CSIRO Submission 09/355

Bushfires in Australia

Prepared for the 2009 Senate Inquiry into Bushfires in Australia

July 2009

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Important Notice

Terms of Reference

On 12 May 2009, the Senate referred the following matter to the Select Committee on Agricultural and Related Industries for inquiry and report on 26 November 2009:

The incidence and severity of bushfires across Australia, including:

a. the impact of bushfires on human and animal life, agricultural land, the environment, public and private assets and local communities;
b. factors contributing to the causes and risks of bushfires across Australia, including natural resource management policies, hazard reduction and agricultural land maintenance;
c. the extent and effectiveness of bushfire mitigation strategies and practices, including application of resources for agricultural land, national parks, state forests, other Crown land, open space areas adjacent to development and private property and the impact of hazard reduction strategies;
d. the identification of measures that can be undertaken by government, industry and the community and the effectiveness of these measures in protecting agricultural industries, service industries, small business, tourism and water catchments;
e. any alternative or developmental bushfire prevention and mitigation approaches which can be implemented;
f. the appropriateness of planning and building codes with respect to land use in the bushfire prone regions;
g. the adequacy and funding of fire-fighting resources both paid and voluntary and the usefulness of and impact on on-farm labour;
h. the role of volunteers;
i. the impact of climate change;
j. fire – its causes (accidental, natural and deliberate) and remedies;
k. the impact of bushfires on biodiversity and measures to protect biodiversity; and
l. insurance against bushfires.

CSIRO's approach to the Terms of Reference

In preparing this response CSIRO has grouped some of the Terms of Reference into the following sections:

1. Impacts, causes and risks (ToR a, b & j);
2. Mitigation and hazard reduction (ToR c & e);
3. Protection (ToR d);
4. Planning and building codes (ToR f);
5. Climate change (ToR i);
6. Biodiversity (ToR k).

There are three Terms of Reference that are not appropriate for CSIRO to comment on. These are: l. insurance against bushfires; g. the adequacy and funding of fire-fighting resources both paid and voluntary and the usefulness of and impact on on-farm labour; and h. the role of volunteers.

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Acronyms Used

BoM	Bureau of Meteorology
CAWCR	Centre for Australian Weather and Climate Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
COAG	Council of Australian Governments
CO2-e	Carbon dioxide equivalent
CRC	Cooperative Research Centre
DF	Drought Factor
FDI	Fire danger index
FFDI	Forest fire danger index
GFDI	Grassland fire danger index
IPCC	Intergovernmental Panel on Climate Change
IFI	Inter-fire interval
ppm	Parts per million
R&D	Research and Development
ToR	Terms of Reference
WHO	World Health Organisation

Acknowledgements

We thank the Department of Climate Change (DCC) for their permission to use material from commissioned research described in the unpublished Williams et al. (2009) report.

Executive Summary

CSIRO undertakes internationally recognised research and development (R&D) in bushfire related research. CSIRO has conducted research relevant to this Senate Inquiry in areas including bushfire impacts, causes and risks as well as fire ecology, fire management and climate change. This submission has been prepared by a team of scientists from CSIRO with experience and international recognition in many facets of bushfire research. It discusses CSIRO's current understanding of fire in the Australian landscape, and indicates some key gaps in knowledge that, if addressed, could enhance response capacity to bushfire risks in the future.

Bushfires are an inevitable occurrence in Australia. Fire is most common over the tropical savannas of the north, where some parts of the land burn on an annual basis. However, the southeast, where the majority of the population resides, is particularly susceptible to large wildfires that threaten life and property. The periods of greatest fire risk vary across Australia because of differences in the rate of vegetation (and hence fuel) production, the rate at which fuels dry out, the occurrence of suitable fire weather for the spread of fire across the landscape, and ignitions.

About 50 million hectares of land are burned across Australia each year on average and about 80% of fire-affected areas are in northern savanna regions. Lightning is the cause of almost all naturally occurring bushfires. Human activities account for most of the rest with accidents associated with burning off, campfires and machinery being the most common sources of ignition. While it is difficult to assess the magnitude of maliciously lit fires, between 25 to 50% of bushfires are thought to be deliberately lit.

Bushfires account for about 10 percent of the cost of all major natural disasters in Australia, and are associated with the greatest loss of life. The full cost of the Feb 2009 Victorian bushfires has yet to be calculated, but the loss of 173 lives was the highest suffered in any Australian bushfire. Climate change information summarised in this submission suggests there will be increasing risks of similar 'Catastrophic' fire-weather in the future.

Impacts of fire on natural systems include effects on water quantity which can increase after bushfires, as a consequence of reduced water use by burnt forest. As the forest recovers water yields can be less than pre-fire levels for many years after a bushfire, because re-growing forest consumes more water than a mature forest. Research is needed to determine the relationships between water quantity, water quality and area burnt by prescribed burning. Biodiversity is also impacted by fire and there is a need to incorporate climate change and its potential effects as a context for 'Adaptive Management' which provides a robust framework for integrating fire and biodiversity management.

While the impact of climate change is likely to be an increase in the frequency of 'Extreme' fire danger days, the impact of climate change on the structure of the forest, fuel availability and thus the behaviour of bushfires is not known. The severity of fire conditions or fire danger is calculated through combining measures of temperature, wind speed, humidity and drought into the Forest Fire Danger Index (FFDI), which has been used for many decades. With the likely onset of climate change effects, modifications to aspects of the FFDI, particularly the assumptions regarding the rate of fuel drying, should be considered to better reflect the change in drying conditions in future. Under climate change it is expected that current 'windows' for hazard reduction burning will change and possibly narrow, meaning less opportunity to conduct safe and effective hazard reduction burns.

In summary, while bushfires are an important part of Australia's natural environment, their impacts can be both tragic and costly. Climate change and changes in community structure are increasing the potential risks of bushfires. There is a need to refine the Forest Fire Danger Index to better reflect changes in fuel drying conditions and also to determine the likely effects of climate change on species composition and forest structure. The use of fuel hazard reduction burning is controversial and more information is needed to provide guidelines for safe and effective hazard reduction. The relationships between water quantity, water quality and area burnt by prescribed burning also need to be better understood. However, despite mitigation actions some bushfires will start, so improving the success of initial response to fire will be critical to reduce the chances of large fires developing. Some fires will inevitably threaten homes, so an improved house loss risk index is needed to better inform communities of the potential for a fire under given fire weather conditions to cause life and property loss. Living safely with fire will require an integrated approach between researchers, government and the wider community.

Introduction

CSIRO is an internationally recognised research and development (R&D) provider in bushfire related research. CSIRO has conducted research relevant to this Senate Inquiry in areas including bushfire impacts, causes and risks as well as fire ecology, fire management and climate change.

This submission has been prepared by a team of scientists from CSIRO with experience and international recognition in many facets of bushfire research. It discusses CSIRO's current understanding of fire in the Australian landscape, and indicates some key areas where further research could enhance response capacity to bushfire risks in the future.

Bushfires are an inevitable occurrence in Australia. Fire is most common over the tropical savannas of the north, where some parts of the land burn on an annual basis. However, the southeast, where the majority of the population resides, is particularly susceptible to large wildfires that threaten life and property. Figure 1 provides a conceptual diagram of the relationships between climate, land management, fire risk and impacts.

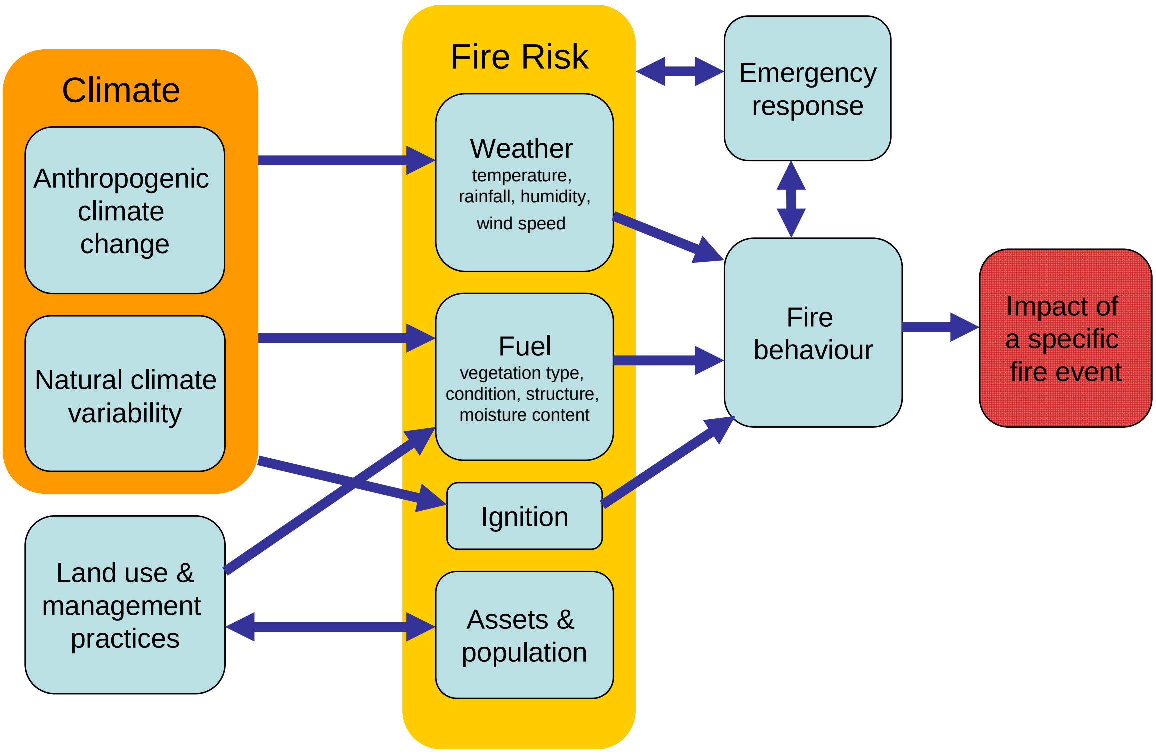

Figure 1: Conceptual diagram of the main links between climate, land management, bushfire risk, fire behaviour and impacts

CSIRO provided a detailed review of some of the relationships outlined in Figure 1 in a submission to the House Select Committee on the Recent Australian Bushfires following the tragic Canberra bushfires of 2003 (CSIRO 2003). This summarised more than 40 years of bushfire research by CSIRO. Its major sections examined fire in the Australian landscape, fire management and suppression, and fire and the urban environment. While this 2003 review contains much information of relevance to this Senate Inquiry, since it was formed in 2003 the Bushfire CRC has increasingly warned about changing conditions and the increased risk of an event such as the 2009 Victorian Bushfires.

For example, the CRC issued a press release including the following statements on 12 January 2009:

> *"Australia's Chief Fire Officers now believe that our current knowledge and practices on bushfire management will not meet the expected needs of the community in coming decades".*

> *"Climate change and drought are altering the nature, ferocity and duration of bushfires and an ageing and declining volunteer population are challenging the way fire agencies are going to be able to manage these events. These issues are being further compounded by the expanding rural-urban fringe and the desire for people to retire to these semi-rural or rural areas. These demographic changes mean there will be increasing numbers of people living in these higher risk zones that are less capable of dealing with the fire risk".*
>
> *"When we consider recent events it is not hard to imagine a repeat of Black Friday. The Victoria fires of 2006 were the longest campaign fires in recorded history. And the Canberra fires of 2003 showed the devastation that can be caused by this type of run away bushfire, how under certain conditions even urban regions can support considerable fire spread entering urban zones within them."*

CSIRO has participated and is continuing to participate actively in post-fire investigations and recovery work following the tragic Victorian Bushfires of February 2009. As part of the Bushfire CRC CSIRO has contributed to the preliminary fire behaviour report prepared for the Royal Commission (Bushfire CRC 2009). CSIRO has prepared a submission on 'Climate Change and the 2009 Bushfires' that was requested by the Counsel Assisting the Royal Commission (CSIRO 2009). CSIRO has recently been asked to prepare an additional report on climate change and the 2009 bushfires for the Royal Commission. A separate CSIRO report on buildings and planning is also being prepared for the Royal Commission. CSIRO staff are working with the Flowerdale community and VicUrban on identifying rebuilding options that seek to offer greater protection against fires and incorporate sustainability principles. CSIRO is also contributing to continuing detailed work analysing fire behaviour.

The following sections consider most of the ToR of the Senate Inquiry. They focus particularly on how changing conditions are affecting the incidence and severity of bushfires and how scientific information on these changing conditions can assist current and future decision making on appropriate fire policies and management actions.

Response to the Terms of Reference

1. Impacts, causes and risks (ToRs a, b & j)

1.1 Scope

This section deals with Terms of Reference:

a. the impact of bushfires on human and animal life, agricultural land, the environment, public and private assets and local communities;
b. factors contributing to the causes and risks of bushfires across Australia, including natural resource management policies, hazard reduction and agricultural land maintenance; and
j. fire – its causes (accidental, natural and deliberate) and remedies.

Sections 1.3.2 and 1.3.3 are drawn largely from the CSIRO Submission on Climate Change and the 2009 Bushfires to the 2009 Victorian Bushfires Royal Commission (CSIRO 2009).

1.2 The impact of bushfires on human and animal life, agricultural land, the environment, public and private assets and local communities

Bushfires are common and widespread in all but the wettest parts of the Australian environment, such as wet eucalypt forest or rainforest ecosystems. The Ellis et al*.* (2004) 'National Inquiry on Bushfire Mitigation and Management' report for the Council of Australian Governments presented data on the total fire affected areas across Australia for the period 1997 to 2003. An average area of 54.5 million hectares was burned each year with 80% of fire-affected areas being located in the tropical grassy woodland savanna regions. Up to 50% of the northern Australian landscape may be burnt in any given year, and most areas burn at least once every three years. Thackway et al. (2008) focussed on measuring fires in forests and used remote sensing as well as state agency data to estimate the area affected. They estimated 24.7 million hectares of forest were burned in the five-year period to 2005-06, of which 5.2 million ha were distributed in southern Australia and 19.5 million ha were in northern Australia.

The Ellis et al*.* (2004) report summarised bushfire impacts and estimated that bushfires account for about 10 percent of the cost of all major natural disasters in Australia, and are associated with the greatest loss of life. The full cost of the Feb 2009 Victorian bushfires has yet to be calculated, but the loss of 173 lives was the highest suffered in any Australian bushfire. However, there is no single source of detailed statistics on bushfire impacts, as each State and Territory keeps their own records. CSIRO is not aware of any recent comprehensive review of the impact of bushfires in terms of human and animal life, public and private assets and local communities.

1.3 Factors contributing to the causes and risks of bushfires across Australia

1.3.1 Fire- its causes (accidental, natural and deliberate)

Fire regimes across Australia vary because of variation in the rate of vegetation (and hence fuel) production, the rate at which fuels dry out, the occurrence of suitable fire weather for the spread of fire across the landscape, and ignitions (Williams et al. 2009). Regional fire regimes differ because of variation in one or more of these key drivers. As a consequence, fire regimes in some areas are constrained primarily by availability of fuel, in others by the occurrence of periods of suitable weather. For example, the tropical savannas of the north tend to burn mainly in the winter-spring period and experience high frequency and relatively low intensity fire regimes (e.g. 1 to 5 year recurrence intervals, < 10,000 kW/m, Williams et al*.* 2002). In contrast, the tall sclerophyll (eucalypt-dominated) forests of the cool, temperate south tend to burn in summer and generally have low frequency/high intensity fire regimes (e.g. > 100 year recurrence intervals, > 10,000 kW/m, Gill & Catling 2002).

Lightning is the cause of almost all naturally occurring bushfires. For example, the Department of Sustainability and Environment (Victoria) estimate that 26% of bushfires on public land are caused by lighting strikes. Human activities account for most of the rest with accidents associated with burning off, campfires and machinery being the most common sources of ignition. (Department of Sustainability and Environment Victoria 2009) Prosecutions relating to maliciously lit fires are rarely obtained, so it is difficult to assess their magnitude. However, Willis (2005) has reviewed bushfire arson including why people maliciously light fires, their impacts, management of offenders and prevention. Though there are considerable variations in rates according to locations and times, he estimated that generally between 25 and 50% of bushfires are deliberately lit.

Climate change can be expected to affect fire regimes, but by differing mechanisms. For example, in arid and semi-arid systems, where grassy fuels predominate, fire activity may decline if rainfall declines (Williams et al. 2009). In contrast, in temperate sclerophyll vegetation, where woody fuels predominate, more frequent days of high fire danger are likely to result in an increase in fire activity. Future fire regimes will also be affected by other agents of change, such as invasions of exotic species. For example, exotic grasses such as Gamba grass (*Andropogon gayanus*) can increase fine fuel loads by five times in tropical savannas (Williams et al. 2009).

1.3.2 Fire danger

The potential for a bushfire to start, to spread across the landscape and do damage defines the danger it poses as a result of the combination of fuel and weather conditions. In Australia, the term fire danger also indicates how difficult a fire will be to suppress. Fire danger rating is ‘a fire management system that integrates the facets of selected fire danger factors into one or more qualitative or numerical indices of current protection needs’ (Chandler et al. 1983). A variety of fire danger ratings are used around the world and most operational fire danger rating systems are based upon the principle that fire danger is determined by wind speed, fuel moisture content, and fuel availability.

There are two fire danger rating systems in use in eastern Australia, one for forest country (the Forest Fire Danger Index (FFDI)) and one for grassland and pastoral areas (the Grassland Fire Danger Index (GFDI)). Two systems are required because forest and grassland fuels have different burning characteristics. For example, forest fuels will burn when grasslands are green and cannot burn, and thus present different levels of danger under the same conditions. In other types of fuels, such as heaths, shrubs or hummock grasses, different danger rating systems could be developed.

The two fire danger rating systems in Australia were developed by A.G. McArthur in the mid-1960s (McArthur 1966, 1967) and have been adopted by all states and territories (except WA in the case of the FFDI) for setting preparedness levels of suppression resources and for declaring days of ‘Total Fire Ban’. Each system is represented by an index which is subdivided into rating classes: ‘Low’ (1-2.5 grass, 1-5 forest), ‘Moderate’ (2.5-7.5 grass, 5-12 forest), ‘High’ (7.5-20 grass, 12-24 forest), Very High (20-50 grass, 24-50 forest) and ‘Extreme’ (50+ grass and forest). These represent the rating of the difficulty of suppression of a well-developed fire in each fuel type.

At a fire danger of ‘Low’, fires either will not burn or spread so slowly that they are very easy to extinguish. At a fire danger of ‘Extreme’ fires start very easily from sources which, under milder conditions, normally do not start fires, (e.g. from the hot molten metal produced when power lines clash together or from the incandescent carbon particles produced by faulty engine exhausts) and spread so rapidly and fiercely that they are virtually impossible to extinguish unless they are attacked within a few minutes of starting (Luke and McArthur 1978).

The factors used to determine fire danger in each fuel type differ slightly, primarily in the treatment of long term moisture. In the GFDI these are degree of grassland curing, air temperature, relative humidity and wind speed. Degree of grassland curing is an estimate of the degree to which the grassland has died off after flowering and setting seed, and thus whether it retains moisture from live cells or is influenced by atmospheric conditions; air temperature and relative humidity provide an estimate of the amount of moisture held within the dead components of the grass. Effects of rainfall are not included, as rainfall events once grasses have cured have a relatively short-lived (1-3 hours) effect.

In the FFDI the factors included are: a measure of the soil dryness (seasonal rainfall deficit), the amount of last rainfall, and the time since last rainfall which are used to determine the percentage of fine litter fuel on the forest floor available for combustion known as the Drought Factor, the air temperature and relative humidity (used to determine the moisture content of the fine fuel) and wind speed. In both meters, the influence of all factors is combined to provide an estimate of fire danger. Not all factors need to be present for fire danger to be High or greater. For example, fire danger may be High with high air temperature and low relative humidity, but little wind. Fuels will be extremely dry and fires may ignite very easily and will not spread very fast, but still be difficult to put out. Conversely when winds are high but fuels are not very dry the fire danger will be High and fires, although difficult to ignite, will still spread and be difficult to suppress. When high air temperature, low relative humidity and high wind speeds coincide, the fire danger will be Extreme.

When first introduced, both systems were capped at an index value of 100 representing the worst possible conditions. For the GFDI, this was based in part upon the conditions experienced during the Mangoplah fire in southern NSW in January 1952. For the forest fire danger index, this was based upon the conditions recorded at Melbourne during the 1939 Black Friday fires (Sullivan 2004). In revising the grassland fire spread prediction system in the late 1990s (Cheney and Gould 1995, Cheney et al. 1998), it was recognised that conditions had occurred subsequent to the introduction of the meter in 1966 that exceeded McArthur's 'worst possible' and so the index was made open-ended (CSIRO 1997, Cheney and Sullivan 2008).

McArthur’s system has been used by rural fire authorities across Australia for more than 40 years, and his fire danger classes have been found to be satisfactory for providing public warnings, setting preparedness levels, and generally providing a good indication of the difficulty of fire suppression over a wide range of conditions (Cheney et al 1990). The amount of fuel present affects fire suppression difficulty; if there is no fuel there is no fire danger at that point in the landscape. However, it is difficult to include fuel load in a fire danger rating system designed to be applied at a regional level. Thus, for general forecasts it is necessary to assume a standard fuel condition. In exceptional circumstances – where fuels are absent or heavily eaten-out across the whole region – sensible adjustments can be made by local fire authorities in setting preparedness levels and providing public warnings on the level of fire danger.

Similarly, difficulty of fire suppression depends on the resources available. For example, one person may find it extremely difficult to suppress a fire under conditions of moderate fire danger, even in sparse fuels. In regions where suppression resources are limited, fire authorities may need to provide public warnings and declare total bans on the lighting of fires at lower values of the fire danger index than are used in areas with higher levels of suppression resources.

The purpose of the McArthur Grassland and Forest Fire Danger Indices (GFDI and FFDI) is to provide a forecast of the likely danger posed by bushfire in standard fuels given a prediction of the weather. These indices required a number of simplifying assumptions to be made in order to be generally applicable for use across the country. One of these was the characteristics of the 'standard' fuel, while another involved the ability of a fire brigade to engage and suppress a fire. To CSIRO’s knowledge, to date no fire authority has raised concerns about the use or application of the fire danger meters. Indeed, fire authorities have utilised particular values of the fire danger index to set suppression levels and to guide planning (Luke and McArthur 1978). The predictions of fire danger of February 7 being the worst since Ash Wednesday in 1983 using the FFDI illustrates the capability of such a system to enable suppression preparedness and planning.

Various revisions have been made to the prediction of fire behaviour (Cheney et al. 1998, Gould et al. 2007a, b). However, by preserving the method of determining fire danger, continuity with historical data is provided that enables fire authorities to benchmark response levels and to compare fire weather occurrences. Climate change will affect the weather conditions that drive fuel moisture content and fuel availability (e.g. changes in number of rainy days, number of days with temperature about 40°C) and therefore also change the climatologies of fuel moisture, fuel availability, and FFDI. How particular fire danger rating systems respond to climate change depends on their sensitivities to weather conditions (Matthews 2009).

Climate change may affect distribution of wind speed, but use of wind in the FFDI calculation is not affected. Fuel moisture is calculated using a simple "instantaneous" model based on air temperature and relative humidity. The simplicity of the model means that although climate change may alter the frequency with which certain combinations of temperature and relative humidity occur, the validity of the model is not affected (because temperature extremes increase only slightly, and relative humidity cannot go below 0). Fuel availability is calculated from the amount and time since the most recent rain event. In the FFDI, drying occurs at a constant rate, irrespective of weather conditions. This simple drying assumption, which was a limitation under past conditions, may become even more important under future climatic conditions.

If modifications are made to the drying assumption, this will not affect determination of FFDI at the upper end of the fire danger scale (i.e. High to Extreme) when the drought factor (DF) is at its maximum, but rather at the lower end when fire danger is Low to High. It is at this end of the fire danger scale that fire and land management authorities are able to conduct fuel management practises, such as hazard reduction burning. Having a better understanding of the changes in FDI following rainfall events under changed future climate conditions is likely to improve the safety, effectiveness, and efficiency of such fuel management tasks.

There is some scope to assess current levels of community understanding of the fire indices and how the community uses this information in preparation, planning and bushfire response decision-making.

1.3.3 Fire behaviour

Fire behaviour is a collective descriptive term for a number of aspects of a bushfire. These include the rate of spread of the fire (i.e. the speed of the fire in the direction of the wind), the fireline intensity (i.e. the rate of energy release per unit length of fireline), flame height, angle and length, and spotting distance (the maximum distance firebrands will be cast by the fire and spot fires initiated).

The climate change modeling presented in Section 5 shows that in south-eastern Australia the number of days of 'Extreme' fire danger is likely to increase in the coming years. However, the conditions that affect relative fire danger do not always affect the speed of a fire in the same way.

Fire danger and difficulty of suppression are related exponentially to wind speed. That is, as wind speed increases, the difficulty of putting out a fire rises at an ever-increasing rate. In both grassland and forest fuels, the rate of forward spread of a bushfire (that is, the speed of the fire in the direction of the prevailing wind) has a near linear relationship to wind speed. Thus, while wind speed is an important factor in predicting both fire spread and fire danger, fire spread cannot be directly linked to a fire danger index.

The fireline intensity of a bushfire is the product of the rate of spread of the fire, the amount of fuel consumed in the fire, and the heat yield (or energy available) of the fuel. The amount of fuel that is consumed in the fire is also a function of the intensity of the fire. A low intensity forest fire will burn only that fuel on the ground (i.e. surface fuel). As the intensity increases, the fire will consume other strata of fuel (see Figure 2), increasing the amount of fuel consumed and thus the intensity. An extremely intense forest fire may consume all fuel strata within the forest including the canopy.

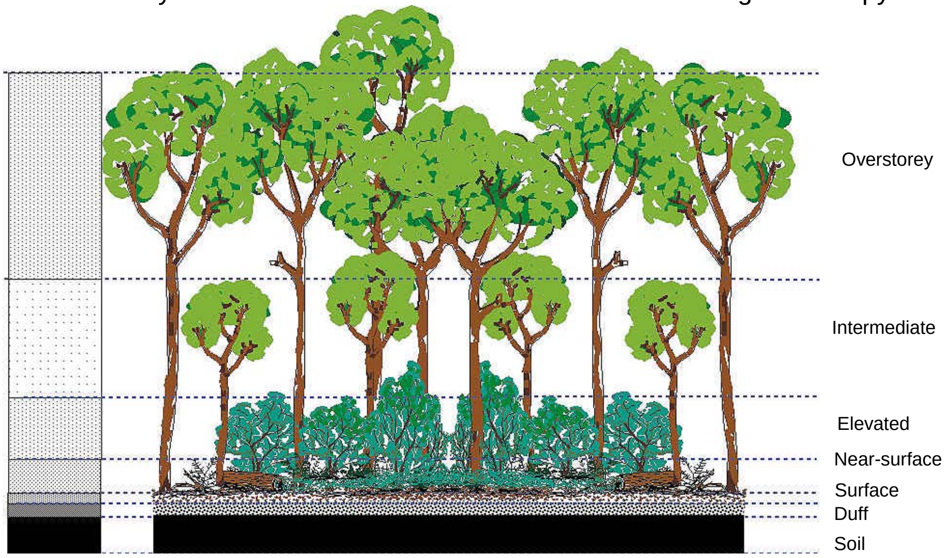

Figure 2: Schematic of the six strata of forest fuel (Source: Gould et al. 2007).

Recent work on determining the behaviour of bushfires in dry eucalypt forests under summer conditions (Gould et al. 2007) found that the speed of a bushfire in these fuels is not only dependent upon the fine surface fuel (as the McArthur system found) but also the structure of the forest understorey. That is, the presence, coverage and height of the near-surface fuel layers. Other layers, such as elevated and intermediate layers, once involved in combustion, contribute to the height of the flames (increasing the difficulty of suppression for a given fire intensity) and provide pathways for the fire to involve the canopy, which may lead to crown fire (see Figure 3). Australian forest types cannot support active crown fire spread without a suitably intense surface fire to provide the energy and mechanisms for fire to reach the often sparse overstorey fuels. It is the bark of the overstorey and intermediate species that provides the fuel for firebrands, which lead to spotting (Ellis 2000).

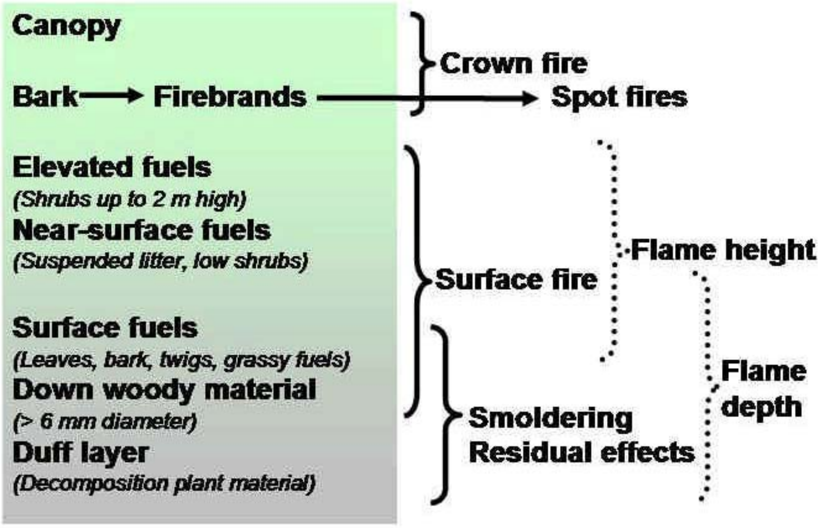

Figure 3: Fuel strata and their relationship with the combustion environment of a bushfire (Source: Gould and Sullivan 2004).

While the impact of changed climate is likely to be an increase in the frequency of extreme fire danger days, the impact of climate change on the structure of the forest and thus the behaviour of bushfires is not known. Changes in species composition and thus structure are likely under sustained changed climate, but the rate of change and the type of change is unknown. Improved modelling of the change in weather variables under changed climate, particularly wind speed, is also critical to predicting the likely change in expected bushfire behaviour under future climate.

2. Mitigation and hazard reduction (ToR c & e)

2.1 Scope

This section deals with ToR c. the extent and effectiveness of bushfire mitigation strategies and practices, including application of resources for agricultural land, national parks, state forests, other Crown land, open space areas adjacent to development and private property and the impact of hazard reduction strategies; and e. any alternative or developmental bushfire prevention and mitigation approaches which can be implemented. Section 2.2 of this submission is drawn from the CSIRO Submission on Climate Change and the 2009 Bushfires to the 2009 Victorian Bushfires Royal Commission.

2.2 Fuel hazard reduction burning

There is a complex set of interrelating issues surrounding fire management options and their effectiveness at the whole of landscape scale that require consideration in assessing the efficacy of fuel hazard reduction burning. These have been separated into a number of key themes outlined below.

2.2.1 Fuel hazard

Fuel hazard is an estimate of that part of fire danger that is due to the vegetation available for burning (i.e. fuel) (Gould and Sullivan 2004). It is the product of vegetation type, condition, moisture content and structure of the vegetation. It does not have components related to topography (slope and aspect) or wind (speed or direction). Essentially it is the relative flammability of the available vegetation and thus the fuel.

Of the three components that combine to determine fire behaviour (fuel, topography and weather), fuel is the only one that can be modified by people to moderate the behaviour of bushfires (McArthur 1962). Reducing the fuel hazard will reduce the overall danger posed by bushfires and increase the potential that a fire may be stopped through natural or artificial means (Cheney 1996).

Fuel hazard reduction can be undertaken in a number ways, from mechanical removal of fuel through slashing and harvesting, application of chemical treatments (flame retardant, herbicide, etc) or application of fire under suitable predefined (i.e. prescribed) environmental conditions. Prescribed burning is the most cost effective way of reducing fuel hazard at landscape scales (Rawson et al. 1985). Hazard-reduction burning is probably the most widespread form of prescribed burning that is deployed on both public and private land in Australia (Gould et al. 2007, Cheney and Sullivan 2008, Dyer et al. 2001)

Most hazard reduction burning conducted in Australia aims to keep the amount of fine surface fuels (fuels less than 6 millimetres in diameter) within the range of 8-15 tonnes per hectare (McArthur 1962; Raison et al*.* 1983; Gill et al*.* 1987; Cheney 1996). Hazard reduction burning also reduces the height, mass and flammability of elevated fine fuels such as shrubs and suspended dead material and is the only practical way of reducing the fibrous bark on trees, the prime source of firebrands that cause spotting (McCaw et al. 2008).

Hazard reduction burning is not intended to stop wildfires, but it does reduce the intensity and the spread of unplanned fires, within the area treated by prescribed fire, by reducing:

- the rate of fire growth from its ignition point;
- flame height and rate of spread;
- the spotting potential by reducing the number of firebrands and the distance they are carried downwind; and
- the intensity of the fire.

As a consequence, hazard reduction burning lowers the risk of crown fires developing in medium to tall forests, will limit the rate of spread and potential impact of wildfires, and makes fire suppression actions safer, more effective and thus more efficient (Luke and McArthur 1978).

The degree of risk reduction will depend on fire weather. During days of extreme fire danger, bushfires will be virtually uncontrollable even if fuels are minimal. However, the number of days each year during which fires will be controllable is many times greater for lighter fuels than for heavier fuels. Thus, there will be more opportunity to suppress fires ignited in summer, and to ensure that they are extinguished before weather conditions worsen. Where fuel loads are very heavy fuel reduction burning requires great care in order to avoid very intense fires. Such fires pose a hazard to suppression crews, particularly as they have a higher probability of escaping fire crew control. A heavy fuel load is one of the factors associated with the development of characteristics of extreme fire behaviour, which include fast rates of fire spread, long flames and crown fires, fire whirls and excessive spotting.

Research by CSIRO and the Department of Conservation and Environment Western Australia (McCaw et al*.* 2003, Gould et al. 2007a, b), based on fire behaviour experiments in south-west Western Australia and modelling, has confirmed that the potential intensity and rate of spread of fires in open eucalypt forests is directly related to the time since last fire. The intensity and difficulty of suppression of fires will continue to increase for at least 15 years after fire because of changes that take place in the structure of surface, near-surface and elevated fuel strata. The amount of most eucalypt fuels will increase rapidly during the first five to eight years after fire and then continue to increase slowly for a further ten years (McCaw et al*.* 2003). In forests dominated by trees with fibrous bark the spotting potential and difficulty of suppression may continue to increase for considerably longer periods after fire as bark continues to accumulate on trees.

The length of time fuel hazard reduction remains effective in assisting suppression of unplanned fires depends upon the number and type of fuel layers involved, and time since fire, as governed by the rate of accumulation of these fuels and the time that it takes for the key layers to build up to their full potential for the site. This ‘effectiveness time’ may be relatively short (less than 1 year) for fuels with a simple structure, such as annual grasses, or it may be many years in more complex fuel types such as tall forests with complex understoreys (Table 1).

Table 1. Period over which fuel reduction burning will assist suppression activities, and the main factors that contribute to difficulty of suppression.

Vegetation type	Persistence of effect on fire behaviour (years)	Factors contributing to difficulty of suppression
Annual grass[1]	1	
Tussock grassland	5	Development of persistent tussock fuel
Tall shrubland[2]	10-15	Height of shrubs, accumulation of dead material (rate of spread, flame height)
Forest, short shrubs, gum bark [3]	10-15	Surface fuel, near-surface fuels structure (rate of spread, flame height)
Forest, tall shrubs, stringybark[3]	15+	Near-surface fuel, shrub height and senescence, bark accumulation (rate of spread, flame height, spotting potential)

If low hazard fuels are maintained adjacent to communities, it is likely that fires will burn out more quickly and residual radiant heat and smoke levels will be less. This means that, following the passage of the fire-front, conditions for residents wishing to extinguish ignitions on structures or to escape from a burning house may be less hazardous. The extent to which houses can survive fires is influenced by many factors including their resistance to ignition by firebrands and the availability of all fuels on the property, including garden fuels, flammable fences and other structures (Ellis and Sullivan 2004).

The 'effectiveness time' or persistence effect of hazard reduction burning, especially the upper bounds of 10-15 years in forests, may be affected by the impacts of climate change. That is, with changes to climatic conditions understorey vegetation species may change and thus may change fuel structure; with declining moisture, rates of fuel accumulation may decline (Williams et al. 2009), potentially lengthening

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[1] Cheney and Sullivan (2008)
[2] Project FUSE: Bushfire CRC (research work in progress).
[3] McCaw et al. (2003), Gould et al. (2007), McCaw (2008)

the effectiveness time. Similarly, increased occurrence of days of higher fire danger may reduce overall effectiveness time. However, there is a need for more reliable information on the effects of increasing carbon dioxide levels on primary production and water use efficiency of native plants. For example, 550 ppm of atmospheric CO_2 may offset a 10% decline in rainfall. However, information about the effects of increased atmospheric CO_2 on native plants is very limited (Stokes et al. 2005). Thus, there is a high degree of uncertainty with respect to climate change impacts on this component of fire management and further research is required.

2.2.2 Risk Management

The risk posed by bushfires to assets (communities, biodiversity, infrastructure, etc) can be moderated by hazard reduction burning. However, the level of burning that occurs will depend on perceptions of acceptable residual risk and acceptable costs (economic, ecological and social). This residual risk will be moderated to some extent by additional actions (such as increased available suppression resources, better community, infrastructure and housing protection, and improved planning and communications).

Prescribed burning is, and will continue to be, an important tool for the management of fire regimes in Australian landscapes in the future. Following the 2003 fires in southern Australia, both the COAG and Esplin Reports (Ellis et al. 2004; Esplin et al. 2003) recommended an increase in the level of prescribed burning in landscapes as part of a general approach to improved fire management. One recent report on fire management on public land in Victoria (Environment and Natural Resources Committee 2007) has recommended (Finding 7.2; p 244) that the level of prescribed burning in the Victorian landscape be increased significantly, partly as a way to mitigate the risk climate change poses to the fire regimes.

The effectiveness of hazard reduction burning will be determined by many factors – the scale of the area to be managed, time since fire, percentage of the total area treated, the suitability, effectiveness, coverage and intensity of the treatment, spatial patterning of prescribed fires, the type of landscape, and fire weather. The level of risk reduction per unit of effort is unclear, with no prescriptions that CSIRO is aware of that take into account landscape complexity under conditions of severe or extreme fire weather. Moreover, as indicated above, there will always be residual risk associated with the use of prescribed fire. With respect to climate change, the extent to which risk reduction by prescribed fire is maintained under scenarios of increasing fire danger is also uncertain. There have been a few recent quantitative evaluations of the relationship between area burnt by unplanned fire (or other measure of risk reduction) and area treated by prescribed fire under climate change scenarios in south-eastern Australia; one example is Bradstock et al. (2008). However, as far as CSIRO is aware, no such analyses have been undertaken in the forested landscapes of Victoria and overall understanding would benefit from further research in this area.

2.2.3 Application & Understanding across Spatial Scales

In assessing the potential and effectiveness of hazard reduction burning it is important to highlight that at the scale of the experimental plot (hectares) there is a mature understanding of the effects of fuel reduction burning on fire behaviour, and the time over which these effects can influence fire behaviour. However, at landscape scales (10s-1000s of km^2) the extent to which the area burnt by unplanned fire is mitigated by given levels of treatment of the landscape is complex. In their global review of the effectiveness of prescribed burning and its role in mitigating unplanned fire, Fernandes and Botelho (2003) concluded that “The best results of prescribed fire application are likely to be attained in heterogeneous landscapes and in climates where the likelihood of extreme weather conditions is low. Conclusive statements concerning the hazard-reduction potential of prescribed fire are not easily generalised, and will ultimately depend on the overall efficiency of the entire fire management process.”

Cary et al. (2009), in a multi-model, multi-continent comparison of the determinants of area burned, in a range of landscapes across the world, found that ‘weather and ignition management were consistently more important for explaining variation in area burned than fuel management approach and effort’, King et al. (2006) using simulation modelling in south-west Tasmania, indicated that strategic location of units treated by prescribed fire enhanced the reduction in the fire risk (in that case to vegetation species susceptible to fire).

2.2.4 Other impacts of prescribed burning

Prescribed burning has impacts on numerous values in landscapes, for example biodiversity, water and human health. The interaction between climate change, unplanned fire and prescribed fire on biodiversity values is a developing research area (Williams et al. 2009). Both hazard reduction burning and wildfire can have positive or negative impacts on biodiversity. In some landscapes, there are potential biodiversity costs associated with the intervals between prescribed fires. Water values in some forests may be affected substantially by wildfires, with effects potentially lasting for decades (Kuczera 1987; Lane et al 2006) but are generally little affected by prescribed burning, with exceptions being on highly erodible soils. Smoke from prescribed fires may present health risks, particularly from particles less than 10 microns in diameter (WHO 2003). Air quality issues will continue to be an important part of fire and land management planning.

2.2.5 Hazard Burning Opportunities

Execution of hazard reduction burning is problematic in many areas due to constraints of smoke management, resources and opportunity (i.e. prescription 'window'). In a number of forest types, such as tall, wet montane eucalypt forests successful execution can limited by the low flammability of surface fuels in general hazard reduction prescription windows. With the expected warmer and drier conditions forecast under changed climate conditions in the future and the subsequent increase in the number of days of extreme fire danger (Lucas et al. 2007), it is expected that current 'windows' for applying prescriptions of hazard reduction burning will change and possibly narrow, meaning less opportunity to conduct safe and effective hazard reduction burns. This will require reassessment of the current operational limits (i.e. work hours, smoke levels, etc) of conducting hazard reduction burning.

3. Protection (ToR d)

3.1 Scope

This section deals with ToR d. the identification of measures that can be undertaken by government, industry and the community and the effectiveness of these measures in protecting agricultural industries, service industries, small business, tourism and water catchments. The section considers general issues related to bushfire suppression and control, rather than specific issues related to protecting particular sectors such as agricultural industries, service industries, small business and tourism. However, specific issues relating to water catchment protection are outlined.

Section 3.2 is drawn from the CSIRO Submission on Climate Change and the 2009 Bushfires to the 2009 Victorian Bushfires Royal Commission (CSIRO 2009). Section 3.4 is drawn mainly from the CSIRO Submission to the Parliament of Victoria's Environment and Natural Resources Committee Inquiry: 'The Impact of Public Land Management Practices on Bushfires in Victoria' May 2007 (CSIRO 2007).

3.2 Bushfire suppression and control

Throughout Australia, the initial suppression response to the outbreak of a bushfire is generally the task of the agency with responsibility for the land on which the fire occurs. This response is usually managed at a district level using locally deployed resources. Fires that escape initial suppression attempts will then subsequently attract support from neighbouring districts coordinated at the state level and other agencies with fire fighting resources. In many cases, water-bombing aircraft are not immediately available for early attack on fires and ground crews generally form the primary type of suppression force.

Analysis of data collected from the initial attack of wildfires in a wide range of Australian fuels (Plucinski et al. 2007, 2008) found four main determinants of the success of early fire containment efforts. These were: time to arrival of initial attack response, prevailing weather, level of fuel hazard, and the size of the fire at arrival of initial attack response. With the exception of the prevailing weather, fire management practices can influence all of these factors to improve the probability of success of initial attack.

Time to arrival of initial attack response following detection (i.e. response time) can be minimised by ensuring the deployment of suppression resources is as rapid as possible, that suppression resources are of an appropriate type for accessing the location of the fire, and that suppression resource base locations allow for an optimal coverage of a given area.

The hazard (amount, coverage, and structure) of the burning fuel (McCarthy et al. 1999, Gould et al. 2007b) has a strong influence on initial attack success, as shown in Figure 4, and can be reduced through the application of fuel management practices such as hazard reduction burning (Cheney 1996). Fires burning in areas that have a reduced level of fuel hazard are much more likely to be quickly contained than those that are burning in heavy fuels that are long unburnt.

The size of a fire at arrival of initial attack (i.e. initial fire size) is influenced by suppression response time, fuel hazard, prevailing weather and topography (Plucinski et al 2007, 2008). Initial fire size may be reduced by reducing suppression response time and decreasing the level of fuel hazard. Improved fire detection efficiency will also reduce initial fire size.

In recent years there has been an increased focus on the use of aircraft in the suppression of bushfires. Aircraft have three main advantages over ground suppression resources: speed, access, and observation (Cheney 1996, Plucinski et al. 2007). When ground travel response times are significant or safe access is difficult, aircraft have the ability to reach the fire early in its development and to initiate suppression. In such situations aircraft can be used to hold or slow fire spread to restrict the growth of the active fire perimeter until ground suppression forces arrive. However, once a forest fire has become fully developed, aircraft become less effective at restricting the spread of the fire, primarily due to the increased speed of the fire and the time taken for the aircraft to refill and return to the fire (i.e. turn around time) (Plucinski 2007).

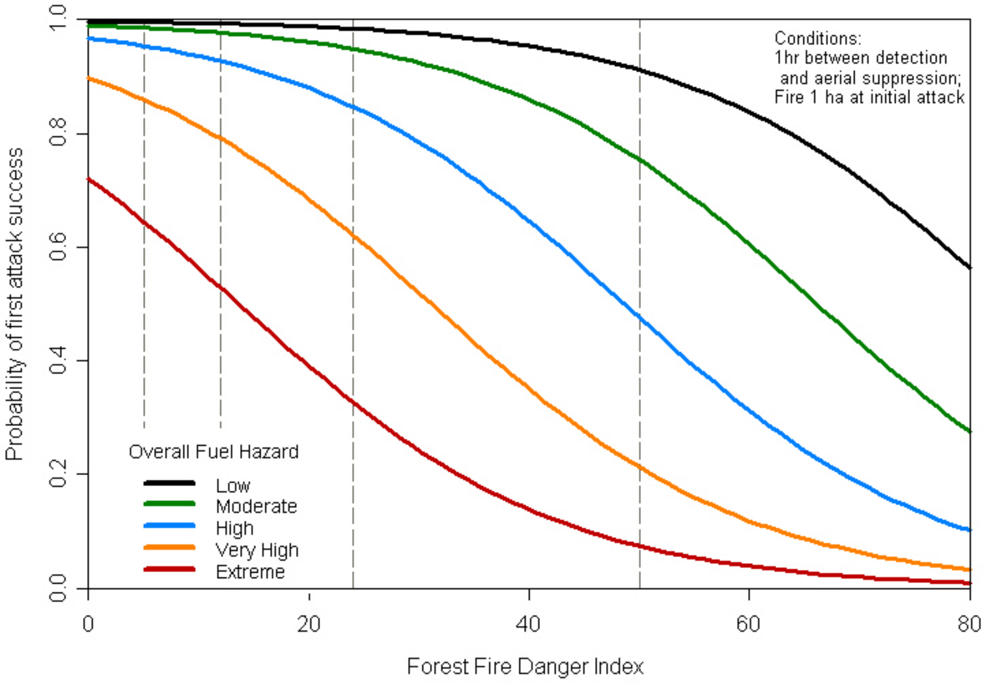

Figure 4: The effect of Forest Fire Danger Index and overall fuel hazard on first attack success (Plucinski et al. 2007).

Aircraft cannot extinguish a bushfire without the support of ground crews (Loane and Gould 1986). While an aircraft can drop water, retardant or chemically-enhanced water (using additives such as surfactants or water enhancing gels), these can only reduce the fire behaviour temporarily; unless directly attacked by supporting ground crews during this period, the fire will eventually burn through, around or over the drop, particularly if the fire is spotting heavily. Aircraft cannot mop-up burning and smouldering fuels which are a primary source of re-ignition (Plucinksi et al. 2007).

Under projected future changed climate conditions, in which the number of days of extreme fire weather is expected to increase for much of south-eastern Australia, improving the success of initial attack will be critical to ensuring large conflagration fires do not develop. Fire management practices, including ignition detection, suppression response using the optimum mix of suppression resources for the conditions and management of fuel hazard, need to be as efficient and as effective as possible to aid initial attack success. A simple adage is that 'small fires are easier to put out than big fires' and this will be even more true given the increased challenges expected from future changes in climate, land use and population demographics.

3.3 Fire weather projections

Improved fire weather modelling could improve long-term strategic planning for future bushfires. Current modelling has been carried out using a regional model nested in two of CSIRO’s global climate models. It would be useful to evaluate the performance of more recent CSIRO global models against other global models developed outside CSIRO. The use of the most reliable models could improve the projections for factors that are critical for bushfires, such as wind speed. Examining daily and annual variability could also assist the assessment of fire weather. The risk of dry lightning (i.e. lightning which occurs without precipitation) is also an important factor affecting fire weather, and this could be analysed in climate change projections. There is potential to enhance the CSIRO-Bureau of Meteorology ACCESS model to include a fire module, linked to a dynamic vegetation model (CABLE). This could provide seasonal and multi-decadal fire weather forecasts.

3.4 Water catchment protection

3.4.1 Water quantity

Water quantity impacts are a function of fire intensity and forest recovery. Bushfires can affect water quantity. The water use by the forest as it regrows after fire results in corresponding changes in the quantity of stream flows and groundwater levels. Where fire intensity is low, the vegetation may recover within weeks to months (Gill 1981). The ground will be protected by vegetation re-growing rapidly and water use patterns will be little affected. Although many native forest species regenerate from trunks, basal organs or seed, very intense fires can defoliate most trees, and kill some. In the case of Alpine Ash (*E. delegatensis*) or Mountain Ash (*E. regnans*) tall open-forests forests, where the trees are killed by intense fire and rely on seed to regenerate (Ashton and Attiwill 1994) recovery of canopy leaf area can take decades. More commonly in mixed species forests, where at least a fraction of the trees can typically resprout and reseed, regrowth can occur within 2-6 years (Gill 1981).

Water quantity typically increases immediately after bushfires. Directly after bushfires, there can be increased stream flows and recharge of groundwater systems (when compared to pre-fire conditions) because of reduced water use by the damaged forest. This initial increase will mainly depend on the type of forest, intensity and severity of fire, amount of rainfall, and the size of storms in which rain falls (Hill et al.2008). Measurements in the Eastern Kiewa catchments for two years after the 2003 fires confirm the increase in stream flow found in several other studies including Brown (1972). Increases were up to 60-70 per cent greater than pre-fire levels where burning was severe (Lane et al*.* 2006).

Water quantity can be less than pre-fire levels for many years after bushfire. The illustration of the effect of time since fire on water quantity uses data from Mountain Ash forests (see Figure 5), because most of the data and research on stream flow changes after bushfires in Australia has been conducted in these forests. After the initial period (two to five years) of reduced water use, the vegetation enters a phase of rapid regrowth and water use increases correspondingly. Water use during this phase is greater than before the fires.

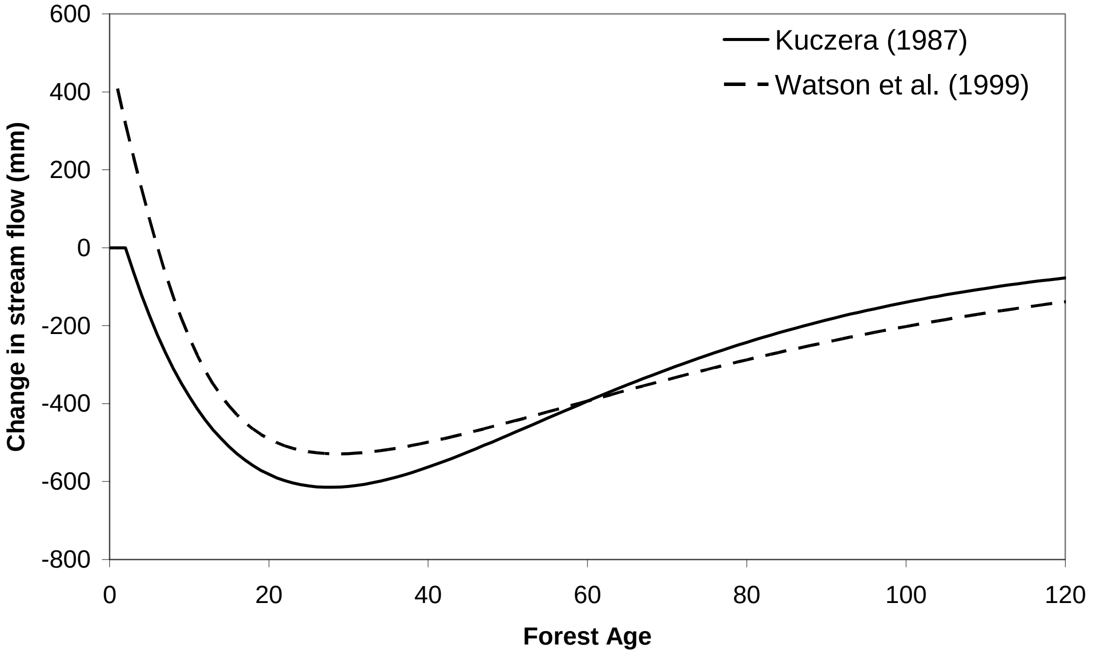

Figure 5: Variation in runoff from Mountain Ash (Eucalyptus regnans) forests in Victoria according to forest age (after Kuczera 1985, 1987 and Watson et al. 1999). Year 0 corresponds to a landscape without forest cover (for example, immediately after an intense wildfire).

These data illustrate that Mountain Ash water use decreases for 20-70 years after fire, as the trees mature and grow. This means that the stream flow impacts of bushfires in catchments dominated by old-growth forest can be felt for decades rather than years. This example is the largest observed change in the quantity of streamflow. In other Eucalypt-forested catchments where rainfall is lower, and the dominant species are capable of resprouting after fire, a similar pattern of reduction in streamflow has been found, but with a smaller magnitude of change (Cornish and Vertessy 2001).

Longer-term impacts on water quantity can be small in some cases. Fire appears to have the greatest impact on water quantity in ash forests such as Mountain Ash, Alpine Ash and Shining Gum (*E. nitens*) growing in wet areas, (Lane et al*.* 2006; http://www.ewatercrc.com.au/bushfire/background_impactflows.shtml). These forests also experience fire less frequently than mixed species forests from drier environments and therefore individual trees grow to a greater age. Rainfall, climate, fire intensity, forest age and species can make the long-term effect of bushfires on water quantity much less marked than shown in Figure 5, and can also be partially offset by stream flow gains in the initial period after the fire (Hill et al., 2008). A study after alpine fires in 2003 predicted an initial increase in stream flows of 14 per cent to 106 per cent for different catchments, lasting for about 7 years (Sinclair Knight Merz 2004). After this period there would be a small reduction in total inflows compared with the no-fire scenario. Stands of the most common plantation species are sensitive to bushfires and may be logged after bushfire has occurred. This means that stream flow and groundwater recharge will typically first increase, but subsequent changes depend on replanting or alternative management actions.

Indicators of important forest characteristics that will affect water quantity in burnt catchments, such as biomass and forest height, fire occurrence and intensity, the degree of canopy scorch, and changes in forest water use during the recovery phase, can be observed at low cost and over large areas using existing satellite technology. These techniques can be developed into operational systems such as the Sentinel bushfire monitoring and early warning systems (Geosciences Australia 2009).

Prescribed burning is not likely to have a significant long-term impact on water quantity. Low-intensity prescribed burning in native forests that experience periodic bushfires is expected to have an insignificant impact on water resources unless it results in mortality of understorey or small trees (creating a ‘thinning’ effect – Gill 1981). However, we are not aware of any specific studies that have measured this impact, and further research on this topic is warranted.

3.4.2 Water quality

Water quality is not normally adversely affected after prescribed burning. The quality of streamflow following bushfires is highly variable but changes are usually small when the fire intensity is low (Prosser and Williams 1998). Although CSIRO is not aware of any specific studies on the effect of prescribed burning on water quality, the evidence from wildfires suggests that if the fire is low intensity - confined to a mild burning of surface litter and live vegetation – then water quality is not significantly degraded (Prosser and Williams 1998). However, prescribed burning can pose significant risks by increasing soil erosion in highly erodible landscapes. This can result from removal of the protective cover of litter and understorey vegetation over extensive areas at regular intervals (Good 1981; Raison *et. al*. 1993). Eroded soil may not necessarily pollute streams, but does lead to depletion of soil fertility from the upper parts of the landscape. Managers should assess risks of soil erosion, and actively plan to exclude fire from erodible portions of landscapes.

Any major influence of prescribed burning on long-term water quality is likely to be via its effects on the frequency and severity of wildfires. Water quality impacts after bushfires are a function of fire intensity and post-fire rainfall. Because fires are heterogeneous, and their effects on vegetation highly variable, the impact of fire on the quality of water subsequently flowing from those catchments is also variable. The main sources of this variability are:

Fire intensity.

High-intensity fires convert ground cover (litter and ground vegetation) to ash and damage the shrub and forest vegetation so that their soil stabilising influence is reduced. Rainfall and overland flow can then act on the bare soil exposed by the fire (Lane et al*.* 2006). Vegetation adjacent to drainage lines and streams may be incinerated in such severe fires and increased rates of gully and streambank erosion may follow. The degree of damage to roots that bind the soil together is particularly important for severe fires. When trees and shrubs die, there is a period of soil instability following the rotting of old roots and preceding the growth of new ones. If intense rainfall occurs in this period of instability then extensive erosion and consequent deterioration of stream water quality may occur. Recovery of water quality from such intense fires has been found to be of the order of 5 years (Brown 1972). Lower-intensity fires burn less surface litter, near surface structures such as roots, and taller vegetation, and may convert surface litter and vegetation to charcoal and similar material. This results in some on-going protection to the soil surface from the erosive action of subsequent rainfall.

Rainfall intensity following fire

The possible effects on water quality are large when thunderstorms follow shortly after the fire when vegetation cover and root growth have had little time to respond. Gentle rains encourage vegetation to regrow and lessen the impact of subsequent rainfall events. The combination of intense rainfall following severe bushfires may produce extensive soil erosion and the delivery of large amounts of sediment, nutrient and ash to the streams of the area (Lane et al. 2006). Lavorel and Steffen (2004) noted that following the 2003 Canberra fires, three of Canberra's four dams were contaminated for several months by sediment-laden runoff. Erosion of hillslopes and streamlines following fires results in a reduction in stream health. Run-off from burnt forests contains mineral clay particles that result in turbidity (cloudiness) as well as ash and a host of other constituents that alter the chemistry of water. These pollutants independently affect water quality and also interact with aquatic biota in complex ways that can have highly variable effects on stream health. For instance, elevated levels of nutrients in surface waters of streams and reservoirs can increase the incidence of algal blooms. Due to the role of light in growing algae, this effect will be mitigated by high turbidity of the water and if the nutrient-rich layer flows into deeper layers within reservoirs (http://www.ewatercrc.com.au/bushfire/background_impactquality.shtm).

The frequency and intensity of fires is a major influence on long-term water quality. Over the centuries a forested catchment will have periods when stable vegetation results in water of a high quality leaving the catchment. These periods will be interspersed with other periods when water quality declines through the combined actions of severe fires and major rainfall events (Shakesby and Doerr, 2006). In the long term, the average water quality is therefore largely determined by the frequency and severity of bushfires.

Several researchers have suggested that the frequency of fires has increased in recent years because of changes in the frequency of ignition and this effect may be exacerbated by climate change (Rustomji and Hairsine 2005)(see Section 5).

The collected studies of water quality following fire events show a wide range of responses observed. These responses range from no significant change from pre-fire water quality, to increases of pollutant concentrations of hundreds times the pre-fire levels. The influences on this spectrum of behaviour are primarily the timing of natural catchment fire recovery processes and the occurrence of pollutant mobilising events. Thus a catchment that has rapid vegetation regrowth prior to erosive runoff is likely to have minor or insignificant reduction in water quality. Conversely, if erosive runoff occurs immediately after the fire event, high levels of pollutants can be transported from the catchment. The timing of the stabilising processes is affected by fire severity. Severely burnt landscapes may take several years to return to pre-fire levels of stability. Furthermore, high energy environments with steep terrain and high intensity rainfall are likely to have more extreme responses when pollutant mobilisation does occur.

Roads, trails and firebreaks are a major source of pollution

It is widely recognised that roads, tracks and firebreaks are a major source of pollution to streams in forested catchments (Croke and Hairsine 2006). Runoff from these areas of bare soil may connect into streams resulting in elevated turbidity and other pollutant concentrations. During major bushfires these sources are likely to be increased in their erosive rate because of the removal of litter cover, increased traffic on road and tracks and in some instances the creation of new firebreaks. To mitigate these effects these areas need to be engineered to safely disperse runoff. Most codes of forest practice provide guidelines for such engineering. During fires in south east Australia in 2003, many hundreds of kilometres of new firebreaks and trails were constructed during fire suppression operations. Until remedial action was taken, these areas of bare ground had a large potential to be the source of sediment and nutrient to streams and rivers.

4. Planning and building codes (ToR f)

4.1 Scope

This section deals with ToR f. the appropriateness of planning and building codes with respect to land use in the bushfire prone regions.

4.2 Appropriateness of planning and building codes

This topic is a focus of the 2009 Victorian Bushfires Royal Commission investigation for which a CSIRO report is being prepared at the request of Counsel Assisting the Royal Commission. An extract of this report can be provided for the Senate Inquiry on a confidential basis if requested by the Select Committee on Agricultural and Related Industries.

4.3 House loss risk

The McArthur forest fire danger index (FFDI) was originally designed to assist fire-fighters in gauging the degree of safety involved in approaching a fire under given weather conditions. A bushfire hazard index for houses was described by Wilson (1984) and implemented as a House Survival Meter by CSIRO Wilson (1987).

Recent research initiatives (Blanchi et al. forthcoming) have explored the link between historic house losses and the fire weather in which these losses have occurred, as well as other factors including building design, surrounding vegetation and human behaviour. There is potential for an improved house loss risk index to be developed and used to better inform communities of the potential for a fire under given fire weather conditions to cause life and property loss. Accompanied by an integrated education policy this tool could assist individuals and communities to understand:

- the potential worst case weather conditions in their region,
- the capacity to prepare and adapt to their regionally specific weather conditions, and
- the significance of forecast weather conditions in relation to the level to which they are prepared, so that an informed decision can be made to stay and defend or leave well before the fire arrives.

5. Climate change (ToR i)

5.1 Scope

This section deals with ToR i. the impacts of climate change on bushfires. Sections 5.2, 5.3 and 5.4 of this submission are taken from the CSIRO Submission to the 2009 Victorian Bushfires Royal Commission (CSIRO 2009). Parts of section 5 have also been provided by the Centre for Australian Weather and Climate Research (CAWCR) for inclusion in the Bureau of Meteorology submission to the Senate Inquiry. CAWCR is a partnership between CSIRO and the Bureau of Meteorology.

5.2 Global observations of climate change

An outline of the ‘Science of Climate Change’ prepared for a CSIRO briefing given at Parliament House, Canberra on 16 March 2009 is attached in Appendix 2.

The consequences of human induced climate change are a current research focus around the world. The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 to assess information relevant to understanding the risk of human-induced climate change. It has produced four assessment reports (1990, 1995, 2001 and 2007). Key conclusions of the latest report (IPCC 2007) are:

- Warming of the climate system is unequivocal;
- Most of the observed increases in globally averaged temperatures since the mid-20th century is very likely (greater than 90 percent likelihood) due to the observed increases in anthropogenic (human) greenhouse gas concentrations; and
- Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized.

An international scientific congress on ‘Climate Change: Global Risks, Challenges & Decisions’ held in Copenhagen in March 2009 was attended by more than 2,500 delegates from nearly 80 countries and reviewed the latest evidence. Recent observations confirm that the worst-case scenario trajectories for factors such as global warming and sea level rise presented in previous IPCC assessment reports, including the 2007 report, are being realised (Rahmstorf et al. 2007).

5.3 Observed trends in fire weather

The McArthur forest fire danger index (FFDI) is based on temperature, rainfall (expressed as a drought factor), humidity and wind speed – the four factors described above. Both the forest fire danger index and the grassland fire danger index (GFDI) have already been described in Section 1.3.2.

When the FFDI is 25-50, the risk rating is ‘Very High’. When the FFDI is greater than 50 the risk rating is ‘Extreme’ and a ‘Total Fire Ban’ is usually declared. The Black Friday bushfires of 1939 were used as an example of a 100 rating on the scale. During the 2009 Bushfires, the index reached well over 100 at many locations.

There is a 35 year trend of an increasing annual total FFDI for south-eastern Australia. Research undertaken by CSIRO and the Bureau of Meteorology, through the Centre for Australian Weather and Climate Research (CAWCR) and the Bushfire CRC, found that the annual total FFDI displays a rapid increase in the late-1990s to early-2000s at many locations (Lucas et al., 2007). Increases of 10-40% between the average level for 1980-2000 and the average level for 2001-2007 are evident at most sites. The increases are associated with a jump in the number of ‘Very High’ and ‘Extreme’ fire danger days. Increasing trends in annual total FFDI for four Victorian sites with high quality data are shown in Figure 6. Hence, the extremely high FFDI values on 7 February 2009 represent a continuation of an increasing trend in the FFDI.

While FFDI is an important element in understanding fire weather, it must be considered in the context of other factors such as fire management and fuel load, as discussed in Section 1.

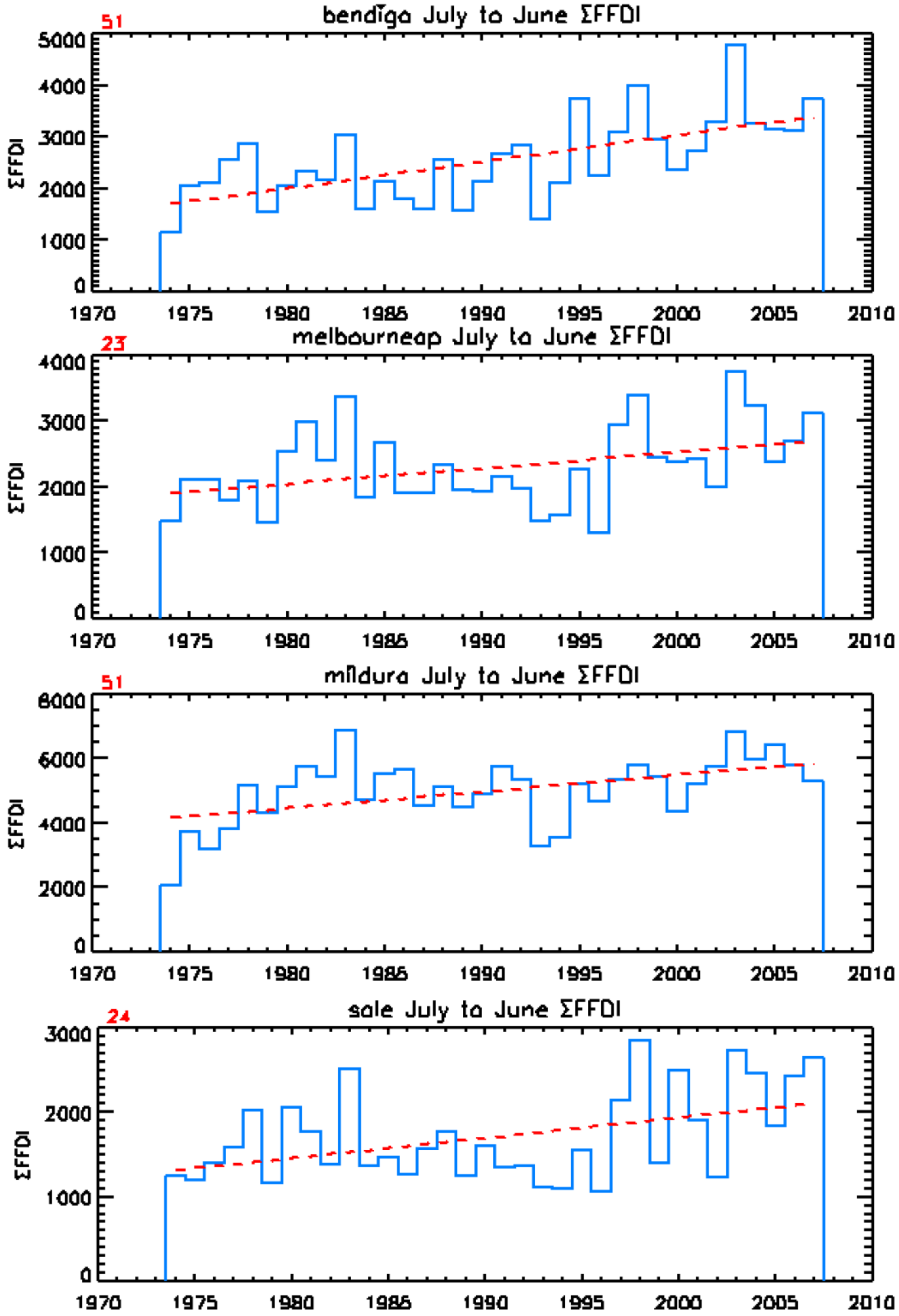

Figure 6: Annual total FFDI (sum of daily 3 pm values, from July to June) at Bendigo, Melbourne airport, Mildura and Sale from 1973-2007. The magnitude of the linear trend is the red number at top left (FFDI units per year). Source: Lucas et al (2007).

5.4 Potential changes in future fire weather risk

Future climate change will depend to some extent on the effectiveness of domestic and international efforts to control greenhouse gas emissions. There are concerted efforts through current international negotiations to seek to stabilise atmospheric carbon dioxide equivalent (CO2-e) concentrations (including the effect of all greenhouse gases) between 450 and 550 parts per million (ppm) by mid century. However, significant climatic changes are predicted to take place even if CO2-e concentrations can be stabilised below 550 ppm (IPCC 2007).

CSIRO has contributed to projections of climate change for Australia (CSIRO and BoM 2007). For example, projections for Victoria indicate a warming climate with increases in extremely high temperatures, decreases in annual mean rainfall and relative humidity, and small changes in annual mean wind-speed. Increases in the area extent and frequency of droughts are likely in south-eastern Australia (Hennessy et al., 2008).

Changes in future fire weather risk depend on projected changes in temperature, humidity, rainfall and wind. A modelling study conducted by the Bushfire CRC, the Bureau of Meteorology and CSIRO (Lucas et al*.* 2007) found that the simulated annual-average number of days with ‘Extreme’ fire danger increases by 5-25% by 2020 relative to 1990, for a low rate of global warming. For a high rate of global warming, the number of ‘Extreme’ days increases by 15-65% by 2020. By 2050, the number of ‘Extreme’ days increases by 10-50% for low global warming and by 100-300% for high global warming.

‘Catastrophic’ fire-weather is defined as having an FFDI of more than 100 (Lucas et al. 2007). This occurred on 16 Feb 1983 (Ash Wednesday), 18 Jan 2003 (Canberra fire) and 7 Feb 2009 (Black Saturday). Only 12 of the 26 sites analysed in south-eastern Australia have recorded ‘Catastrophic’ fire-weather days since 1973. By 2020 for high global warming, ‘Catastrophic’ fire-weather days are predicted to occur at 20 sites, 10 of which have return periods (average time between events of the same magnitude) of around 16 years or less. By 2050 for high global warming, ‘Catastrophic’ days are predicted to occur at 22 sites, 19 of which have return periods of around 8 years or less, while 7 sites have return periods of 3 years or less (Lucas et al. 2007).

The implications for fire behaviour will be complex, since more frequent fires will affect ecosystem dynamics and fuel load. Increased fire frequency may result in more frequent less intense fires in a particular location, but may also increase the area burned in a given region. How the landscape and fuels respond to climate change depends on changes in growing conditions (rainfall, temperature), and interactions with fire regimes (i.e. the pattern of recurrence of fires across the landscape) (Gill 1975, Bradstock et al. 2002) and land management practices. On the one hand, elevated carbon dioxide levels may enhance vegetation production and thereby increase fuel loads (Booth et al. 2008). On the other hand, drought may decrease long-term vegetation production (and fuels) and may decrease fuel moisture (thereby increasing potential rates of spread). The outcomes of these interacting processes on fire regimes will depend on whether factors act synergistically or antagonistically. They are therefore highly uncertain, and require much further research (Williams et al. 2009).

6. Biodiversity (ToR k)

6.1 Scope

This section deals with ToR k. the impacts of bushfires on biodiversity and measures to protect biodiversity. The section is mainly based on the Williams et al. (2009) report to the Department of Climate Change on ‘The impact of climate change on fire regimes and biodiversity in Australia - a preliminary assessment’. We are grateful to the Department of Climate Change for their permission to use extracts from this unpublished document.

6.2 Impacts of bushfires on biodiversity

Fire has been a factor in the Australian landscape for millions of years. However, conditions changed with the arrival of Aborigines more than 40,000 years ago. Indigenous Australians certainly burned some parts of the landscape, but the extent and frequency of burning, along with their impacts on native plants and animals are poorly understood. Conditions changed even more dramatically with European settlement in 1788. The record of species loss in Australia since European settlement is among the worst of any country in the world. More than 20 mammal species have been lost and many of the species that have survived have had their distributions dramatically reduced. Lindenmayer (2007) has attributed causes of species loss and decline to:

- Land clearing,
- Introduced herbivores, such as rabbits,
- Soil compaction and grazing by domestic animals,
- Feral predators, such as the red fox, and
- Altered fire regimes.

For example, Lindenmayer (2007) describes how mallee fowl (*Leipoa ocellata*) populations have declined in areas where their habitat is burned too frequently, as the species relies on litter (i.e. dead leaves and twigs) for building its nests. He is particularly concerned about altered fire regimes in northern Australia. In this region more intense fires, occurring with greater frequency and later in the dry season, particularly threaten birds and small mammals. Around Australia many of the changes in frequency and intensity of bushfires appear to be associated with climate change (see, for example, information for south-eastern Australia in Section 5), so the remainder of this section looks at likely impacts of climate change on fire regimes and biodiversity.

Climate change and fuels

Fuel amount and type is determined by interactions between productivity, decomposition and consumption. These processes depend on rainfall and temperature, and are likely to be influenced by climate change. Fuels may be dominated by the woody components – leaves twigs, bark live shrubs - or by grass. There is a general positive relationship between mean annual rainfall and fuel production within fuel types. Reductions in rainfall are likely to result in reductions in vegetation productivity and therefore fuel accumulation rates and equilibrium loads, assuming no change in decomposition. An example of the potential impacts of 20% lower rainfall on fuel loads is provided for the Karri and Jarrah forests of south-west Australia. Lower fuel accumulation rates and decreases in equilibrium fuel loads (reflecting decreases in forest productivity) of up to 50% are indicated.

The impact of rising atmospheric CO_2 on fuels is uncertain, and will depend on changing patterns of moisture and temperature. Increased CO_2 may increase vegetation productivity, leading to more litter and grass fuels. Furthermore, the Carbon: Nitrogen ratio of litter (a measure of its propensity to decay or be consumed) may rise, resulting in slower litter decomposition or reduced palatability to herbivores.

Detailed studies of biomass and fuel accumulation rates are needed at a range of locations in Australia to identify whether rates have changed over the last 30 years in response to changes in temperature, rainfall and CO_2. A major impact on fuel dynamics in coming decades is likely to occur because of the spread of invasive species. Exotic grasses such as Gamba grass (*Andropogon gayanus*) can increase fine fuel loads by 5 times in tropical savannas. Other examples include Buffel grass (*Cenchrus ciliaris*) in arid hummock-grass systems.

6.3 A national framework for evaluating fire regimes – the 4 switch model

Williams et al (2009) present a national framework to evaluate the potential effects of climate change on fire regimes - the ‘4-switch’ model. Biomass (fuel) production and mass, biomass availability to burn, as determined by moisture content, suitable fire weather and ignition represent a sequence of conditional processes that are required for fires to occur. Each can be regarded as a switch, and all four switches must be simultaneously “on” in order for fire to occur. Should any switch be “off” in a particular locality, fire will not occur. The rates of switching on and off differ across Australia, and different biomes have differing, and characteristic, limiting switches. Identification of the ‘limiting’ switch in different ecosystems is important, because switches are likely to be differentially sensitive to climate change. This model explains why fire regimes at landscape scales vary in differing biomes.

The model is applied to four different biomes, to assess how fire regimes may respond to projected climate change: the tropical savannas of northern Australia, the arid hummock-grasslands and shrublands of central Australia, the semi-arid grassy woodlands of inland eastern Australia, and the temperate sclerophyll forests of south eastern Australia. In the tropical savannas, climate change is unlikely to have major effects on area burned and fire frequency. This is because the primary climatic and fuel drivers of fire (biomass, low moisture, spread capacity) in the annual wet-dry climate are non-limiting on an annual basis. Similarly, in arid regions, drought and fire weather are essentially non-limiting on an annual basis, and landscape fire will continue to be limited to periods following above average rainfall, even under climate change scenarios. In both savannas and arid regions, invasion by exotic grasses (as a consequence of deliberate introductions and unplanned spread) are more likely to have a major impact on fire regimes than is climate change. In the grassy woodlands, which subscribe a broad arc from the sub-tropics to the temperate zone, outcomes will depend on prognoses of available moisture and land use, and how these affect fuel amount and continuity. In the southern sclerophyll dominated vegetation, where both overstorey and understorey are dominated by woody plants, the primary effect of climate change on fire regimes is most likely to stem from the projected increase in the frequency of occurrence of days extreme of fire weather, which has the potential to increase area burnt and therefore shorten the intervals between fires.

6.4 Climate change, fire regimes and biodiversity – Four case studies

Williams et al (2009) explored the interactions between climate change, fire regimes and biodiversity in four case studies:

1. Alpine ash forests of south-eastern Australia;
2. Sclerophyllous forest and shrubland vegetation of south-western Western Australia;
3. Tropical savannas of northern Australia; and
4. Sclerophyllous vegetation of the Sydney basin in south-eastern Australia.

A comprehensive national treatment of climate change impacts on fire regimes and biodiversity, at a regional level, was beyond the scope of the study in Williams et al (2009). The case studies illustrate our current understanding of climate – fire regime – ecosystem dynamics in biogeographic regions with differing climate, vegetation and fire regimes, and where suitable data and diagnostic capacity are available to identify potential approaches to the problem.

Case Study 1: Alpine Ash Forests of the south-east highlands

The tall Alpine Ash (Eucalyptus delegatensis) forests of south-eastern Australia are relatively well known ecologically and so provide a benchmark for what we know and what we need to know if realistic predictions about the impacts of changed fire regimes on biodiversity are to be made. Being an obligate seeder, populations of the species are killed by fires of sufficient intensity to scorch the crown completely. Under enhanced atmospheric CO2 concentration, the productivity of the forest may rise, resulting in higher fuel loads. With changes in weather towards drier and warmer conditions, the chance of fire occurrence would be expected to rise. All these changes point towards an increased risk of local extinction of alpine ash if fire return intervals fall below the period needed for juveniles to flower and seed. However, the species may be able to migrate (altitudinally) in response to warming. Alpine Ash is an ideal target species for monitoring, and reacting to, any changes observed in the distribution as a consequence of changes to climate and fire regimes.

Case Study 2: Mediterranean Forests and shrublands of south-west Western Australia

South-west Australia is one of 25 global biodiversity hotspots and its unique flora and fauna is considered to be particularly vulnerable to the likely deleterious impacts of climate change. The vegetation ranges from tall forest to shrubland as a consequence of variation in moisture availability and soil nutrients. Under a climate change scenario of continued warming and drying, plants are likely to show reduced growth rates and slower post fire recovery rates, and communities are likely to show lower fuel accumulation rates, if temperature and moisture act alone. CO_2 fertilization may also affect fuels, but in an ecosystem specific way. In dry woodlands and shrublands drought effects might more than offset any potential CO_2 fertilization effects. In contrast, in wetter forest areas, growth and fuel conditions might be maintained due to greater water-use efficiency brought on by CO_2 fertilization. A greater frequency of high to extreme FFDI days under future climate change is likely to result in reduced intervals between fires. A warmer, drier climate will make sensitive and restricted habitat types, including riparian zones and wetlands, more vulnerable to fire. These habitat patches support a high proportion of species with fire sensitive populations of plants (i.e. obligate seeders) and habitat dependent fauna (e.g. quokka and some ground nesting bird species) relative to the surrounding forest matrix. Projected climate shifts are also likely to increase the time to reproductive maturity for many perennial plant species (by slowing growth rates), so that estimated minimum safe fire interval may increase while actual interval is projected to decrease. Although such impacts are likely to be greatest on obligate seeder plant species, resprouter species may also show gradual population decline. Given the high biodiversity values of south-west Western Australia, further research is warranted to investigate the interactive effects of climate change and fire regime change as threats to the biodiversity of this globally important region.

Case Study 3: Tropical Savannas of northern Australia

The vast, sparsely populated landscapes of northern Australia are dominated by savannas – a more or less continuous cover of C4 grasses and a variable cover of trees. The fire regimes in the savannas are driven primarily by the monsoonal, wet-dry tropical climate, which produces fine fuels annually during the wet season, which then dry off each dry season. Fire is very extensive. The mesic savannas of the Kimberley, the Top End of the Northern Territory and Cape York Peninsula have an annual abundance of tall tropical grasses, where neither fuel nor fire weather is limiting, and average fire frequency is about one year in two. In the semi-arid savannas in Western Australia and Northern Territory, fire frequency is about one year in four, whereas in semi-arid Queensland, where properties are smaller, and land-use intensive, fire frequency is less than one year in ten. In arid savannas, dominated by hummock, spinifex grasses, fires are infrequent, and occur primarily in or following years of above average rainfall. Across the savannas, land use change (intensification of grazing; spread of exotic grasses) may exert a stronger influence on future fire regimes than climate change.

There is general resilience in the vegetation to variation in fire regimes, but there are also some plant species and vegetation types that are highly sensitive to variation in intensity and/or interval components of fire regime, for example *Callitris species*; some monsoon thickets; and heath lands of the Arnhem Land Plateau. Certain faunal groups such as small mammals, are also sensitive to short fire intervals. Biodiversity monitoring programs have detected declines in a range of some faunal groups over the past decade; increased fire frequency and extent have been linked to this phenomenon, and climate change has the potential to exacerbate this problem. Targeted, active fire management strategies and programs for mitigation of fire, and associated biodiversity monitoring programs, both key components of current biodiversity conservation management, will become even more important under a regime of changing climate.

Case Study 4: Warm temperate sclerophyllous forests and woodlands of the Sydney Basin

The Sydney Basin has a high diversity of vegetation types and species, and includes high numbers of obligate-seeding plants. The distribution of plant functional types is partly affected by gradients of temperature and moisture. A warmer and drier climate may favour obligate seeders over resprouter functional types, predisposing vegetation to structural and compositional change under any regime of higher fire frequency. Simulation modeling indicates that increases in FFDI could result in increased area burned. The consequences of such changes in fire regimes for biodiversity are, however, mixed. Shifts in inter fire interval (IFI) were predicted to be insufficient to significantly change landscape-scale extinction probability of IFI-sensitive plant species, assuming prescribed burning is held at current levels.

In contrast, the probability of crown fires may increase by up to 20% under the high emissions scenario. Elevated risks to people and property, intensity sensitive populations of some taxa (e.g. arboreal mammals) and soil stability may ensue. The effects of warming and drying on fire weather and hence area burned may outweigh any diminution of fuel loads caused by declining moisture.

Prescribed burning can have major effects (positive and negative) on biodiversity, catchments and human protection. Moderate increases over current levels of prescribed burning (e.g. 2 – 3 fold increase) are unlikely to increase risk to the integrity of plant diversity in the widespread, species-rich dry sclerophyll vegetation. Commensurate risk reduction to urban and other ecological values sensitive to fire intensity is, however, likely to be small. Larger increases in prescribed burning (i.e. > 5 fold) would be needed to counteract effects of the high climate change scenario. Such an increase may not be feasible on the basis of cost and resources. Benefit-cost analysis of various prescribed burning options (treatment strategy; area burnt) as a function of risk to various landscape values (life, property, biodiversity, water) is an urgent research need.

6.5 A response framework for fire-biodiversity management

The management of fire regimes is currently recognised as an important component of biodiversity conservation, but is complex because of potential conflicts between effective protection of human lives and property on the one hand, and the maintenance of biodiversity on the other. Across Australia systems for managing fire for biodiversity conservation objectives vary, but have many common elements, such as codes of practice, the mapping of fire histories, the use of functional groups of plants to set thresholds (especially for desired minimum and maximum inter-fire intervals), and the use of prescribed burning to achieve multiple objectives.

The primary implication of the Williams et al. (2009) analyses for the management of fire in areas managed for biodiversity conservation is that fire management at landscape scales is likely to become more complex in the coming decades. However, because of the uncertainty and complexity of climate change-fire regime-biodiversity interactions, a prescriptive solution is difficult to provide. CSIRO's approach has been one of scenario setting and evaluation, and CSIRO considers that this approach is likely to remain the most constructive for the foreseeable future as more regional analyses are undertaken.

6.5.1 Adaptive Management – an even more pressing need

A key message of the Williams et al. (2009) report is to incorporate climate change and its potential effects as a context for Adaptive Management, the most robust framework for integrating fire and biodiversity management. The key features of an adaptive management framework are:

- having stated objectives;
- monitoring ecosystem states;
- monitoring drivers of change; and
- revising activities in the light of the results of monitoring.

Management systems in a number of Australian States and Territories are developing rapidly and the inclusion of climate change as a driver of change for biodiversity via altered fire regimes adds another dimension of relevance for managers. There are no prescriptive, generic 'solutions' to the problem of mitigating risk to multiple values and assets posed by climate change to fire regimes in areas managed for biodiversity conservation. However, the lessons learned from fire and biodiversity management over recent decades have application to the question of climate change, fire and biodiversity. Key features of an adaptive system that enables multiple risks posed by altered climate and altered fire regimes to be evaluated and mitigated include:

- Monitoring the spatial and temporal components of fire regimes at landscape scales;
- Identification of various taxa and communities that are sensitive to different components of fire regime;
- Understanding thresholds and domains of concern for impacts of disturbance regimes on biodiversity (in this submission, an example from the Sydney Basin is presented);

- Identification of the trade-offs that will be necessary to minimise risk to multiple values; and
- Developing and refining the means to evaluate the effectiveness of fire management actions against stated land management objectives.

6.5.2 Prescribed burning

Prescribed burning will continue to be an important component of fire and biodiversity management. There have been calls, especially in south-east Australia, for more prescribed burning in the landscape, partly as a strategy to mitigate fire risk in the face of climate change. However relatively large amounts of prescribed burning would have to be implemented in Australian forested landscapes to achieve modest levels of risk mitigation for urban and other assets. The relative benefits and costs of prescribed burning, and its effectiveness in achieving multiple land management goals in different land tenures requires more research. Potential changes to fire regimes as a consequence of climate change provide an excellent opportunity to further this research.

6.5.3 Seven priority areas for action

Williams et al. (2009) identified seven priority areas for action. One relates to the current state of national fire regimes, three to ecosystem dynamics, and three to ecosystem management.

1. Determination of Australia's fire regimes. Without baseline data, any knowledge of the effects of climate change on fire regimes is necessarily limited.

2. Determining the potential impact of climate change on fire weather in other regions of Australia. These can be undertaken using the protocols used for south-eastern Australia summarised in this submission.

3. Evaluation of the relative importance of elevated fire danger, elevated atmospheric CO_2*, and changing moisture availability as determinants of future fire regimes*. This requires much more research and analysis, using regional climate change scenarios, regional fuel change scenarios, and spatially explicit fire and biodiversity models.

4. Expanding our understanding of the effects of variation in fire regime components on fauna. Knowledge and assumptions regarding fire regime effects on plants do not necessarily apply to fauna, where further research and field validation are required.

5. Review and assess current adaptive management capacity to accommodate change. The climate change, fire regime and biodiversity scenarios outlined in the Williams et al (2009) report raise the issue of how to manage fire within reserves and other public lands. Williams et al. (2009) deliberately avoided providing prescriptive actions, highlighting that, given the uncertainties, the potential options require concerted discussion between researchers and land managers at National and State fora. These discussions were identified as the number one priority action for Phase 2 of the process that was commenced with the Williams et al. (2009) report.

6. Explore approaches to domain and thresholds of concern. This could begin immediately, in a range of conservation reserves. In addition to thresholds for interval, thresholds for intensity, fire season and fire type need to be explored.

7. Undertake benefit-cost analyses of potential management responses. This issue is particularly acute, because all aspects of fire management are resource-intensive, yet there have been few detailed analyses of returns on management investment that CSIRO is aware of.

Though the key message concerning Adaptive Management and the seven priorities were devised particularly for addressing biodiversity concerns, the use of Adaptive Management and several of the priorities have relevance for developing general strategies for reducing risks associated with the changing incidence and severity of bushfires in Australia.

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Appendix 1 – Contributing Authors

Dr Trevor Booth, Theme Leader in CSIRO's Climate Adaptation National Research Flagship coordinated development of this submission. Contributing scientists with particular expertise relevant to the following sections include:

1. Impacts, causes and risks (ToR a, b & j)
    Dr Andrew Sullivan and Dr Stuart Matthews

2. Mitigation and hazard reduction (ToR c & e)
    Dr Andrew Sullivan and Dr Dick Williams

3. Protection (ToR d)
    Suppression and control - Dr Matt Plucinski
    Fire weather projections – Mr Kevin Hennessy
    Water catchment protection – Dr Peter Hairsine

4. Planning and building codes (ToR f)
    Mr Justin Leonard

5. Climate change (ToR i)
    Mr Kevin Hennessy

6. Biodiversity (ToR k)
    Dr Dick Williams

Appendix 2 - The science of climate change

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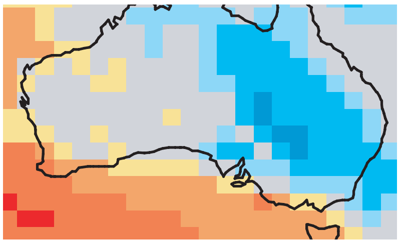

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The science of climate change

Global temperatures are rising

Over the past century the global average surface temperature has risen by 0.74 °C.

The observed increase in average temperatures is widespread around the globe, with rising trends recorded on all continents and in the oceans.

The warming has been fastest over land and greatest in the upper northern hemisphere. Global ocean temperature rose 0.10 °C between 1961 and 2003, to a depth of 700 m.

In Australia there has been a 0.9 °C warming since 1950.

A shift of just a few degrees in global temperature can cause major changes

Average northern hemisphere temperatures during the second half of the twentieth century were the highest of any 50 year period in the past 1300 years, based on at least 10 temperature reconstructions.

However, this level of warming is not unusual in the Earth's geological history. For millions of years the planet has experienced a series of ice ages and warmer inter-glacial periods, driven mainly by changes in the Earth's orbit.

During the last major ice age, the global average temperature was only 3 to 5 °C cooler than today, and sea levels were up to 120 m lower than present. Around 125,000 years ago our ancestors lived through an inter-glacial period when the polar regions were 3 to 5 °C warmer than the present and sea levels were an estimated 4 to 6 metres higher than the twentieth century. This illustrates that even a few degrees change in global temperatures can create a vastly different environment.

Global sea levels are rising

From 1870 to 2007 the global average sea level rose by close to 20 cm. Sea levels rose at an average of 1.7 mm per year during the 20th century, accelerating to 3.4 mm per year from 1993–2007.

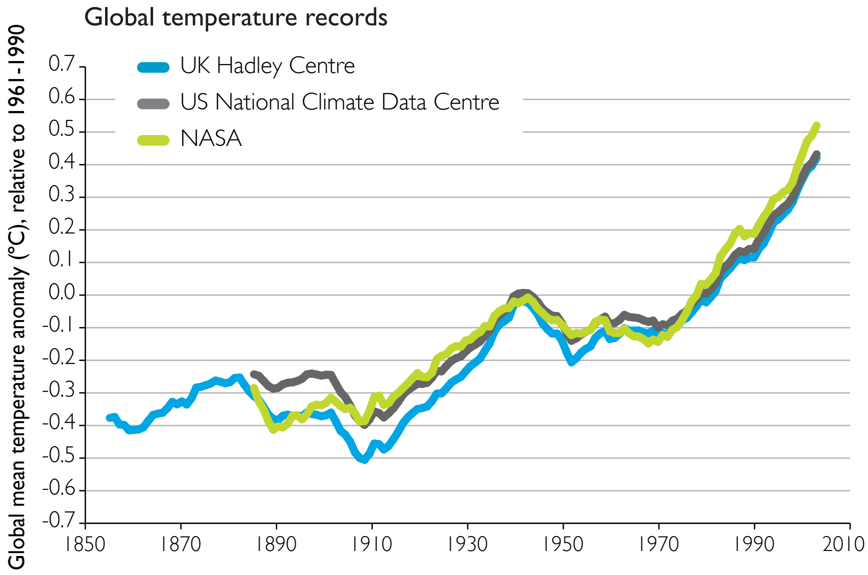
As water warms, it expands in volume. This thermal expansion of the ocean is a major cause of sea-level rise in the 20th century. The other main contributors are the melting of ice-caps and glaciers around the world, and smaller contributions from the Greenland and Antarctic ice sheets.

Extreme weather events and precipitation patterns are changing

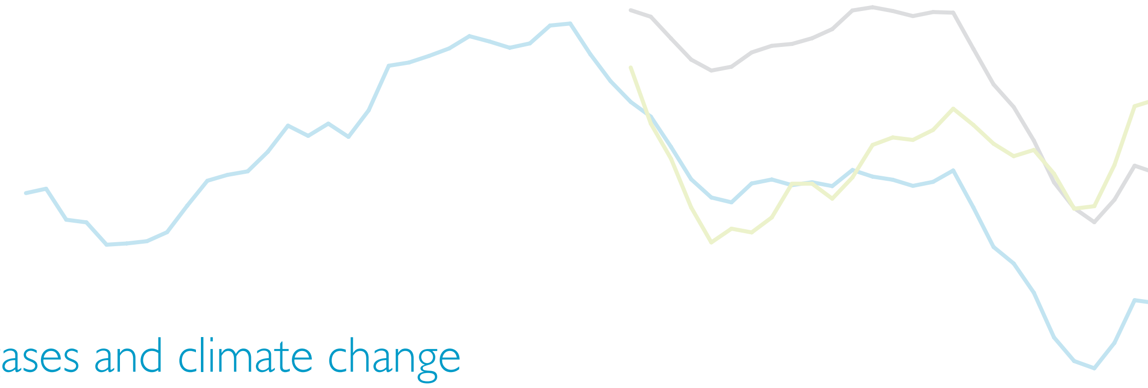
Over the last 50 years globally, there have been fewer cold days and nights, and more hot days, hot nights and heatwaves. Heavy rainfall events and extreme sea-level events have increased over most areas.

Since 1900, precipitation has increased significantly over eastern parts of the Americas, northern Europe, parts of Asia and north-western Australia. Reduced precipitation has occurred in central and southern Africa, the Mediterranean and parts of southern Asia. Since 1950, there has been significant drying in south-western and eastern Australia.

These long-term global climate trends are occurring alongside normal weather variations that happen naturally over seasons or decades. The way short-term and long-term variations interact can reduce or worsen the impacts we experience, making it harder to pinpoint all the causes of local temperature changes or specific weather events.



> Figure 1: The three most complete global temperature records available – from the UK Hadley Centre, NASA, and the US National Climate Data Centre – all show a clear upward trend in global average temperatures over the last 150 years (calculated using an 11 year running average).



Greenhouse gases and climate change

Greenhouse gases (GHGs) are a natural part of the atmosphere, trapping and re-radiating heat from the Earth's surface. The natural greenhouse effect is crucial in maintaining a surface temperature that can support life.

The main greenhouse gases are water vapour, carbon dioxide (CO_2), methane, nitrous oxide, halocarbons and tropospheric ozone. Greenhouse gas concentrations are often expressed as a carbon dioxide equivalent (CO_2-e).

Many other natural and human factors also affect the climate. Natural variability such as the El Niño cycle and variations in solar activity can affect the temperature, while large volcanic eruptions can lead to cooling. Changes in land-use can either reduce or increase the amount of heat absorbed by the Earth's surface. Airborne particles (aerosols) have a net cooling effect.

Concentrations of GHGs in the atmosphere have increased since 1750 and now exceed pre-industrial levels

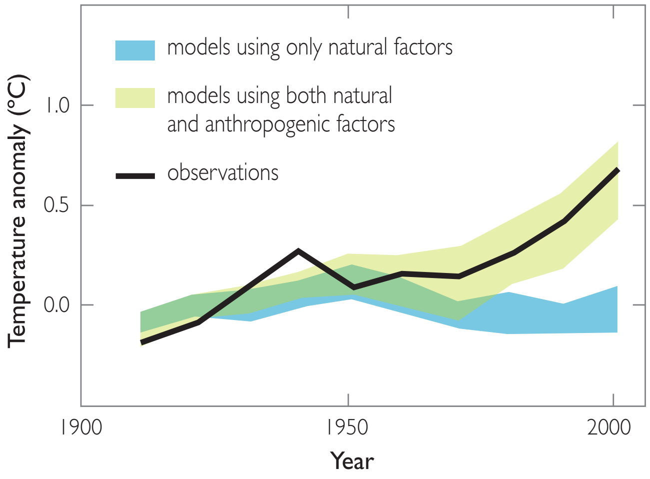
Since the Industrial Revolution, CO_2 concentrations have risen 37%, methane 150% and nitrous oxide 18%. The global increases in CO_2 concentration are due primarily to fossil fuel use and land-use change, while the increases in methane and nitrous oxide are primarily due to agriculture. The CO_2 concentration in 2008 of 383 parts per million (ppm) is much higher than the natural range of 172 to 300 ppm that existed over the last 800,000 years.

There is greater than 90% likelihood that most of the global warming since the mid 20th century is due to increases in greenhouse gas emissions from human activities

The physical and chemical processes involved are well understood and documented, and there is less than 5% likelihood that the observed warming is due to natural causes alone (Fig 2).

Evidence of human influence has been detected in ocean warming, sea-level rise, continental-average temperatures, temperature extremes and wind patterns. This conclusion is consistent with the observed melting of glaciers and ice sheets.

Global average temperature



> Figure 2: The observed increases in global average temperatures cannot be explained by natural factors alone.

Carbon dioxide affects more than just the climate

About 25% of the CO_2 emitted into the atmosphere is absorbed by the ocean and another 25% is absorbed by the terrestrial biosphere. In water, the CO_2 forms a weak carbonic acid, making the oceans more acidic. Ocean acidification interferes with the formation of shells and coral, and has far reaching implications for the health and productivity of the world's oceans. Higher CO_2 levels can also increase plant growth and productivity but this can be offset by changes in climate such as less rainfall or higher temperatures.

Measuring the climate: then and now

Today, scientists from many nations work together to run a sophisticated global network of weather stations, ocean buoys, tide gauges, satellites and atmospheric sampling stations that constantly measure and record weather, sea levels and greenhouse gas concentrations.

Researchers also analyse older records such as ships' logs, weather reports, tidal records, and archaeological evidence to build up a picture of the Earth's climate over hundreds of years.

To look back beyond this, scientists analyse proxy temperature records such as the annual growth rings of trees and corals, and small fossils in lake sediments. For example, sediment cores can indicate how coastlines have shifted with changes in sea level. Bubbles of air trapped deep in polar ice can reveal temperatures and atmospheric concentrations of greenhouse gases up to 800,000 years ago.

The amount of future climate change depends on the level of global greenhouse gas emissions

Research groups around the world have independently developed climate models, which each have their own strengths and weaknesses. After careful testing, these models are used to project likely future changes in the climate based on various emission scenarios.

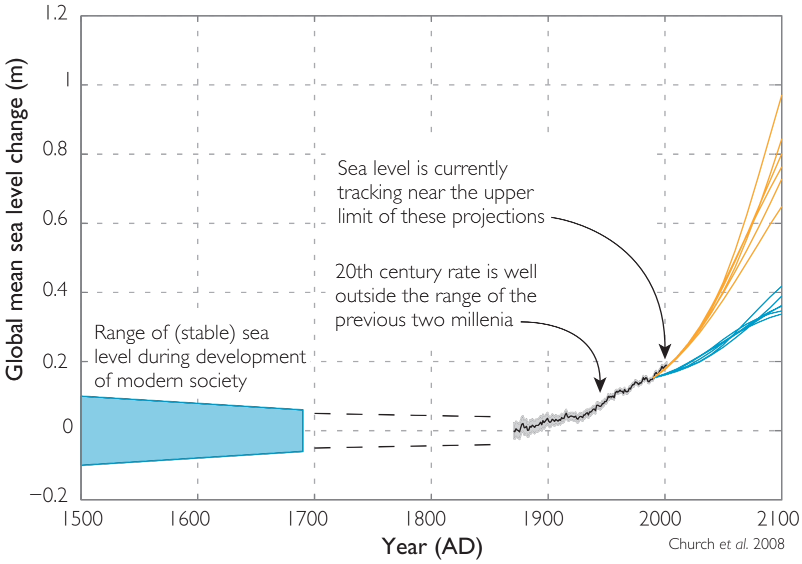
Concentrations of greenhouse gases are continuing to rise, and some GHGs have long lifetimes in the atmosphere. Due to this inertia, the climate changes projected for 2030 are unavoidable.

The current rate of GHG emissions is above the highest scenario developed by the Intergovernmental Panel on Climate Change (IPCC). The scenarios used in the IPCC's most recent report no longer adequately describe emerging emission trends over the next few decades. New estimates accounting for recent emission trends indicate that by 2030 CO_2 emissions may be 17 to 52% higher than estimated by the IPCC. This would likely result in a global warming of 0.8 to 1.5 °C by 2030.

Continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21st century. There is greater than 90% likelihood that these changes will be larger than those already seen during the last century.

There is greater than 90% likelihood that heat waves and heavy rain events will continue to become more frequent around the world. Sea-ice and snow cover are projected to shrink. There is greater than 90% likelihood that rainfall will increase in high latitudes and greater than 66% likelihood that rainfall will decrease in most sub-tropical and temperate land areas. There is greater than 66% likelihood that the area affected by droughts will increase and there is greater than 66% likelihood that that tropical cyclones will become more intense.

Today's sea level is unprecedented during modern civilisation



Church *et al.* 2008

> Figure 3: Global sea level was stable for at least two thousand years before starting to rise in the 19th century and the rate of rise has increased since then. Currently sea level is tracking near the top of the IPCC projections. The orange lines show the high (95%) values for six IPCC SRES scenarios. The blue lines show the low (5%) values for the same six scenarios.

By 2050, different trends in emissions have a significant influence on climate outcomes. If significant mitigation efforts start in 2010, leading to emissions peaking in 2020 and CO_2 equivalent concentrations stabilising around 600 ppm after 2060, scientists project a warming of 1.1 to 2.2 °C by 2100. The chance of avoiding a warming of 2 °C would be around 90%.

However, if global emissions continue to climb so that CO_2 equivalent concentrations exceed 970 ppm by 2100, then temperatures are projected to increase by 2.2 to 4.7 °C by 2100, and there would be little chance of avoiding a 2 °C warming.

Sea level is projected to rise further by the end of this century

Ongoing warming of the oceans and melting of ice are expected to lead to continued sea-level rise of at least 18 to 79 cm this century. Due to limited understanding of how ice-sheets in Greenland and the Antarctic will respond to rising temperatures, a rise of more than 79 cm by 2100 cannot be ruled out. Although our understanding of how ice sheets melt and decay is improving, there is currently no scientific consensus on a best estimate of their contribution to sea-level rise by 2100.

Projections for Australia's climate

Australian average temperatures are projected to rise by 0.6 to 1.5 °C by 2030 and by 1 to 5 °C by 2070

The warming projected for Australia in 2070 is 1.0 to 2.5 °C for a low emission scenario (similar to a 500 ppm CO_2 equivalent path) and 2.2 to 5.0 °C for a high emission scenario (similar to the world's current path).

Warming is projected to be lower near the coast and in Tasmania and higher in central and north-western Australia. These changes will be felt through an increase in the number of hot days. In Canberra, for example, the present annual average of five days over 35 °C may rise to seven to 10 days by 2030 and eight to 26 days by 2070.

Average annual rainfall is likely to decrease over much of Australia

Projections indicate that by 2030, southern Australia may receive up to 10% less rainfall while northern areas see changes of -10 to +5%. By 2050, southern areas may get 0 to 20% less rainfall, with changes of -20 to +10% in the north. Water security problems are projected to intensify by 2030 in southern and eastern Australia as a result of reduced rainfall and higher evaporation.

The frequency and extent of droughts is projected to increase over most of southern Australia. However, it is difficult to determine with certainty how much of the drying of the past decade is due to human activities.

The pattern of severe weather events is expected to change

The effects of climate change will be superimposed on natural climate variability, leading to changes in the frequency and intensity of extreme weather events.

- There is greater than 90% likelihood that extreme fire weather will occur more often in southern Australia, with longer fire seasons.
- Days with heavy rainfall are projected to become more intense over most areas in summer and autumn and in northern areas in winter and spring.
- Tropical cyclone days are projected to increase in the north-east but decrease in the north-west, with the strongest cyclones becoming more intense.
- The number of days with large hail is projected to increase along the east coast from Fraser Island to Tasmania and decrease along the southern coast of Australia.

Coastal settlements and infrastructure

By 2050, Australia's growing coastal towns and cities will face heightened risks from sea-level rise and more frequent severe storms and flooding. Global climate models indicate that mean sea-level rise on the east coast of Australia may be greater than the global mean sea-level rise. In low-lying areas, a mean sea-level increase of 18 to 79 cm or more could lead to coastal inundation tens or even hundreds of metres inland depending on local topography.

Risks to major infrastructure are expected to increase, including: failure of flood protection, urban drainage and sewerage; increased storm and fire damage; and power-outages during heat waves.

The natural environment

Significant loss of biodiversity is projected to occur as early as 2020 in some ecologically rich sites. For example, rising sea temperatures are almost certain to increase the frequency and intensity of mass coral bleaching on the Great Barrier Reef. Other sites at risk include the Queensland wet tropics, Kakadu wetlands, south-west Australia, sub-Antarctic islands and the Australian alps.

Primary industries

Production from primary industries is projected to decline by 2030 over much of southern and eastern Australia due to increased drought, reduced water resources and higher temperatures. Changes in the distribution and abundance of commercial fish species may create new opportunities in some coastal regions, but overall projected changes in climate pose some very significant risks to the fishing industry.

Human health

One of the major health impacts is likely to be an increase in heat-related deaths. Without preventative action, the number of heat-related deaths in people aged over 65 could rise from 1,115 per year at present in the major capital cities, to between 4,300 and 6,300 per year by 2050. Some mosquito-borne diseases may move south, e.g. dengue fever.

Science based solutions

A comprehensive response to climate change requires three broad areas of action: mitigation, to reduce greenhouse gas emissions; adaptation, to prepare for impacts that are now unavoidable; and continued research to better understand the earth's climate systems.

Reducing greenhouse gas emissions

Many of the impacts of climate change can be reduced, delayed or avoided by reducing greenhouse gas emissions. One of the key messages from the science is that mitigation efforts over the next few decades will have a large influence on whether GHG concentrations can be stabilised at a level low enough to reduce the risk of more serious climate change impacts.

Cutting Australia's GHG emissions is a major national undertaking that involves households, companies, communities and governments. The goal of CSIRO's Energy Transformed National Research Flagship is to develop stationary and transport technologies to halve GHG emissions, double the efficiency of the nation's new energy generation, supply and use, and to position Australia for a future hydrogen economy.

Preparing for the impacts of climate change

Australians have a long history of coping with the vagaries of a highly variable climate, and the nation enjoys a high standard of living, so we have the capacity to adapt and prepare for some of the impacts of climate change. Early studies indicate that for Australian agriculture, adaptation measures could reduce the impacts of climate change on productivity by almost 50 per cent, and substantially reduce the economic cost to regional communities.

Potential actions to adapt to life in a changing climate include: choosing development sites that will be less affected by extreme weather events; improving building design; reducing water use and developing new water sources; switching to more drought-tolerant crops; improving the resilience of ecosystems threatened by climate change; and assisting our neighbours in the Asia-Pacific region.

Climate change research is improving our knowledge and addressing uncertainties

Our present scientific understanding of climate change, although incomplete, is sufficiently robust to inform decision-making and action.

However, the fact that many key aspects of the science of climate change are now well understood and agreed has not eliminated all uncertainties. Remaining uncertainties arise from three main sources:

- Current limits and gaps in our knowledge about physical climate processes, for example: how much influence are aerosols having on the climate system?
- The complexity of modelling the global climate system, for example: how can we more accurately simulate future rainfall patterns?
- The inherent difficulty of predicting human behaviour, for example: how fast will developing economies grow and how will this affect their net emissions of GHGs and aerosols?

Furthermore, the risk posed by positive feedback loops is poorly understood. Potentially significant feedbacks that could accelerate climate change and its impacts include: the release of GHGs from melting permafrost; changes in how much carbon dioxide is absorbed by the natural environment as temperatures rise; and increased heat absorbed by the oceans as sea ice retreats.

For further information

Further information and resources, including a fully-referenced version of this brochure, are available at www.csiro.au/climatechange

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