AUSTRALIAN FOREST PRODUCTS ASSOCIATION
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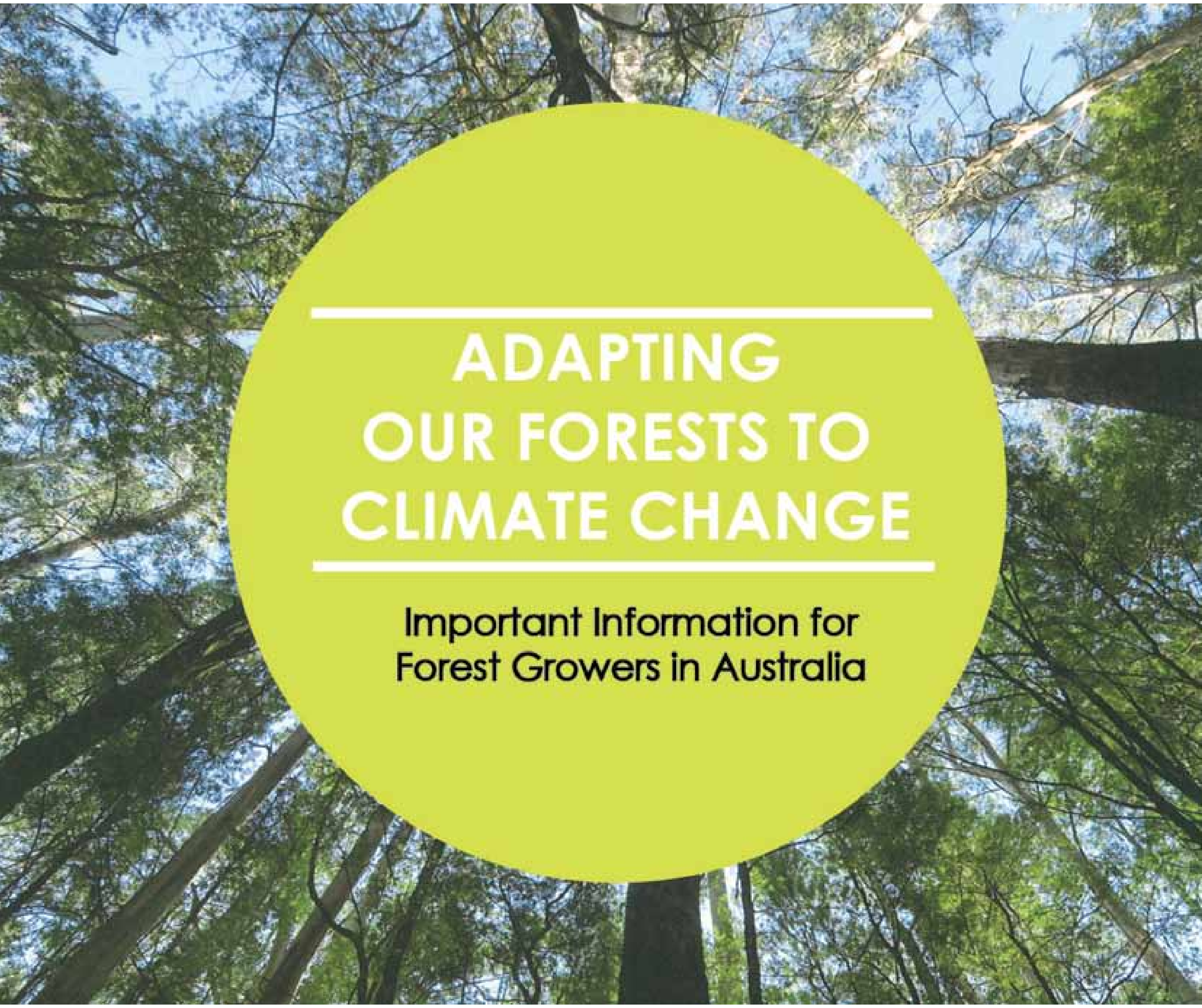
Plantation Forest Industry Climate Change Adaptation Handbook



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Acknowledgements

This handbook has been prepared as part of a three year project initiated by the forest industry to promote awareness of future climate change scenarios and relevant adaptation management options and strategies, which can be used to improve adaptive capacity in dealing with climate change. While many of the generic principles are relevant to the industry value chain as a whole (e.g. growing, processing and distribution), the initial focus of this handbook is on the forest plantations sector, reflecting a research and policy focus on this particular sector. Presently, there is a limited amount of scientific and other technical information on adaptation options for the native forest sector and broader processing issues, which is a research gap.

The project was managed by Michael Stephens from the Australian Forest Products Association (AFPA) in collaboration with relevant researchers, industry practitioners and companies involved in climate change issues and adaptation responses.

The handbook has been prepared from a relevant selection of scientific information and literature compiled from the project. AFPA would like to acknowledge the valuable input provided by the many regional workshop presenters during the course of the project, from which a lot of the material contained in this handbook has been drawn. They included:

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Purpose

This Handbook has been designed to provide initial guidance and insight into the topic of climate change adaptation as it relates to the forest based industry. The intended audience is forest industry planners, practitioners and other key decision makers with a direct interest in commercial aspects of future climate change risks and management responses. It covers:

- future climate scenarios;
- forestry and forest industry implications;
- possible impacts for forest regions;
- industry adaptation;
- enterprise level responses;
- approaches to uncertainty and risk management;
- barriers to adoption and uptake;
- broader socio-economic issues; and
- further reading.

The focus is on different types of climate risks and adaptation options for forest plantations managed for timber production. It does not address risks to native forests used for timber production or plantations used for other purposes.

As such, it should be regarded as a starting point for increasing awareness of likely hazards and management options rather than a detailed scientific understanding of all of the relevant issues. The reader is referred to the references and websites in the Handbook for further information.

The Handbook is only a snapshot of the available information at the time of writing which will change in the course of time through additional research and knowledge of our understanding of future climate risks, tools and needs.

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What is adaptation?

A changing climate imposes significant challenges and some opportunities for the forest and forest based industries in dealing with these changes. But what do we mean by the term adaptation?

The Intergovernmental Panel on Climate Change (IPCC) has defined adaptation as:

'the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (McCarthy et al. 2001).

In other words, adaptation is the process of undertaking action to deal with the effects of climate change to either reduce harm or promote their benefits. From a commercial forest production perspective, this would involve taking action to either reduce or avoid commercial losses, or to increase commercial returns, from a changing climate.

Mitigation, on the other hand, is action taken to influence the future climate by directly reducing greenhouse gases (i.e. emissions) from the atmosphere or by promoting the removal of greenhouse gases through sequestration activities, such as the planting of new forests.

Adaptation and mitigation can be complementary activities, particularly in the forest sector. For example, the establishment of new forests can sequester carbon dioxide from the atmosphere while promoting improved productivity and resilience of agricultural lands to climate change. Similarly, the increased use of woody biomass for renewable energy can enhance the diversification and resilience of the forest based industry to climate change (e.g. offsetting the lower productivity of forests) while displacing higher emission fossil fuels.

This introduces a further concept – vulnerability to climate change. Vulnerability is a function of the exposure and sensitivity of a system to climate change (Figure 1). Exposure is the extent to which changes in climate conditions, and related effects such as increased disease, insect pests or fire, are likely to impact on the forest or production chain, while sensitivity refers to the degree of impact from these changes. Sensitivity will be determined, in part, by the management options available to respond to change. Vulnerability can be a useful tool when evaluating the implications of climate change on ecosystems, communities and industries.

Future conditions in the wider operating environment need to be considered in options for managing climate risks. Assessments of the potential impacts and the options to adapt to climate change need to consider social, economic and other environmental change that will affect commercial timber production. Indirect effects are also important. Climate change will affect timber production potential and supply capacity of forest production regions in other parts of the world and it will affect the economic conditions for competing products as well as markets more generally.

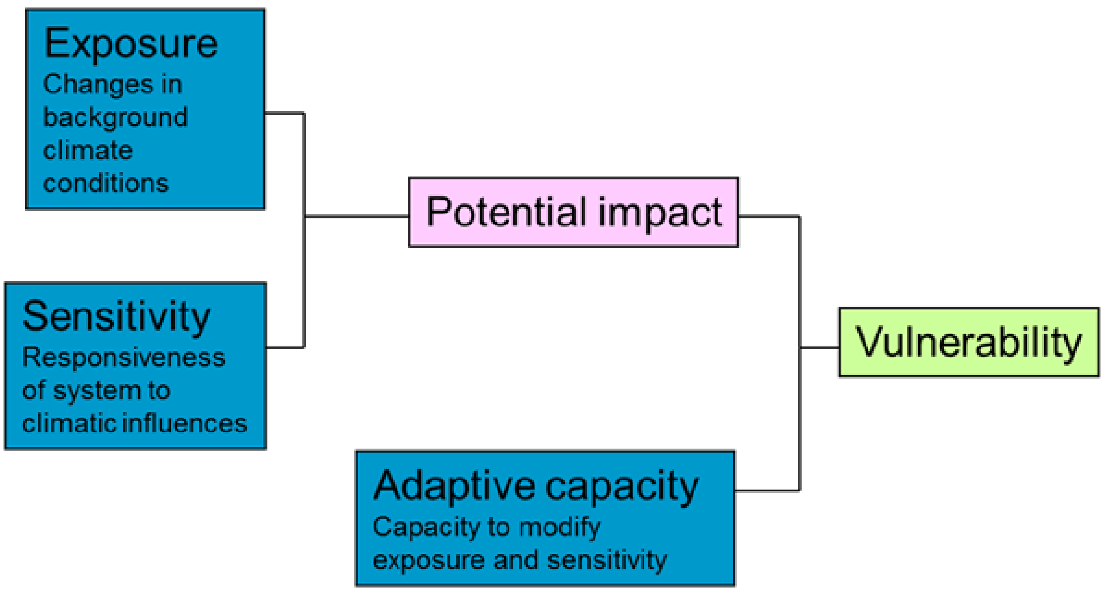

Figure 1: Factors influencing vulnerability (or resilience) of forests to climate variability and climate change (Allen Consulting Group, 2005)

Future climate scenarios

There is increasing scientific evidence and consensus that the world's climate is changing under the influence of increased greenhouse gas emissions. Climate change will cause a range of impacts on forests and forestry activities with a consequent need for adaptation responses to emergent risks and opportunities.

Projected climatic changes of particular importance to the forest based industries include: changes in temperature, rainfall and elevated atmospheric CO_2 concentrations (Pinkard et al 2010).

Mean annual temperatures (MAT) are projected to increase by between 0.4 and 2°C by 2030 and between 1 and 6°C by 2070, with considerably larger changes in some regions (Pinkard et al 2010). This is illustrated in Figure 2, which shows projected MAT for 1980, 2030 and 2070 for two global climate models.

A general reduction in average annual rainfall and hence of runoff is anticipated (Figure 3), although forecast changes to rainfall amount and seasonality are variable between models. Higher temperatures are also expected to increase evaporation and reduce relative humidity.

Atmospheric concentrations of CO_2 continue to rise by between 2 and 4 ppm annually and future levels are expected to reach between 400 and 450 ppm by 2030. The incidence of extreme weather events is also expected to change, with increased frequency and intensity of heavy rainfall events, drought and extreme fire days.

A decrease in frost frequency is anticipated, although frost severity may increase in some areas (Pinkard et al 2010).

Forestry and forest industry implications

The area of commercial plantation forest in Australia is just over 2 million hectares, with 1.02 million hectares of coniferous plantation and 980 000 hectares of broadleaved plantation (Gavran 2012). Australia's commercial plantations are located mainly in the north-eastern coastal, southern and eastern regions of Australia (refer Figure 4).

The coniferous plantation estate is dominated by *Pinus radiata* or radiata pine (75.5 per cent) and *Pinus elliotti* and *Pinus caribaea* hybrids known as southern pines (14.7 per cent), which are primarily managed for sawlog production. Most radiata pine is located in the Murray Valley, Green Triangle, Central Tablelands of New South Wales and Tasmania regions, and most southern pines are located in the South East Queensland region.

The broadleaved plantation estate is dominated by *Eucalyptus globulus* (55.1 per cent) and E*ucalyptus nitens* (24.1 per cent), which are primarily managed for short rotation pulpwood production.

In 2010-11, the gross value of log production from plantation forests was $1.38 billion and from naturally regenerated forests was $460 million (ABARES 2012). The forest industry also supports an important range of domestic value added activities, including the production of sawn timber and engineered wood products used for housing, construction and furniture, and pulpwood for making paper products and for woodchip exports.

The Australian forest and forest products industry had an annual turnover of $22 billion and directly employed 75 000 people in 2009-10 (ABARES 2012). Over recent decades, the contribution of the plantation industry relative to total industry output has grown, accounting for 20 million cubic metres of log removals or 76 per cent of domestic log production in 2010-11 (ABARES 2012).

Projected changes in climate and a trend towards more frequent extreme climatic events suggest that even within the relatively short timeframe of current rotation lengths, climate variability and climate change can affect forest productivity and operations across a range of forest areas and industry sectors (Pinkard et al 2010).

Plantation productivity may be increased by rising levels of atmospheric carbon dioxide, but may be reduced by increased temperature and increased water loss (evapotranspiration), that will be compounded if rainfall is reduced. There are also potential problems from increased pest and disease risks, as well as more frequent and severe bushfires (Booth et al 2010). Increased temperature may also increase productivity depending on geographic location, species and current climatic conditions.

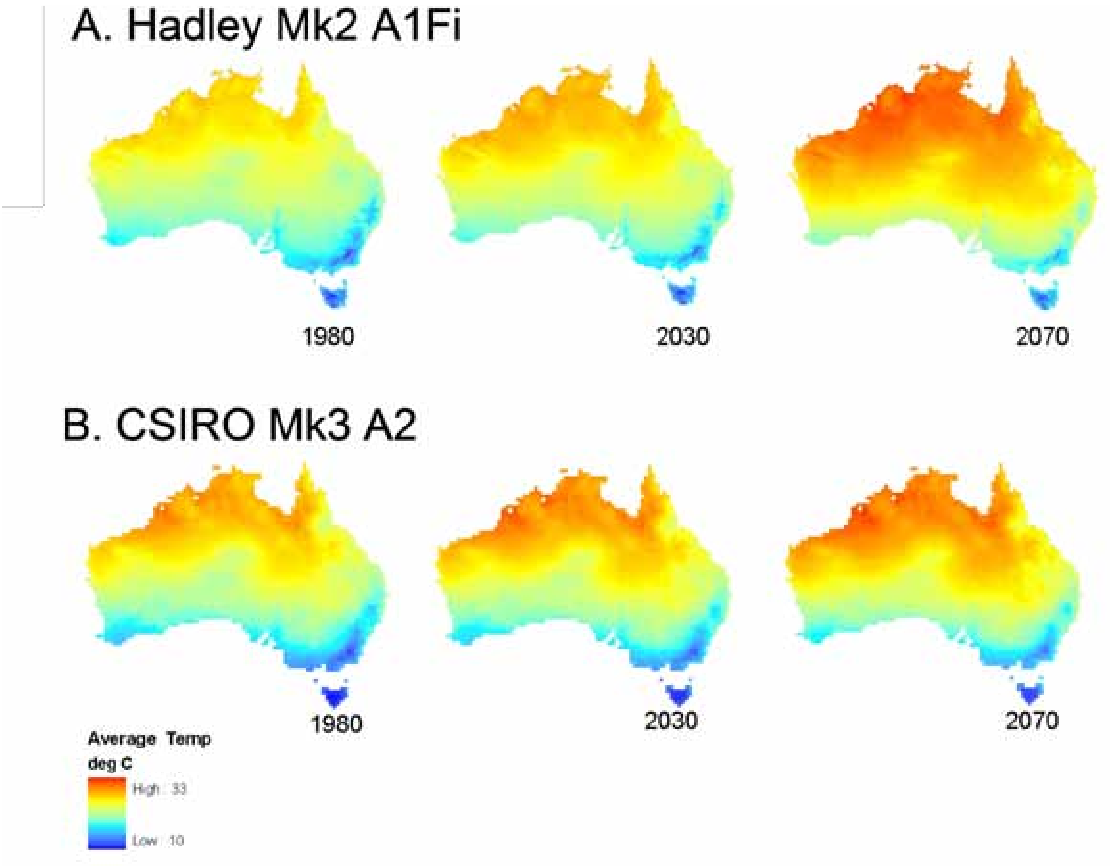

Figure 2: Annual average temperature surfaces from the (A) Hadley Mk2 A1Fi and (B) CSIRO Mk3 A2 future climate projections. Source: Battaglia et al (2009).

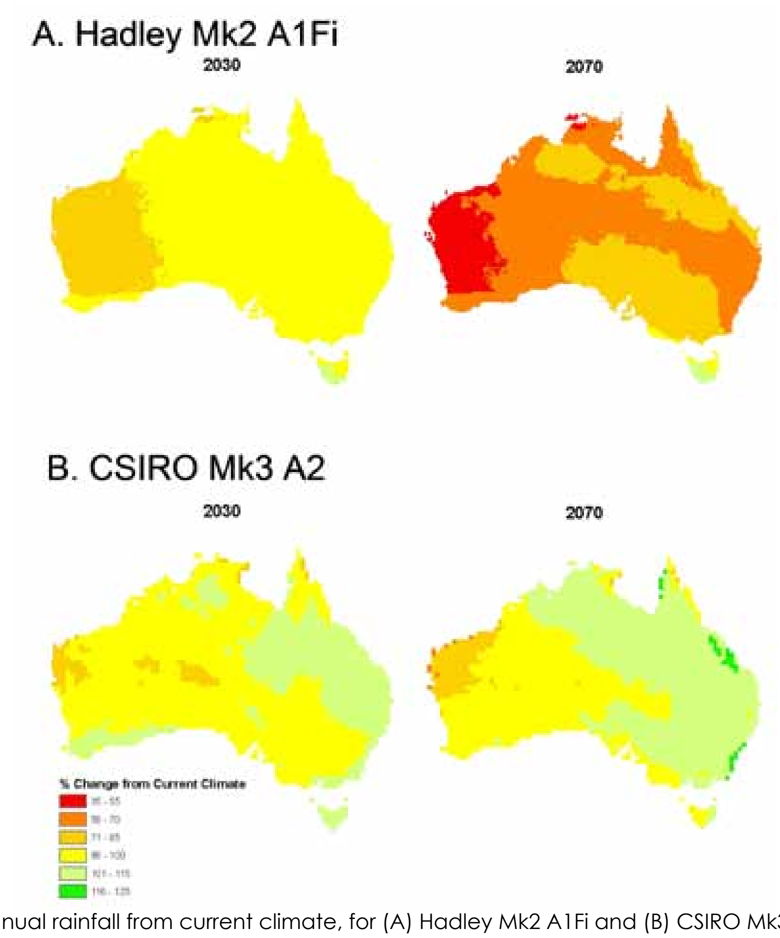

Figure 3: Projected change in annual rainfall from current climate, for (A) Hadley Mk2 A1Fi and (B) CSIRO Mk3 A2 future climate projections. Source: Battaglia et al (2009).

Figure 4: Major plantation areas in Australia categorised by the National Plantations Inventory. Accessed at: http://adl.brs.gov.au/mapserv/plant/region.phtml

However, Australian plantation forests are only classified as moderately vulnerable to climate change (Pinkard et al 2010). The two major commercial plantation species (*Eucalyptus globulus; Pinus radiata*) have broad climatic ranges and can tolerate a range of climate conditions, although sensitivity to factors such as extended drought varies considerably between species. Australia's plantations are therefore considered to have high adaptive capacity, with large potential to benefit from adaptation activities and practices. This presents the industry with opportunities as well as threats from climate change (Pinkard et al 2010).

In contrast the 147 million hectares of native forest are considered highly vulnerable to climate change because their current distributions cover only narrow climatic ranges and small changes in climate may have large impacts on future distributions (Booth et al 2010). This may have direct implications for the Australian forest industry, where almost 25 per cent of total domestic logs harvested are sourced from sustainably managed naturally regenerated forests.

A number of aspects of climate change are of particular importance to forestry:

- rises in temperature, particularly at the extremes;
- changes in total rainfall and seasonal rainfall distribution manifesting as changes in soil water availability;
- changes in atmospheric CO_2 concentration; and
- increased frequency or intensity of storms or flooding and weather conditions producing large-scale wildfires.

There is a high degree of interaction between these factors and responses to climate change will vary depending on the particulars of local site and climate (Battaglia et al 2009). The extent to which future climate departs from current conditions for a given species will also influence adaptive

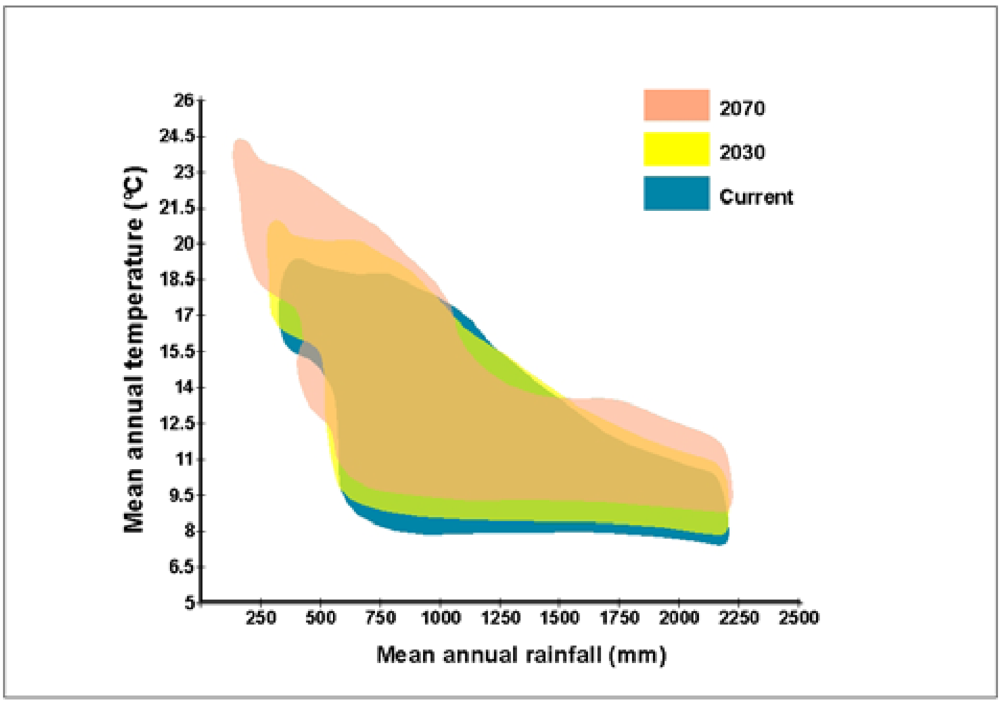

Figure 5: Current temperature and rainfall envelope across the current distribution of radiata pine compared to projected changes in these two climatic variables. Source: Michael Battaglia and Jody Bruce, personal communication, CSIRO.

capacity and productivity. For example, the future temperature and rainfall conditions across the distribution range for the major softwood plantation species in Australia (*Pinus radiata*) could be quite different to the current temperature and rainfall 'envelope', (Figure 5).

Predicted changes in plantation productivity

Recognising the complexity of these biophysical interactions, which may have positive or negative effects on various regions and parts of the forest industry, the CSIRO conducted a series of modelling simulations to spatially assess plantation change taking into account the degree of uncertainty in underlying variables and the risk that drought death may restrict commercial gains (Battaglia et al 2009). The major conclusions drawn from these spatial analyses are described below.

The following plantation species and region combinations are predicted to increase in production with little increase in risk of drought death or uncertainty based on model assumptions:

- *Eucalyptus globulus, Eucalyptus nitens* and *Pinus radiata* in Tasmania;
- the mid to lower northern regions of the hybrid pine estate; and
- *P. radiata* and *E. globulus* plantations in East Gippsland and higher altitude parts of central and north-east Victoria.

The following plantation species and region combinations are predicted to increase in production, with an increase in risk of drought death or predictions associated with high uncertainty based on model assumptions:

- that part of the Western Australian E. globulus and *P. radiata* estate in the high rainfall zone (>1000mm) where soils are fertile and deep;
- plantations of radiata pine in northern and central New South Wales/ACT; and
- *E. nitens, P. radiata* and *E. globulus* plantations in Victoria and the Green Triangle.

The following plantation species and region combinations are predicted to decrease in production (unless significant adaptation occurs), with an increase in risk of drought death or predictions associated with high uncertainty based on model assumptions:

- *P. radiata* plantations in southern NSW, and possibly at the western edge of the southern and central estates; and
- the eastern and northern extents of the Western Australian *E. globulus* and *P. radiata* estates.

Climate induced mortality

In addition to changes in the growth rates of trees, a changing climate can also affect the survival of trees and incidence of mortality, thereby affecting the overall productivity and commercial returns

Figure 6: An example of drought stress and mortality in a stand of *Pinus pinaster* (maritime pine), Western Australia. Dead or dying trees are indicated by their yellow or brown colour. Source: Don White, CSIRO.

from plantations. These effects are clearly evident from the scenario modelling undertaken by CSIRO, which included assessing the effects of predicted climate on both growth rates (Figure 7a) and mortality (Figure 7b), with particular relevance to the projected incidence of tree death in the northern zones of south-west Western Australia.

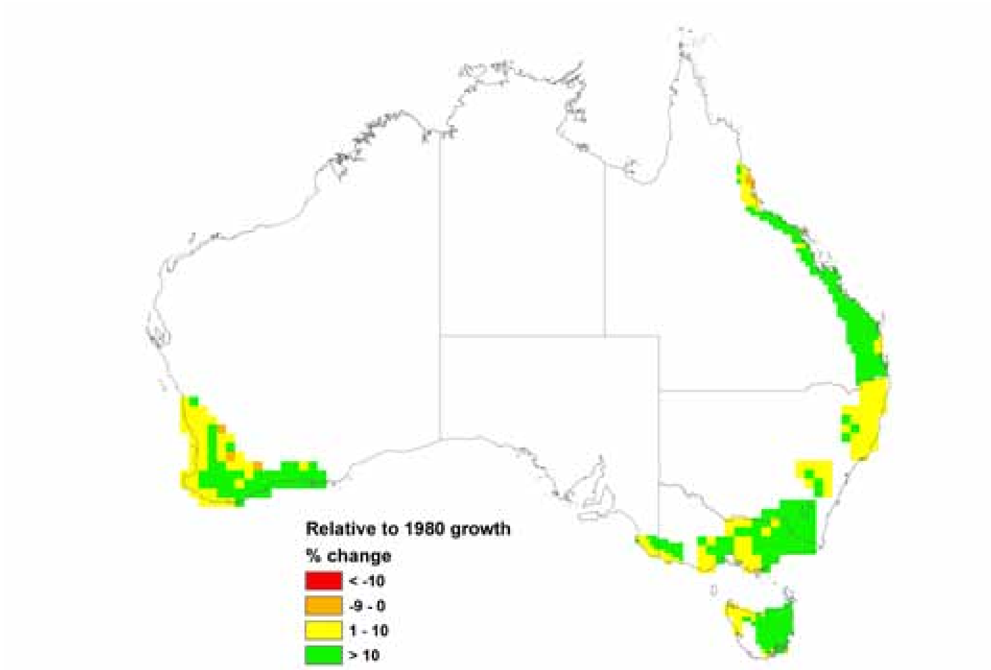

Figure 7a: Difference in plantation productivity between current and 2030 climate (averaged across all scenarios). Source: Michael Battaglia, personal communication, CSIRO.

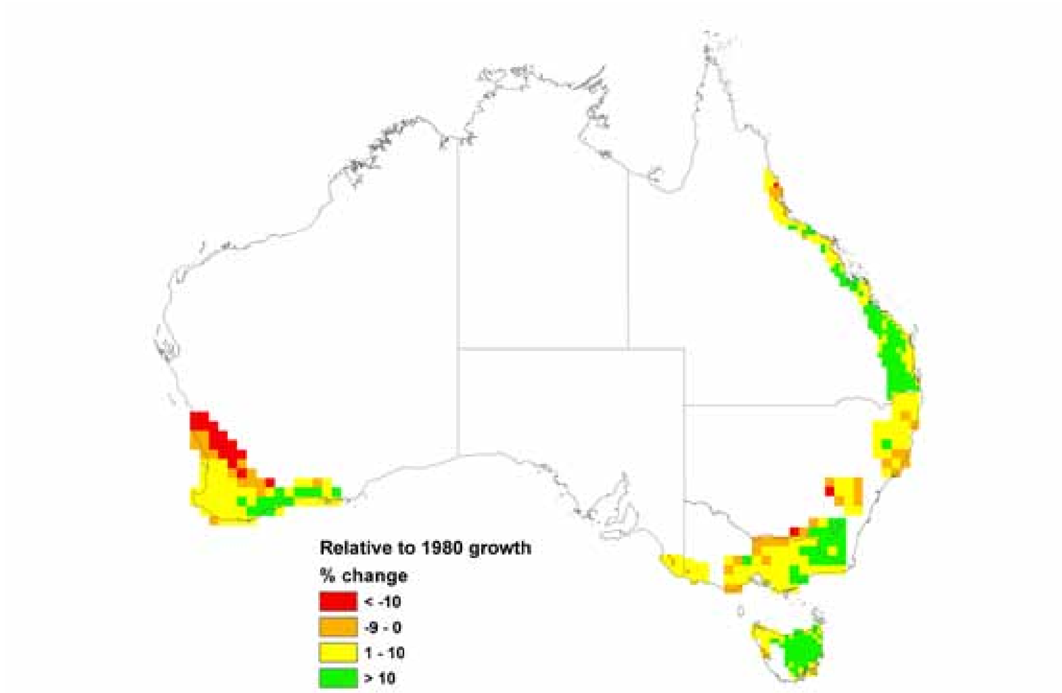

Figure 7b: Difference in plantation productivity between current and 2030 climate (averaged across all scenarios), including mortality. Source: Michael Battaglia, personal communication, CSIRO.

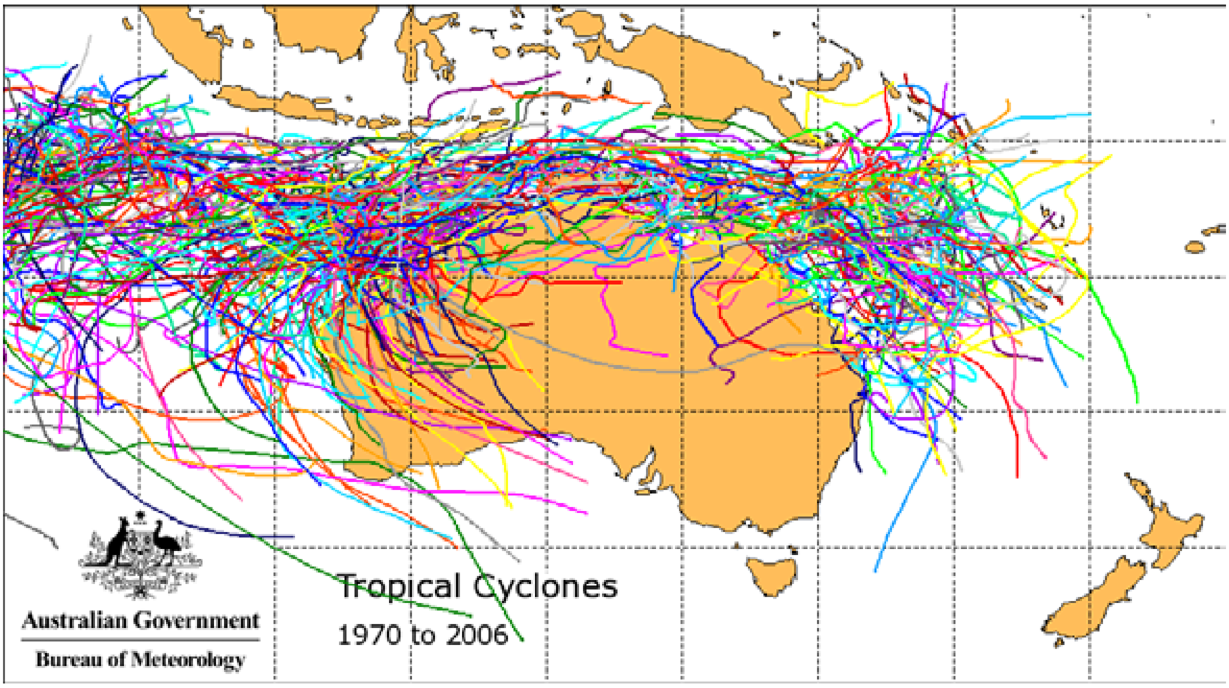

Figure 8: Tropical cyclones 1970 tp 2006. Source: Bureau of Meteorology

Extreme weather events: case study

Cyclones are a common feature of climatic events in northern Australia. In the future, an increase in the severity of tropical cyclones is predicted, with associated higher risks of more severe damage to plantations, industry processing facilities and infrastructure.

In far north Queensland, for example, the region has experienced several Category 5 (severe) cyclones over the past decade, including cyclones Larry, Ului and Yasi. On 2 February 2011 cyclone Yasi had a direct hit on a major commercial plantation near Cardwell, with damaging consequences (Figure 9).

Current projections suggest that the frequency of tropical cyclones may not increase, but are likely to become more intense and impact on areas further south of current ranges. The incidence of extreme weather events raises a number of important management and operational considerations to minimise commercial losses. These include preventative land management practices (e.g. choice of species, plantation design and location in the landscape) as well as contingency planning and operational aspects of dealing with the direct consequences of these events, such as the ability to conduct salvage logging with suitable infrastructure and access to markets.

Figure 9: Stand of *Pinus caribaea* impacted by cyclone Yasi. Source: HQPlantations.

Broader industry flow-on effects

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) modelled the possible effects of climate change on forest growth and log availability in six regions across Australia, with similar findings to the CSIRO modelling described earlier. Surrogate species were used to simulate the effects of projected climate change on a number of native forests and plantations species for which growth rate data were not available to calibrate the physiological growth model used (i.e. 3-PG2 Spatial). Actual species were used when data were available for 3PG including blue gum in the Green Triangle and south-western Western Australia; Caribbean pine in northern Australia; maritime pine in south-west Western Australia; and radiata pine in the Green Triangle, south-western Western Australia and Tasmania (ABARES 2011).

The study used two greenhouse gas emission scenarios (A1B and A2) developed by the Intergovernmental Panel on Climate Change (IPPC) to estimate climate change in 2030 and 2050. The results of these scenarios are shown below in terms of their projected impacts on forest growth rates (Figure 10), log availability (i.e. log supply) (Figure 11) and other socio-economic factors, including value of production and employment (Figure 12).

The results illustrate a range of possible future impacts across the major forest growing regions, based on the modelling parameters described above and assuming the absence of any adaptation measures.

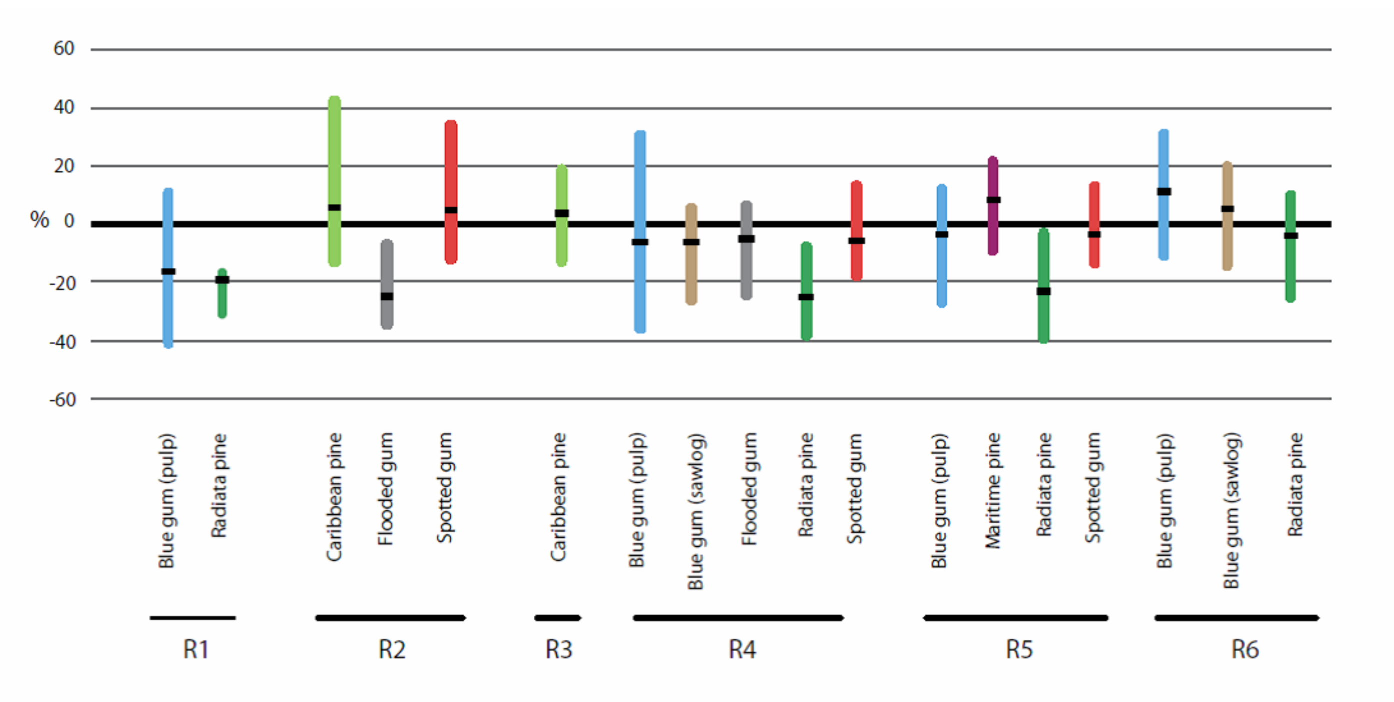

Figure 10: Projected percentage change in growth rates due to climate change (2030 A1B scenario). R1 = Green Triangle; R2 = north-eastern NSW- south-eastern QLD; R3 = northern Australia; R4= south-eastern NSW – eastern Victoria; R5 = south-western WA; and R6 = Tasmania. Source: (ABARES 2011).

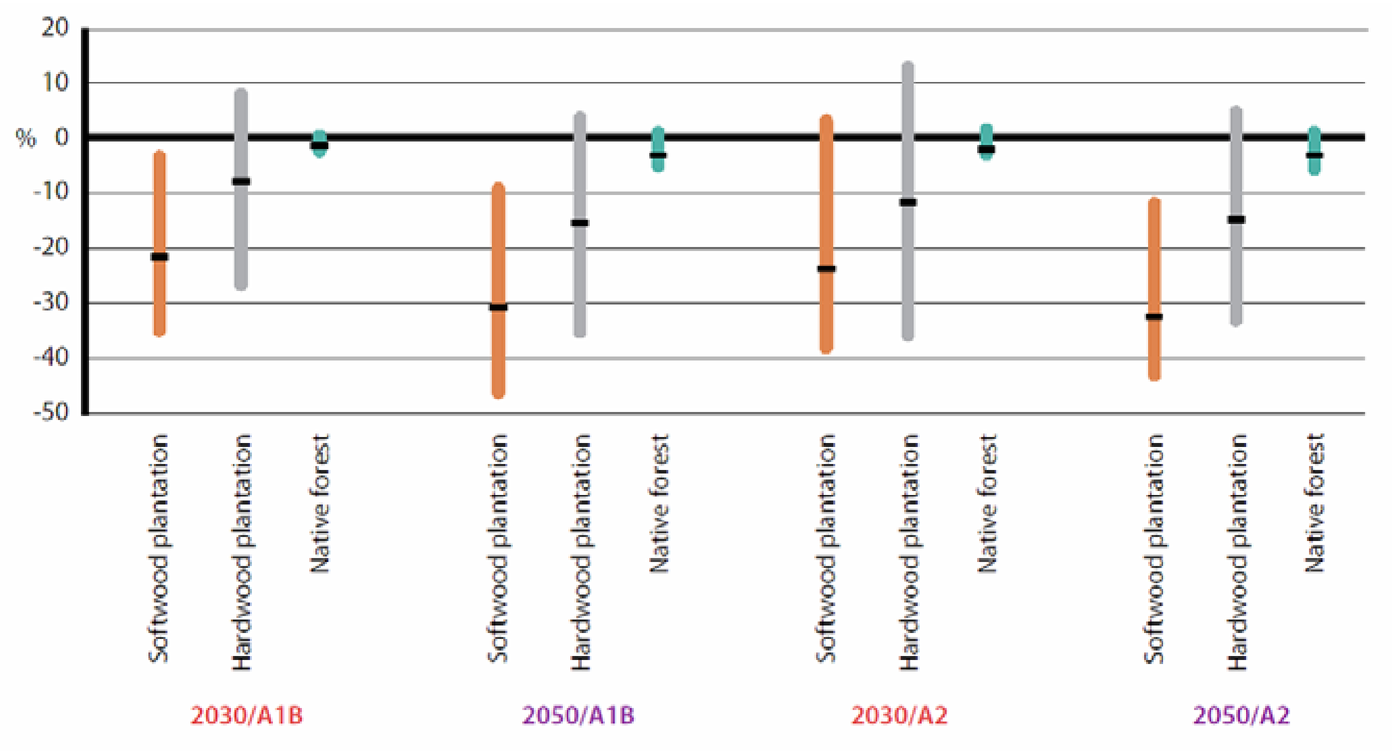

Figure 11: Projected changes in log availability due to climate change. The solid dashes show the effect on log availability due to median model effect of climate change, the bars above and below the dashes show the range. Source: (ABARES 2011).

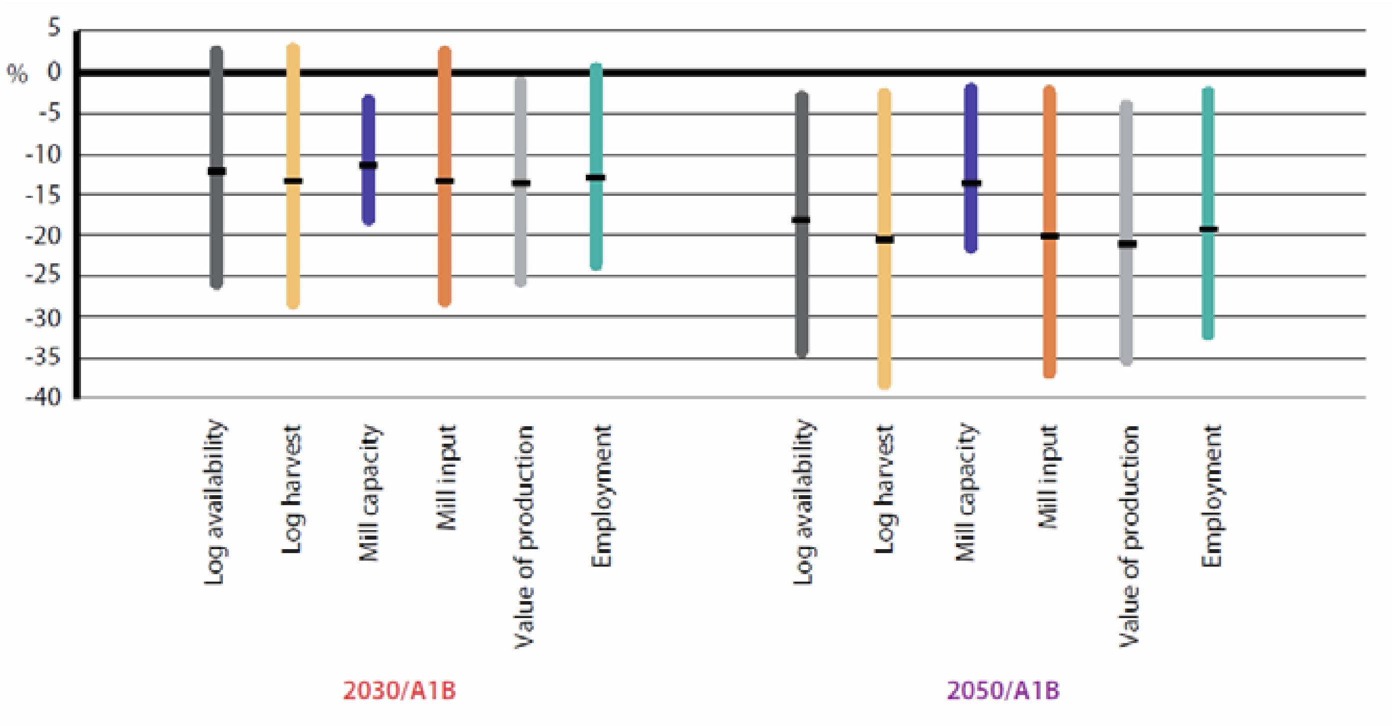

Figure 12: Projected change in socio-economic factors due to median and range of effects of climate change on log supply under the A1B scenario in log availability due to climate change. The solid dashes show the effects on socio-economic factors due to median model effect of climate change on log supply, the bars above and below the dashes show the range. Source: (ABARES 2011). Battaglia, personal communication, CSIRO.

Industry adaptation

Successful adaptation will require both strategic and operational planning at the individual enterprise level as well as across the industry more widely, and will depend on time scales and the degree of current and future impacts (Figure 13).

Adaptation options for plantations currently growing will be more limited than those for future plantings. In the short term, adaptation will revolve around managing risks and vigour such as managing drought risk through thinning regimes and weed control, fire risk through residue management, and vigour through fertilising, weed control and pest management (Pinkard et al 2010). These sorts of responses should be sufficient to deal with small incremental changes in climate, but may not be appropriate responses to extreme weather events.

Over the longer term, as climate change progresses, more complex responses will be required, such as deployment of new genetic material, product diversification, development of new practices and products or changes in the distribution of plantations. These sorts of responses are likely to provide additional benefits but at a greater cost than initial within-rotation adaptations (Pinkard et al 2010).

Successful adaptation may require integration across all facets of timber production, from seedling production to processing. Developing adaptation strategies will be complex, requiring strategic planning to assist in operational decision-making by a range of enterprises and stakeholders (e.g. industry, researchers, governments).

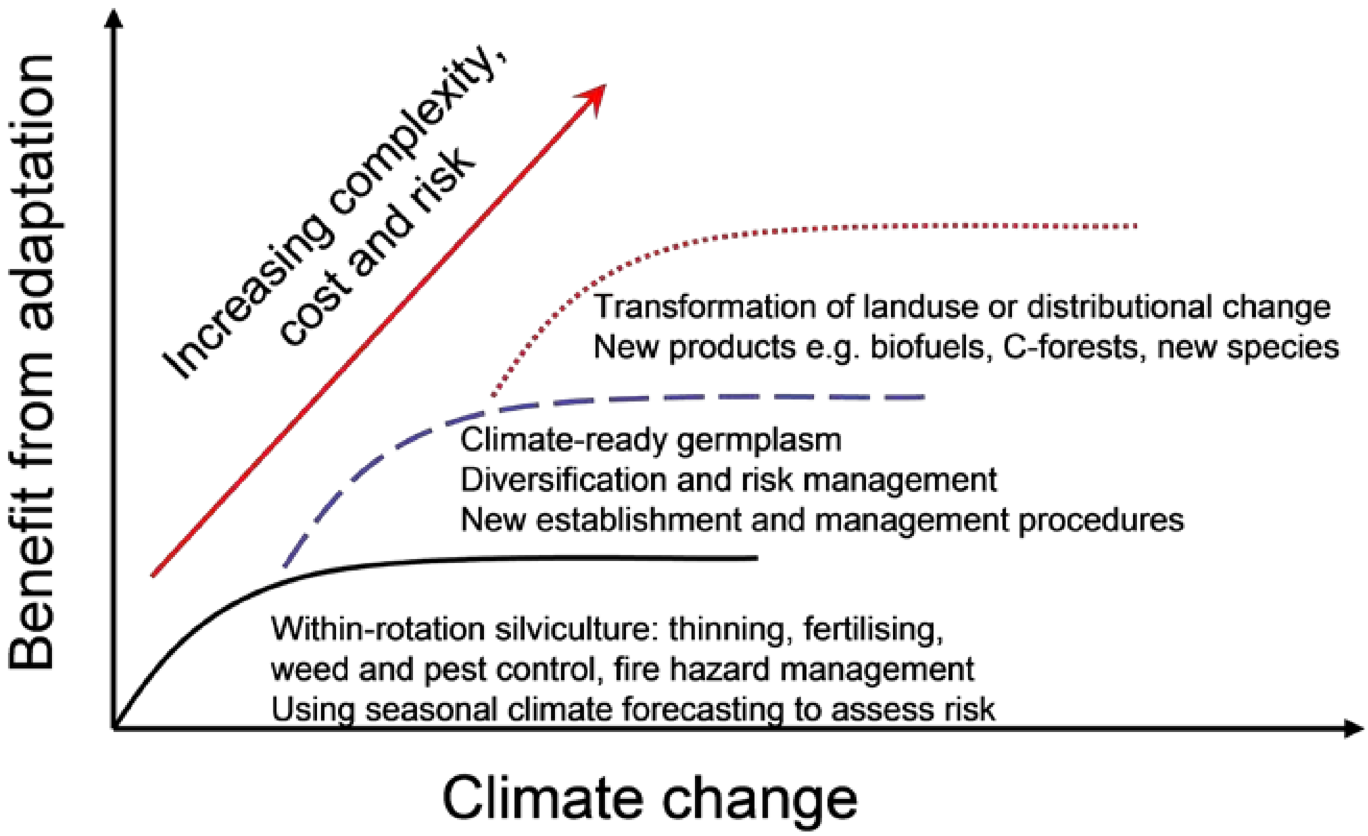

Figure 13: Relationship between climate change impacts, adaptation responses and the potential benefits from adaptation (Pinkard et al 2010, adapted from Howden et al 2010).

Enterprise level responses

At an enterprise level, planning for risk and uncertainty as a consequence of a changing climate should be adopted as part of an overall approach to sustainable forest management. The likelihood and significance of impacts can then be explicitly incorporated into adaptation strategies. The downside risks of climate change as well as the upside opportunities from a changing climate should be part of an ongoing adaptive or environmental management system.

A proactive rather than reactive approach to adaptation is required which monitors continuously what does and does not work, and allows for the costs and benefits of options to be taken into account (including the 'do nothing' option). This would enable periodic monitoring and early detection of climatic and abiotic changes that can be incorporated into enterprise decision making and development of management options. For example, the identification of climate change hazards and risk management options should be incorporated into routine environmental or adaptive management systems (Figure 14), to provide a holistic management response to these risks in addition to other commercial and environmental values.

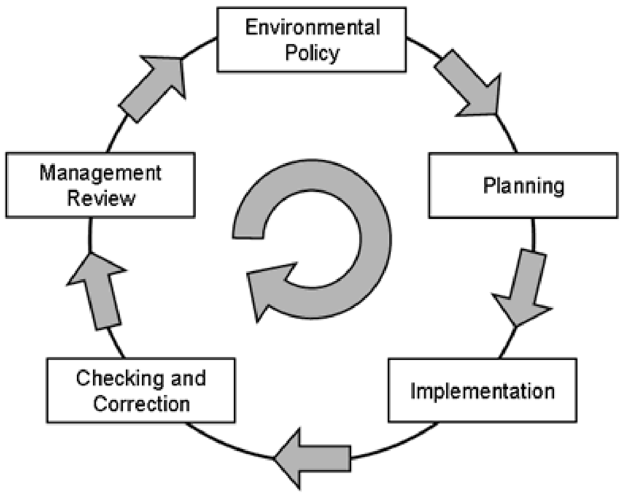

Figure 14: Typical environmental management system (adopting the 'plan, do, monitor, review' process). Source: http://www.niehs.nih.gov/about/stewardship/faq/index.cfm

It is also increasingly recognised that forest managers and enterprises need to build adaptive responses that are flexible and capable of dealing with a range of climate scenarios and possible outcomes, given current levels of uncertainty surrounding future emission levels and climate scenarios (Figure 15).

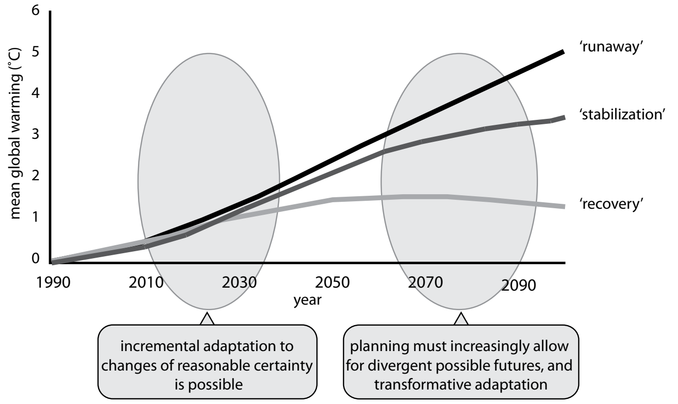

Figure 15: Future projections of climate change diverge over time as social uncertainty outstrips scientific uncertainty, with changing implications for adaptation. Source: Stafford Smith et al (2011).

Management options

There is a relatively wide range of options available to industry for dealing with climate change, although fewer options exist once trees are established as part of a normal rotation. The main options are described in Booth et al (2010) and can be sorted into short term (e.g. within rotation) and longer term (e.g. multiple rotation) responses. These are:

Short term responses

- Spacing and thinning: Simple management adaptations to reduced rainfall include planting trees at wider spacings or thinning existing stands. Wider spacing of trees reduces competition between trees and can be an effective safeguard against drought-induced mortality although may reduce stand growth (see, for example, Figure 16).

- Watering: There may be potential for the wider use of watering and/or effluent irrigation as a direct response to reduced water availability but will depend on the cost of water.

- Nutrients: Nutrient-limited stands produce fewer leaves that make them less vulnerable to water stress. However, better nutrition also ensures good use of site resources and can enhance tree resilience to adverse conditions. Nutrient management therefore offers a number of options that would depend on site conditions.

- Fire management: Warmer, drier and potentially windier conditions pose a significant fire risk to long term investments such as forestry. Adaptation options include increased use of firebreaks and access trails, fuel reduction practices (e.g. fuel reduction burns) and fire fighting equipment and personnel.

- Pest, disease and weed management: Options for dealing with changes in the range of pests, diseases and weeds include selection of more resistant trees for planting, better control plans and good weed management, particularly if wider tree spacings are used which will take longer for trees to outcompete and suppress weeds.

Longer term responses

- Selection of genotypes: Choice of species for specific traits and characteristics (e.g. growth, drought tolerance) is an important tool in plantation management and involves the selection of appropriate tree species and provenances (i.e. seed of a species from a particular location), hybrids or clones.

- Site selection: An obvious adaptation to expected changes in climate is to plant on sites with more favourable environmental conditions, such as wetter sites in areas with reduced rainfall.

- Establishment: Mortality during establishment is a risk, particularly for plantings in lower rainfall regions. A wide range of establishment strategies are available, including the use of direct seeding, tubestock and natural regeneration in combination with different site preparation options (e.g. ripping, site burning). Other options can include greater retention of post-harvest biomass (i.e. slash) for the next rotation and extended fallow periods to manage nutrient budgets.

- Assessment of climatic conditions: Improved monitoring of future climatic conditions and projections can assist in the development of a risk management framework and for identifying relevant adaptation options.

Figure 16: Aerial image of radiata pine forest in Tumut for a thinned (lower half) and unthinned (upper half) stand. Tree mortalities from a recent drought event are indicated by the white dots. Source: Christine Stone, NSW Department of Primary Industries.

Planning for risk and uncertainty

The potential impacts presented in previous sections are predictions of what could occur under future climates, not predictions of what will happen. There is considerable underlying unknowns and uncertainty in these predictions about future climate change and associated impacts on forests and forest related industries. This risk and uncertainty can arise from uncertainty in climate scenarios, as well as incomplete knowledge on the sensitivity of systems to climate change and the extent of adaptive capacity in both the forests and the managers (i.e. overall vulnerability). It is therefore important for forest managers to begin to incorporate management frameworks that can assess the degree of risk and uncertainty arising from climate change, particularly regarding major likely hazards and managing for a range of potential futures. A hazard is broadly defined as an act or phenomenon that under certain circumstances can lead to harm. The major identified hazards for the plantation based industries include:

- more prolonged droughts and higher mean annual temperatures (including the impacts of high temperatures at the upper end of the range);
- higher incidence of more severe fire danger rating days (i.e. likelihood of severe fires); and
- higher susceptibility to pest and disease outbreaks, resulting from changes in both pathogen vectors and the health of trees influenced by climatic factors.

Consequently, the development of appropriate tools for dealing with climate risks and priority hazards is an important and emerging area of commercial interest for Australian forest growers. The CSIRO, with support from Forest and Wood Products Australia, is looking into these aspects of plantation industry adaptation, by examining changes in priority hazards (i.e. drought, fire, pests) for wood production. This work is focusing on tools for assessing the probability of loss, where losses arise through changes in wood volume or quality brought about by a more variable climate. Loss functions are being investigated in terms of their bio-physical components (change of state for wood production), which would need to be incorporated into the value component of risk assessment, taking into account financial and stakeholder elements of loss (Figure 17).

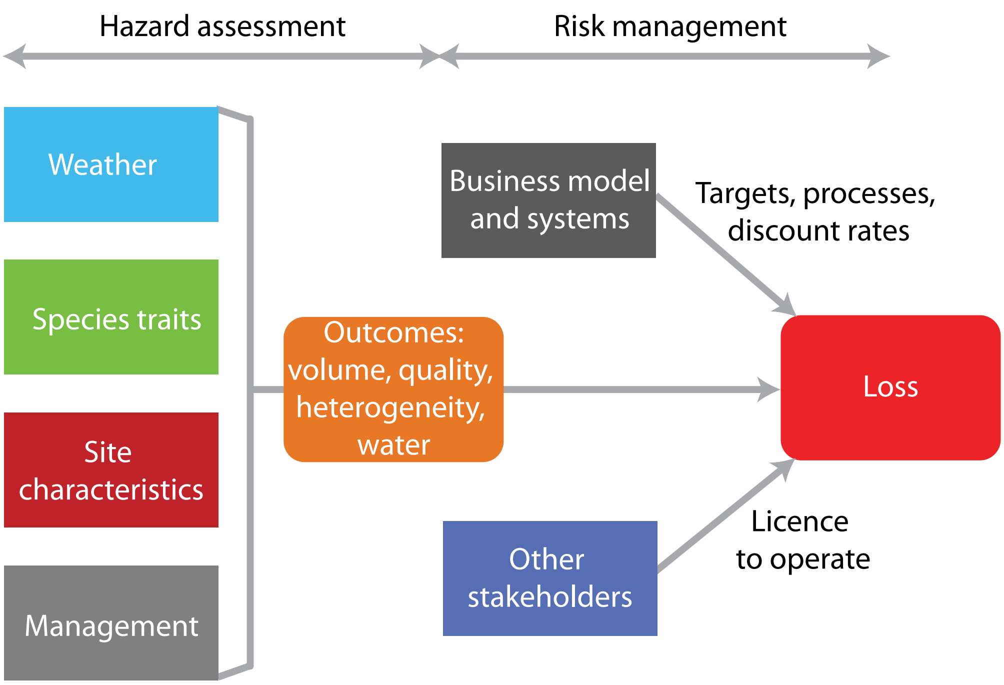

Figure 17: Key elements of hazard and risk assessment for commercial plantations. Source: Michael Battaglia, personal communication, CSIRO.

Typical risk assessment matrix

A common approach in risk assessment is to measure risk in terms of the loss (e.g. tree dieback, commercial loss) and probability of occurrence of an event. If the occurrence can be quantified probabilistically (e.g. 30% chance in any one year), the loss (e.g. $100 in forgone income) can be quantified in expected value terms (e.g. $100 multiplied by a probability of 0.30 to produce an expected average annual loss of $30). However, part of the difficulty in risk management is that the measurement of loss and probability of occurrence can be very difficult.

A risk management matrix is often used as a simple tool to increase the visibility of risks and assist decision making (Table 1). Using this approach, key hazards can be ordered into risk categories (e.g. high, medium, low) based on their likelihood to occur and magnitude of consequences (e.g. degree of harm, commercial loss). The assignment of hazards to risk categories is influenced by the two primary criteria of likelihood and consequence, which can be based on qualitative or quantitative information. One issue with respect to this approach is the similar ranking often provided for low likelihood/high consequence events and high likelihood/low consequence events. Often, risk managers may be more concerned with the impacts of catastrophic events, given their significant consequences to the enterprise and stakeholders, whereby additional weighting may need to be given to these types of events.

Risk asessment matrix			
	Consequence (impact)		
Likelihood	***Severe***	***Moderate***	***Minor***
Very Likely	High	High	High
Likely	High	High	Medium
Possible	Medium	Medium	Medium
Unlikely	Medium	Low	Low
Very Unlikely	Low	Low	Low

Table 1: Typical risk assessment matrix

The international standard for risk management, AS/NZS ISO 31000-2009 Risk Management – Principles and Guidelines, is an example of a systematic framework for dealing with risk at an organisational level.

However, in many cases it may not be possible to assign probabilities to particular events. In these situations, scenario planning can be a useful tool for forest managers. Scenario planning – the development and use of plausible and compelling stories about how the future will unfold – can allow managers to identify options and decide priorities in the context of uncertain future conditions. The emphasis on informing decision making under conditions of uncertainty distinguishes scenario planning from other tools such as forecasting, which has a narrower focus on predicting likely futures. Scenarios can be presented in many forms, including graphs, maps and narratives, that can assist with decision making (for further information, see for example, Biggs et al 2011).

Assessment tools for plantations

With respect to tools that can assist the assessment of plantation management risks, greater use of probablistic measures and metrics is anticipated, in order to capture the degree of future uncertainty and risk in priority hazards.

Firstly, there is the level of uncertainty around future climate which includes a range of future projections from global climate change models. One way in dealing with this uncertainty is to select a subsample of global climate models that will (a) envelope uncertainty in terms of best and worst case outcomes, and (b) give the most likely outcome (identified from the range of climate models available). An example is provided in Table 2, which captures the range of estimates for future rainfall for the area centred upon 32.5 S and 116.5 E. The majority of models predict drier and warmer conditions by 2050, with a number of outliers predicting little change or wetter conditions. This provides a means for assessing the level of agreement between models and likely future impacts that can feed directly into the risk management process.

Other types of assessment tools might involve the frequency of events occuring over a given planning period, given the stochastic nature of climatic processes. An example is provided in Figure 18, which shows the return frequency (i.e. number of

Climate Futures for region centred on 32.5 S 116.5 E 2050 A1FI					
		Slightly Warmer <0.5	Warmer 0.5 to 1.5	Hotter 1.5 to 3.0	Much Hotter >3.0
Rainfall Annual (% change)	Much Drier <15%			Likelihood: 1 of 24 models (50%)	Likelihood: 1 of 24 models (4%)
	Drier -15 to 5%			Likelihood: 1 of 24 models (25%)	Likelihood: 1 of 24 models (8%)
	Little Change -5 to 5%		Likelihood: 1 of 24 models (4%)	Likelihood: 1 of 24 models (4%)	
	Wetter 5 to 15%			Likelihood: 1 of 24 models (4%)	
	Much Wetter >15%				

Table 2: Example of an analysis of 24 global climate models for one location (32.5 S, 116.5 E), highlighting the most likely climatic outcome (i.e. where most models agree) and the best and worst case scenarios. Source: Clarke et al (2011).

rotations out of 20) of mortality classes associated with drought in Western Australian blue gum plantations, based on modelled simulations. A higher mortality class indicates a higher risk of drought death.

The development of tools and metrics (indicators) that allow an assessment of probabilities of outcomes will draw upon a range of approaches, depending on data availability. Where observational data are available, statistical approaches can be used. Where data are insufficient to allow a quantitative assessment of hazards, elicitation methods that draw on expert knowledge may be required. Bayesian approaches (i.e. belief networks) that integrate expert knowledge with empirical data may also be particularly useful because new data can be incorporated as they become available.

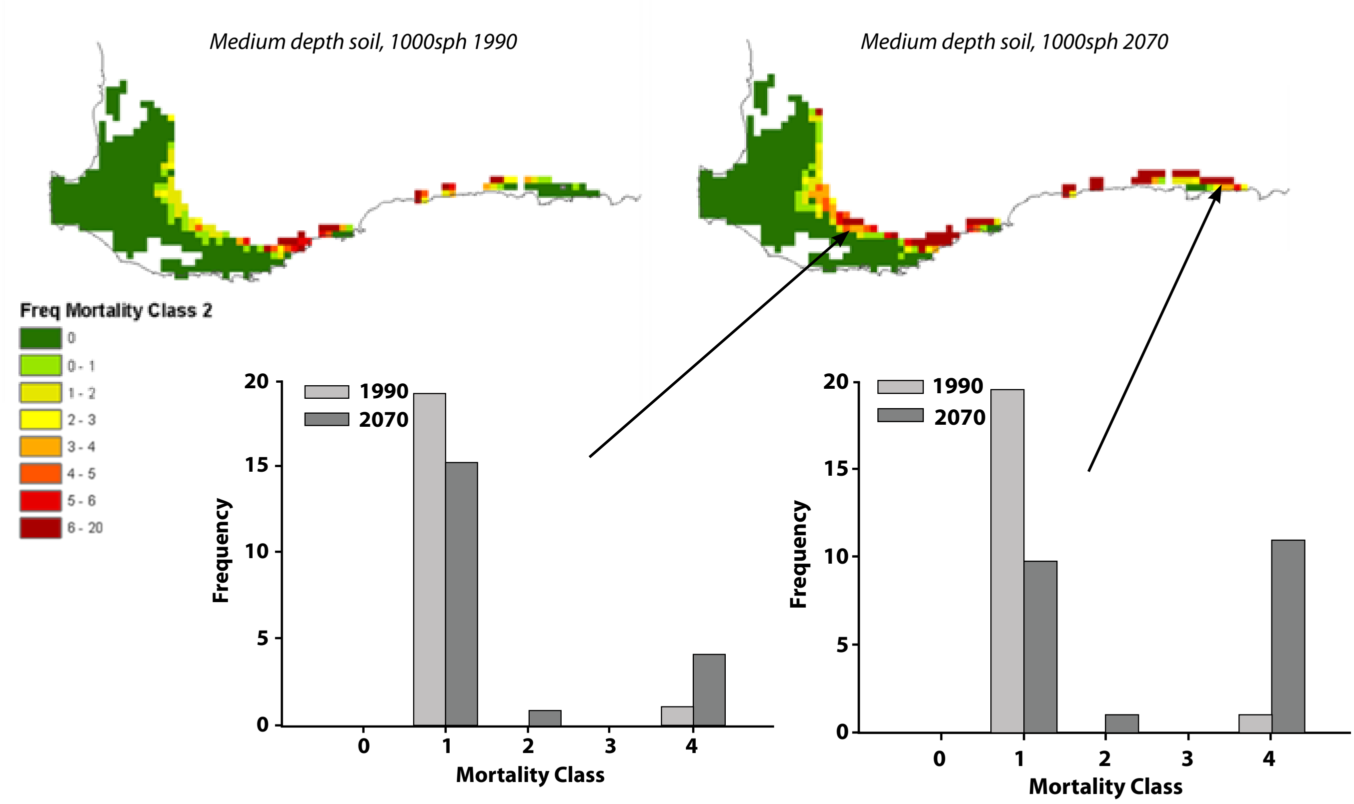

Figure 18: Example of a probabilistic approach to examining the return frequency of mortality-inducing droughts in Western Australia. The redder the colour, the higher the frequency of significant mortality events associated with drought. The histograms indicate the potential frequency of mortality events occurring within specific grid cells. Source: Jody Bruce and Michael Battaglia, personal communication, CSIRO.

Barriers to adoption and uptake

There are a number of barriers to adaptation to climate change in the forest industry (Pinkard et al 2010). These include:

- lack of belief that climate change is occurring;
- uncertainty about the impacts of climate change at a range of scales, particularly with respect to large between-site local variation;
- lack of tools to assist managers in dealing with the complex nature of climate change impacts in the forest enterprise; and
- financial barriers.

A better understanding of social beliefs and targeted education campaigns will improve industry awareness of climate change issues and adaptation responses at a broad level. More work is also needed to fully understand the socio-economic, biophysical and operational barriers to adaptation.

The industry may need new decision systems to support managers in identifying appropriate management strategies under a changing climate. Such systems will need to deal explicitly with risk and uncertainty, recognising that risks may change considerably within and between rotations and in a broader landscape context (Pinkard et al 2010). Some of these new approaches have been outlined in this handbook.

As a first step, integrating risk planning for a changing climate into sustainable forest management practices will enable forest enterprises to monitor and better understand the impacts of current climatic events. This will help build adaptive capacity for identifying longer terms trends at a site and regional level and the development of appropriate responses.

Broader socio-economic issues

In addition to adaptation options at the forest management unit or enterprise level, broader land use and adaptation policy measures may be needed. For issues with broad socio-economic implications, such as management of water and fire risk in the landscape, and economy wide mitigation and adaptation strategies, some sort of government-sponsored adaptation may be necessary.

For example, incentives to encourage inclusion of forestry sequestration in carbon trading schemes and/or incentives for alternative crops (e.g. biochar, bioenergy), may be a necessary part of the overall policy mix for effective mitigation and adaptation.

It is therefore important that the forest industry engages with policy-makers and the community to ensure that climate adaptation policies promote adaptation and provide appropriate support for industry participation. Furthermore, institutional capability is equally important with respect to adaptive capacity in dealing with climate change. For example, the management of forest fuels and effective coordination of public land and fire management agencies, in conjunction with forest industry brigades, is important in dealing with the threat of more severe wildfires in the future (see, for example, Stephens 2010).

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www.abares.gov.au

Australian Forest Products Association (AFPA) climate adaptation project:
www.ausfpa.com.au/site/projects.php

CSIRO Adaptation Flagship:
www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/ClimateAdaptationFlagshipOverview.aspx

Forest and Wood Products Australia (FWPA):
www.fwpa.com.au/research-and-development

National Climate Change Adaptation Research Facility (NCCARF):
www.nccarf.edu.au/

United States Department of Agriculture (USDA) Forest Service Climate Change Resource Centre
www.fs.fed.us/ccrc/