons with higher than average temperatures and runoff events. For example, in the summer of 2007, South Australia recorded increased infections with Cryptosporidium (400 cases in 3-4 months compared to typical annual rate of 100-120) (Cunliffe 2011). The increased number of cases occurred when temperatures were high and behaviour was influenced by drought (sharing baths, retaining water in wading pools). The influence of the behavioural changes were an observation but couldn't be quantified (Cunliffe 2011).

With respect to runoff, Signor et al. (2007) found that the daily infection risks from waterborne diseases were greatest in those months when there was a higher frequency of runoff events. Based on quantitative microbial health risk modelling within an agricultural catchment in the Adelaide Hills, the proportions of infections attributable to runoff event periods from *Cryptosporidium, Giardia* and *Campylobacter* spp. were 57%, 80%, and 28% respectively.

On a global scale, Lloyd et al. (2007) utilised log-linear regression to quantify the relationships between diarrhoea incidence rates in children under five and climatic variables, drawing on studies published between 1954 and 2000. They found a significant increase in diarrhoea incidence with decreased rainfall, but little evidence for associations with temperature or climate type. The authors concluded the most likely mechanism was that low rainfall leads to water scarcity, which in turn leads to the use of unprotected water sources and reduces hygiene practices (Lloyd et al. 2007).

In a single case-study in Bangladesh, Hashizume et al. (2007) estimated the effects of rainfall and temperature on the number of non-cholera diarrhoea cases in Bangladesh, finding the number of cases increased by 5.1% for every 10mm increase above a threshold average rainfall. The number of cases increased by 3.9% for every 10mm decrease below the same threshold of rainfall. They also found that ambient temperature was positively associated with the number of non-cholera diarrhoea cases (Hashizume et al. 2007).

Projected impacts

While there are several references to climate change exacerbating health risks due to waterborne infections (e.g., Hanna and Spickett 2011), most do not attempt to estimate the likely impact. Bambrick et al. (2008) have conducted comprehensive modelling exercises to estimate the impact of climate change on the incidence of *Salmonella*-related gastroenteritis in Australia, and from this, produced estimates for all bacterial gastroenteritis. As noted by the authors, such modelling exercises have large inherent sources of uncertainty, most notably underreporting and specific relationships between particular pathogens and climatic variables. This work estimated the impact of climate change on the burden of disease associated with bacterial gastroenteritis in Australia under five different temperature scenarios. The modelling considered the differential relationships between temperature and selected pathogens and adjusted for population growth. The estimates for 2050 range from 205,000 new cases (under the M4 scenario[2]) to 305,000 new cases (under the U1 scenario[3]), relative to the 2001 baseline (Bambrick et al. 2008). Whilst not directly comparable, these estimates can be considered in light of the following effect estimates on an international scale.

Kolstad and Johansson (2011) combined a range of linear regression coefficients derived from a 19-model ensemble to compute projections of future climate change-induced increases in diarrhoea in the tropics and subtropics. Projected temperature increases of up to 4°C were associated with mean projected increases of relative risk of diarrhoea of 8–11% by 2010–2039 and 22–29% by 2070–2099 (Kolstad and Johansson 2011).

Bosello et al. (2006), in a study of the projected worldwide economic impacts of climate-change induced effects on human health, project an additional 485,352 additional deaths due to diarrhoea in 2050 (Bosello et al. 2006).

BACKGROUND

Climate change is projected to affect both water quantity and quality, variables that directly influence the incidence of waterborne infectious diseases. With regards to water quantity, both extremes of drought and deluge are linked to higher levels of water contamination by infectious disease agents such as bacteria, viruses, protozoa and parasites. Australia experiences both extremes naturally and climate change is expected to exacerbate both of these.

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[2] **Mitigation Scenario 4 (M4)**—*Best estimate* (median) strong mitigation scenario where stabilisation of 450 ppm CO2 equivalent (CO2 stabilised at 420 ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~1.5°C in 2100.

[3] **Unmitigated Scenario 1 (U1)**—Hot, dry scenario, using A1FI emissions path, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.

The majority of water-related disease transmissions arise through four pathways: waterborne (e.g., ingestion of contaminated water), water-washed (e.g., inadequate hygiene leading to illness), water-based (e.g., via aquatic species, such as snails), and water-related insect vectors. Poor water quality is associated with a range of health-related concerns, mostly pertaining to the waterborne transmission of pathogens (Goater et al. 2011). Examples of health effects from water contamination include skin and eye irritation, mild gastroenteritis, severe diarrhoea and potentially life-threatening dysentery, hepatitis and cholera (Australian Institute of Health and Welfare 2011).

Primary waterborne pathogens of concern in Australia include protozoans such as *Cryptosporidium parvum* and *Giardia lamblia*, bacterial pathogens (e.g., *Salmonella, Shigella, Campylobacter*), and viruses (e.g., enteroviruses, rotaviruses, parvoviruses, and adenoviruses) (Australian Institute of Health and Welfare 2011 ; Goater et al. 2011). Major transmission pathways for waterborne pathogens include:

- ingestion (drinking) → gastrointestinal system (e.g., bacteria, viruses, protozoa, and helminths),
- inhalation and aspiration (aerosols) → respiratory system (e.g., *Legionella*, *Mycobacteria*, viral infections),
- contact (bathing) → skin, mucous membranes, wounds, eyes (Goater et al. 2011).

The relationship between gastroenteritis and climate varies across pathogens, with different pathogens having variable routes of transmission to humans, and most having more than one possible mode of transmission. Climate potentially has an effect on diarrhoeal disease via the environment, the food chain, water supplies, and animal and human behaviours (Wang et al. 2010). Pathogens that are commonly transmitted by food or water may be susceptible to changes in replication, survival, persistence, habitat range, and transmission under changing climatic and environmental conditions. Factors that may affect these pathogens include changes in temperature, precipitation, extreme weather events (i.e., storms), and ecological shifts such as changes in habitat (Gamble et al. 2008). Because of the vastness of the Australian continent and the range of climatic and environmental conditions experienced, each community's risk and/or vulnerability to water-related hazards will vary, both spatially and temporally. The number and types of water-related, pathogenic hazards and exposure pathways will be also be influenced by factors such as water system components (water volume, flows, and chemistry) and land use type (urban, periurban, rural, remote) (Goater et al. 2011).

Goater et al. (2011) note a lack of validated methodologies to evaluate relationships between climate and environmental factors (such as water availability), and community health, and warn that the magnitude of uncertainty is likely to be considerable when assessing the risks of climate change impacts on water resource availability (Goater et al. 2011).

The mechanisms by which climate change could impact the incidence of waterborne infectious diseases include:

- disruption of water purification and sewage disposal infrastructure by floods, including via higher turbidity and nutrient loadings associated with floods (Australian Institute of Health and Welfare 2011; Wang et al. 2010 ; Waring and Brown 2005);(IPCC 2008). This includes impacts on "treatability" of water through, for example, higher organics interfering with disinfection and high turbidity interfering with filtration (Cunliffe, 2011).

- lowered dilution capacity and a higher water pollutant concentration (including microbial pollutants) in areas where water resources are diminished (IPCC 2008);

- higher temperatures favour the growth of naturally occurring pathogens and harmful organisms e.g., *Naegleria fowleri*, *Legionella*, Cyanobacteria)

- promotion of algal blooms that impair water quality through undesirable colour, odour and taste, and possible toxicity to humans and livestock due to warmer temperatures, combined with higher phosphorus concentrations in lakes and reservoirs, (IPCC 2008)

- through an increased geographic range and burden of disease associated with certain *Vibrio* species (the cause of shellfish-related illnesses), especially *V. vulnificus* and *V. parahaemolyticus* due to increasing global temperatures (Gamble et al. 2008);

- higher temperatures changing behaviours such as recreational use of water, increasing exposure among certain groups, especially children (Gamble et al. 2008) (Cunliffe 2011);

- increased exposure of leafy produce to contamination by faeces from nearby livestock or feral animals due to events such as storms (Gamble et al. 2008);

- increased risk of gastrointestinal illness through contact with contaminated floodwaters (Gamble et al. 2008);

- increased use of suboptimal water supplies in areas of compromised water availability (e.g., due to drought, contamination or salinisation) increasing the incidence of waterborne infections (Goater et al. 2011).

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