Australian Government

Australian Bureau of Agricultural and Resource Economics and Sciences

Potential effects of climate change on forests and forestry: **summary for northern Australia**

August 2011

www.abares.gov.au

Science and economics for decision-makers

ABARES 2011, *Potential effects of climate change on forests and forestry: summary for northern Australia*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, August.

ISBN 978-1-921192-81-4

Postal address:
ABARES
GPO Box 1563
Canberra ACT 2601

Phone: +61 2 6272 2010
Fax: +61 2 6272 2001
Email: info@abares.gov.au
Web: www.abares.gov.au

ABARES project 43077

Acknowledgments
ABARES thanks the following people in alphabetical order for their contribution in this project: Guy Barrett, Dr Sarah Bruce, Bethany Burke, Kevin Burns, Dr Tim Clancy, Dr David Cunningham, Dr Stuart Davey, Robert Dillon, Geoffrey Dunn, Dr Saan Ecker, Brendon Finch, Ian Frakes, Mijo Gavran, John Gray, Robert Kancans, Edwina Heyhoe, Dr Karen King, Chris Lancaster, Dr Greg Laughlin, Dr Sinniah Mahendrarajah, Todd McInnis, Mathew Miller, Martin Mutendeudzi, Dr Sonja Nikolova, Michael O'Keeffe, Mark Parsons, Dr Dirk Platzen, Dr Kim Ritman, Ian Ruscoe, Dr Jackie Schirmer, Dr Udaya Senarath, Dr John Sims, Dr Sharan Singh, Philip Townsend, Jahnvi Vedi, Andrew Wilson and Johnny Xu. Dr Sharan Singh managed the project. Alastair Sarre provided scientific editorial input. ABARES wishes to acknowledge Dr Phil Polglase for providing review comments. ABARES also appreciates the input of the CSIRO Climate Adaptation Flagship and the CSIRO Sustainable Agriculture Flagship for assistance with climate data and modelling forest growth. This project was funded by the Australian Government.

Potential effects of climate change on forests and forestry: **summary for northern Australia**

August 2011

Key Points

one.	Climate and tree growth modelling are used to project the potential effects of climate change on forests and forestry in the northern Australia study region by 2030 and 2050, under two greenhouse gas emission scenarios devised by the Intergovernmental Panel on Climate Change.
two.	Under both emission scenarios, temperatures are projected to increase across the region due to climate change, which would reduce the growth rates of Caribbean pine plantations in the region.
three.	The various climate models and climate change scenarios give a wide range of projected effects on tree growth. This study used a range of models with varying reliability and many inputs and assumptions. These factors need to be considered when interpreting the results.
four.	Uncertainty remains around the interaction of high carbon dioxide and tree growth. However, the carbon dioxide fertilisation effect may partially or fully offset modelled declines in tree growth with future warmer and drier climates.
five.	The supply of Caribbean pine logs in the region is projected to be about 6 per cent lower in 2030 and up to 11 per cent in 2050 as compared with the baseline, due to reduced tree growth rate. These estimates do not take into account any adaptation measures that could be adopted.
six.	Declining log supply would result in reduced investment in harvesting, haulage and log processing capacity and could lead to reductions in the value of production and employment.
seven.	A few communities in the region are dependent to a significant degree on employment in the forestry and wood products industries. Those communities may be vulnerable to changes in employment in the industries due to climate change.
eight.	A range of climate change adaptation measures can be taken to improve the productivity and protection of forest plantations in the region in the face of climate change. These include selection of suitable species and silvicultural regimes.

Contents

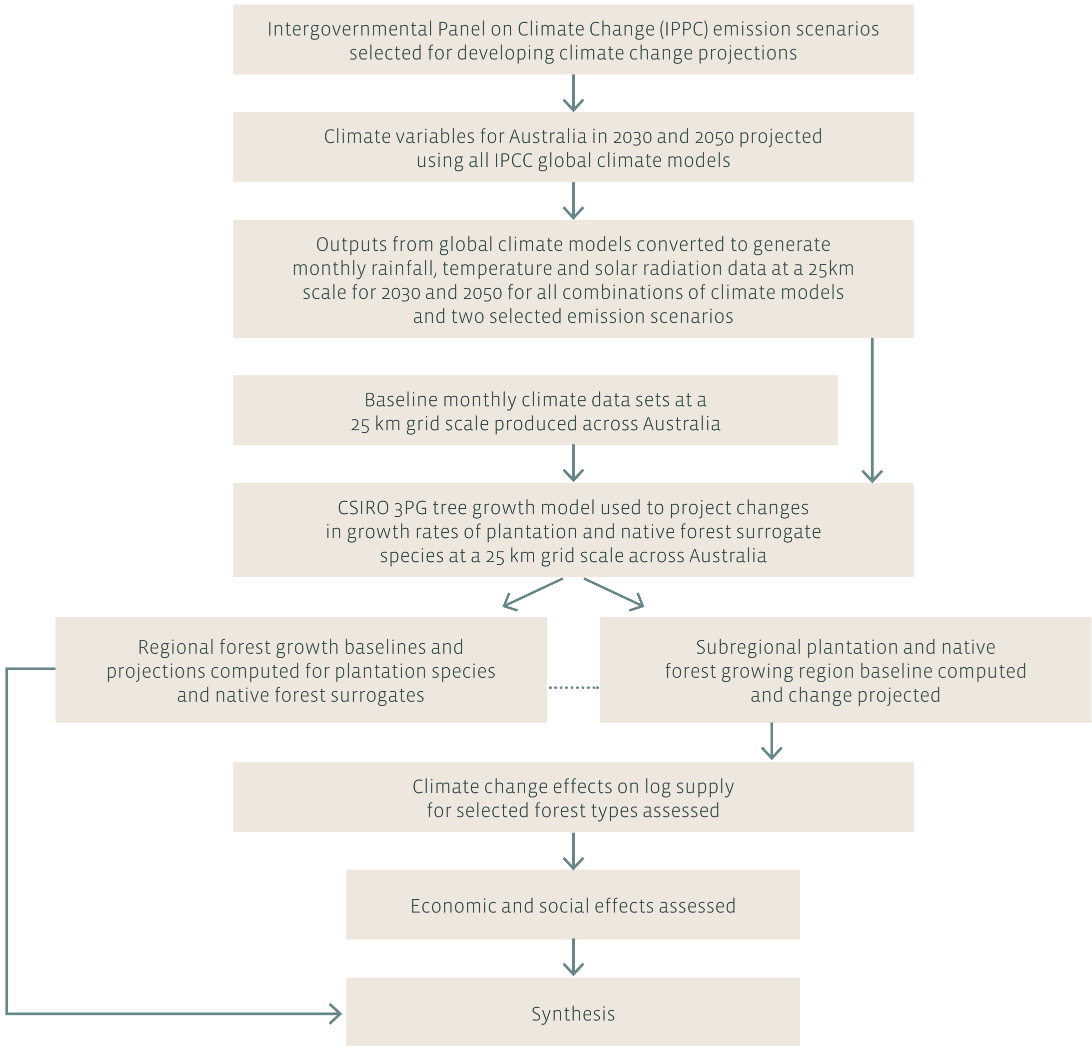
Tables

1. Introduction

This is a summary of a more detailed assessment of the potential effects of climate change on forests and forestry in the northern Australia study region (ABARES 2011b). That more detailed assessment, in turn, is part of a larger assessment that projects the potential effects of climate change on forest growth in six regions across Australia and estimates the effects of those changes on wood production, the forestry and forest products industries, and the communities dependent on those industries. The assessment also identifies opportunities for adaptation to such effects. This is one of six regional summaries; a seventh document synthesises the study's overall findings.

Figure 1 outlines the method used in the study, and box 1 (page 16) sets out some of the assumptions made in producing the results presented in this document. Details of how the climate change, tree growth, economic and social effects were assessed are provided in separate reports.

FIGURE 1: METHOD USED IN THE STUDY OF POTENTIAL EFFECTS OF CLIMATE CHANGE ON FORESTS AND FORESTRY



2. Region overview

The northern Australia study region (depicted in map 1) covers an area of about 89 million hectares, including coastal Queensland north of about Mackay, the Cape York Peninsula, and northern parts of the Northern Territory and Western Australia. The climate ranges from subtropical to tropical. The historical average rainfall and average maximum temperature are 968 mm and 31.4 °C, respectively. Representative mean maximum temperatures across the region include; Darwin (January 33.4°C, July 32.6°C); Mackay (January 32.8°C, July 22.5°C); and Weipa (January 34.1°C, July 31.7°C).

The plantation and farm forests in the region comprise a wide range of species. The most widely planted species are Caribbean pine (*Pinus caribaea*) and mangium (*Acacia mangium*), amounting to about 25 500 and 24 400 hectares, respectively. The area of plantations of African mahogany (*Khaya senegalensis*) and other speciality hardwoods has increased rapidly in the past few years and there are also areas of hoop pine (*Araucaria cunninghamii*) plantations.

Wood is harvested periodically in native forests in the region, including as a by-product of land clearing (see below). Map 1 shows the distribution of forest types and map 2 shows the distribution of forests where wood may potentially be harvested (MIG 2008). The area of each forest type that may potentially be used for wood production is shown in table 1.

TABLE 1: POTENTIAL WOOD PRODUCTION FORESTS IN THE NORTHERN AUSTRALIA STUDY REGION, BY FOREST TYPE

Forest type	Area ('000 hectares)
Callitris medium open	155
Eucalypt tall open	27
Eucalypt medium closed	76
Eucalypt medium open	5 205
Hardwood plantation	16
Softwood plantation	16
Total	**5 495**

Source: MIG (2008); Gavran and Parsons (2010)

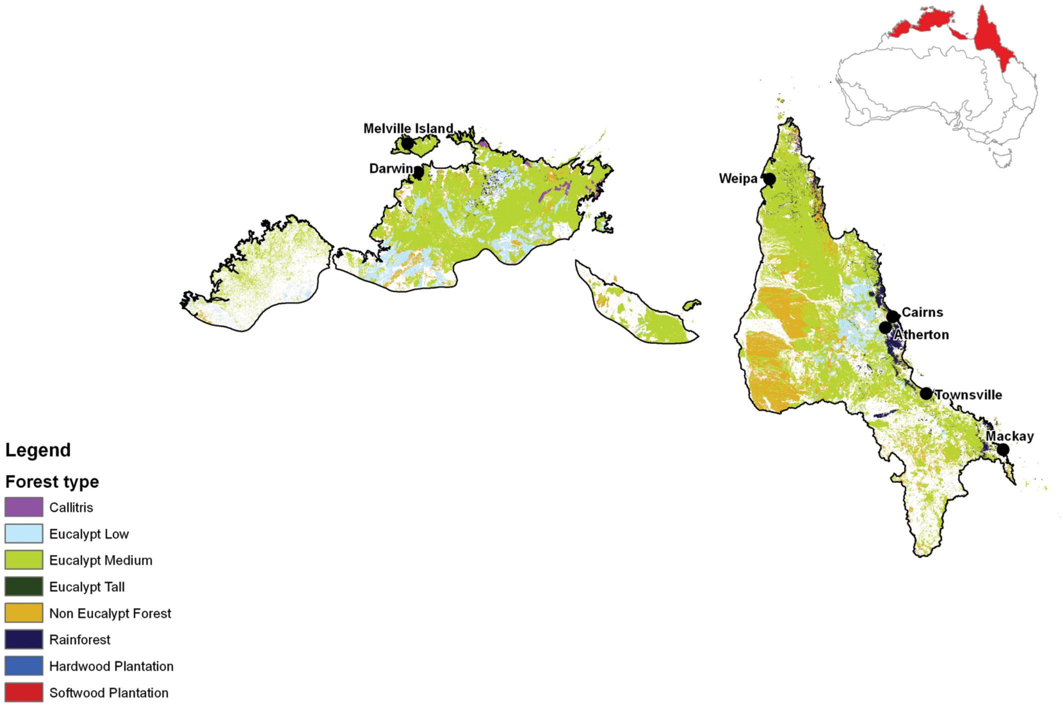
Over 49 000 cubic metres of softwood were harvested in the region in the financial year 2006–07. Of this, around 10 000 cubic metres were used to produce poles and most of the remainder—sawlogs and pulplogs—were exported as logs. Around 25 000 cubic metres of native forest hardwood sawlogs were harvested in the region in the 2005–06 financial year. Wood supply from native forests in this region was considered in the north-eastern New South Wales – south-eastern Queensland study region (ABARES 2011b).

The Caribbean and hoop pine plantations in North Queensland support a number of sawmills, and some sawlogs have also been harvested in Caribbean pine plantations on Melville Island. Hardwood plantations in the region have not yet reached harvest age.

A few forest-based industries in the region currently use, or have recently used, native forest logs as follows:

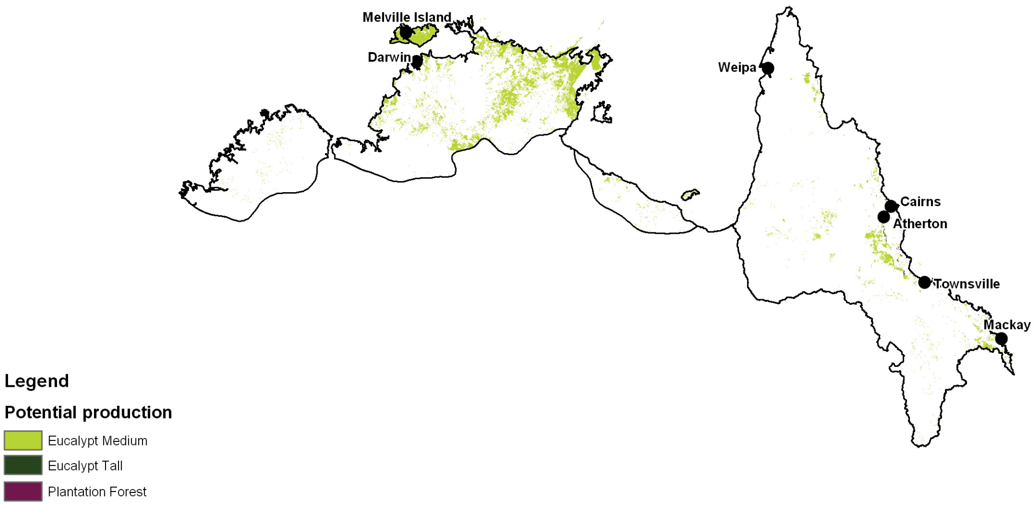
- Some logs harvested in native forest are milled to provide sawnwood for local use.
- Logs cleared from bauxite mining sites near Weipa are milled to produce sawnwood to supply east-coast Australian markets.
- In the period 2004–2006, logs cleared from sites being prepared for plantation development on Melville Island were exported.

MAP1: FOREST TYPES, NORTHERN AUSTRALIA STUDY REGION



Notes: Plantations may not be visible at this scale (see Map 2)

MAP 2: FORESTS CURRENTLY POTENTIALLY AVAILABLE FOR WOOD PRODUCTION, NORTHERN AUSTRALIA STUDY REGION



3. Regional climate change projections

Two greenhouse gas emission scenarios, developed by the Intergovernmental Panel on Climate Change (IPCC), referred to as A1B and A2, were selected for this study. While the global warming projected by these two scenarios is similar during the study period (table 2), the two scenarios were used because they showed regional differences in projected rainfall and temperature that were likely to lead to differences in tree growth.

TABLE 2: ESTIMATED GLOBAL CHANGE IN MEAN ANNUAL TEMPERATURE (AND RANGES) RELATIVE TO 1990 UNDER TWO EMISSION SCENARIOS, 2030 AND 2050

Emission scenario	2030 °C	2050 °C
A1B	+0.9 (+0.54 to +1.44)	+1.5 (+0.92 to +2.45)
A2	+0.8 (+0.48 to +1.28)	+1.4 (+0.84 to +2.24)

Notes: 1. A1 scenarios are characterised by rapid economic growth, a global population that reaches nine billion in 2050 and then gradually declines, the quick spread of new and efficient technologies, and a convergent world (i.e. income and way of life converge between regions). **2.** Under the A1B scenario, which is one of the A1 scenarios, there is a balanced emphasis on all energy sources. **3.** A2 scenarios are characterised by a world of independently operating, self-reliant nations, a continuously increasing population, regionally oriented economic development, and slower and more fragmented technological change and improvements to per capita income.

Source: CSIRO (2007)

A CSIRO model called 3-PG2 Spatial (hereinafter referred to as 3PG) was used to project forest growth in 2005 under existing climatic conditions and by 2030 and 2050 for the climate change projected under the two selected emission scenarios. 3PG models forest growth based on photosynthetic processes, soil characteristics, water availability, plant attributes and climate. For the A1B emission scenario, regional climate data inputs for 3PG were derived from 22 global climate models. For the A2 emission scenario, 17 of those global climate models were used (the other five models could not be used in the A2 scenario because they could not provide the necessary monthly temperature and rainfall data). Table 3 presents the highest, lowest and median changes in rainfall and maximum temperature for all models used in each emission scenario for the northern Australia study region.

Climate models provide projections for rainfall, temperature, solar radiation and other climate variables at 125 to 400 km grid square, which is too coarse for the model used in this regional study. For use in the 3PG forest growth model, these data were converted to a 25 km grid scale. The effect of climate change in each 25 km grid square was then averaged across the study region or subregion.

Growth data were available to calibrate 3PG for Caribbean pine but not for the other species used in plantations in the study region. Therefore, the study only projects growth rates for Caribbean pine.

TABLE 3: RANGE OF MODEL RESULTS FOR PROJECTED CHANGES IN RAINFALL AND MAXIMUM TEMPERATURE, NORTHERN AUSTRALIA STUDY REGION

	Scenario A1B				Scenario A2			
	Change in rainfall (%)		Change in maximum temperature (°C)		Change in rainfall (%)		Change in maximum temperature (°C)	
Year	2030	2050	2030	2050	2030	2050	2030	2050
Highest	+22.4	+66.3	+3.6	+4.2	+104.4	+93.7	+2.8	+3.8
Lowest	−50.4	−34.3	+1.0	+1.7	−33.6	−34.4	+0.8	+1.6
Median	−2.0	+9.8	+2.1	+2.2	+13.3	+6.7	+1.8	+2.4

Notes: 1. Average baseline annual rainfall ranges across the region from 600 mm to 1700 mm. **2.** Average baseline maximum temperature is 31.4°C.

4. Tree growth projections

Map 3 shows the estimated growth rates of Caribbean pine across the northern Australia study region in 2005, as well as the actual distribution of plantations of this species. Table 4 presents the estimated growth rates for Caribbean pine numerically for the region as a whole and for the subregion in which the plantations currently grow; these are used as the baseline for estimating the effect of climate change on growth rates in 2030 and 2050.

Figure 2 shows, for both emission scenarios, the projected effects across the whole region of climate change on the growth of Caribbean pine, and figure 3 shows these effects within the subregions in which Caribbean pine plantations currently occur. On average across the whole region the median change seems to be marginally positive. In the plantation subregions, growth rates for Caribbean pine are projected to decline against the 2005 baseline growth rates due to the increased temperatures projected to occur by 2030 and 2050 as a result of climate change.

Increases in atmospheric carbon dioxide (CO_2), which have not been modelled in 3PG, may compensate to some extent for the decline in growth rates by providing a fertilisation effect (see figure 4 and associated discussion). The fertilisation effect may be offset, in turn, by changes in the distribution, incidence and severity of pests, diseases and weeds (Pinkard et al. 2010).

TABLE 4: BASELINE (2005) GROWTH RATES OF FOREST SPECIES, NORTHERN AUSTRALIA STUDY REGION

Species	Average growth rate (m^3 per hectare per year)	
	Whole region	Plantation subregion
Caribbean pine (sawlog)	14.6	24.4

Potential effects of climate change on growth rates of Caribbean pine at subregional level are described below and shown in figure 3.

Effect on Caribbean pine growth rates

Of the 22 climate models used in projections of Caribbean pine growth rates under the A1B scenario, the 3PG outputs for 16 indicate an overall decline, in those areas where the species is currently grown, by 2030 and for 15 the 3PG outputs indicate a decline by 2050. Under the A2 scenario, the 3PG outputs for 12 of the 17 climate models used project a decline in growth rates by 2030, and for 13 the 3PG outputs project a decline by 2050.

Under the A1B scenario, the median projected effect is an 6 per cent decline in growth rates (averaged for those areas where the species is currently grown) by 2030 and 2050. For 2030 the best projected effect is a 6 per cent increase in growth rates and the worst projected effect is a 22 per cent decline. For 2050 the best projected effect is a 7 per cent increase in growth rates and the worst projected effect is a 23 per cent decline.

Under the A2 scenario, the median projected effect is a 6 per cent decline in growth rates (averaged for those areas where the species is currently grown) by 2030 and an 11 per cent decline by 2050. For 2030 the best projected effect is a 7 per cent increase in growth rates and the worst projected effect is a 28 per cent decline. For 2050, the best projected effect is a 6 per cent increase in growth rates and the worst projected effect is a 21 per cent decline.

In summary, median projections indicate a minor decline in Caribbean pine growth rates (figure 3).

MAP 3: CARIBBEAN PINE PLANTATION DISTRIBUTION AND ESTIMATED GROWTH RATES, 2005

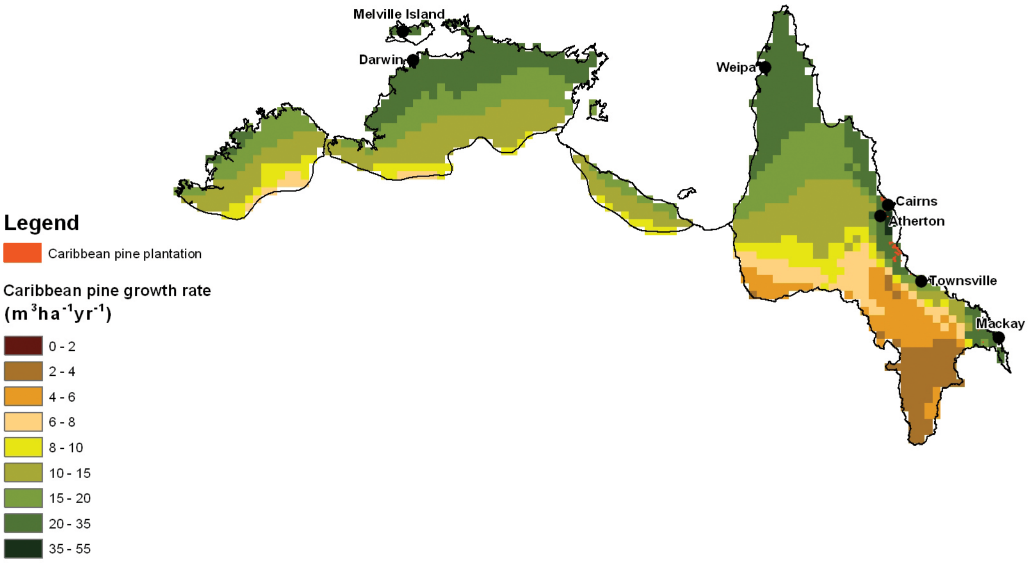
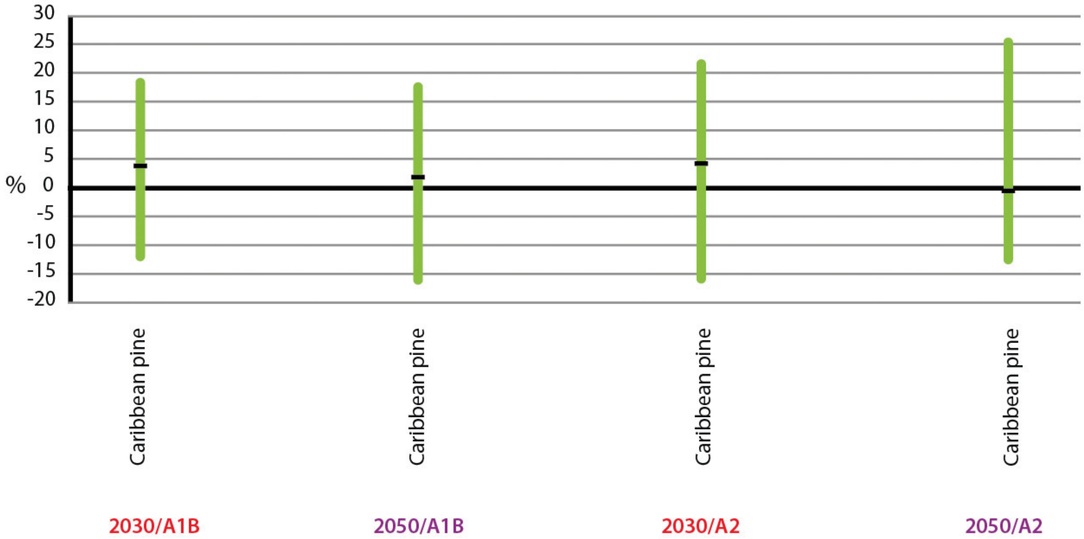
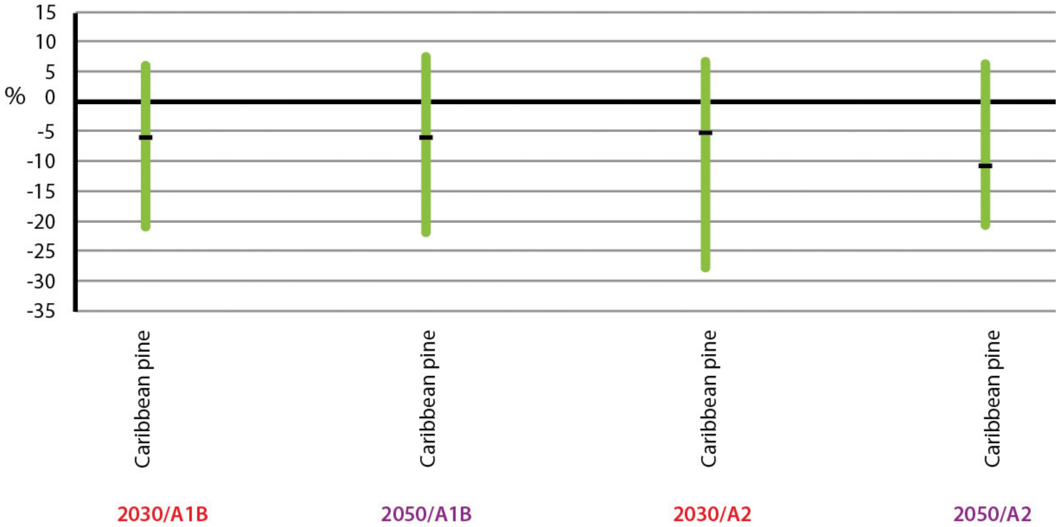


FIGURE 2: PROJECTED PERCENTAGE CHANGE IN CARIBBEAN PINE GROWTH RATES DUE TO CLIMATE CHANGE, WHOLE REGION



Note: The dashes show the median projected effect against the projected baseline; the bars above and below the dashes show the range.

FIGURE 3: PROJECTED PERCENTAGE CHANGE IN CARIBBEAN PINE GROWTH RATES DUE TO CLIMATE CHANGE, CARIBBEAN PINE PLANTATION SUBREGION



Note: The dashes show the median projected effect against the projected baseline; the bars above and below the dashes show the range.

5. Sensitivity analysis

This study did not consider the effects of increasing carbon dioxide on forest growth by 2030 and 2050. These results are conservative estimates because potential increases in carbon dioxide fertilisation in these timeframes may enhance growth, although the extent of this enhancement is uncertain (box 1).

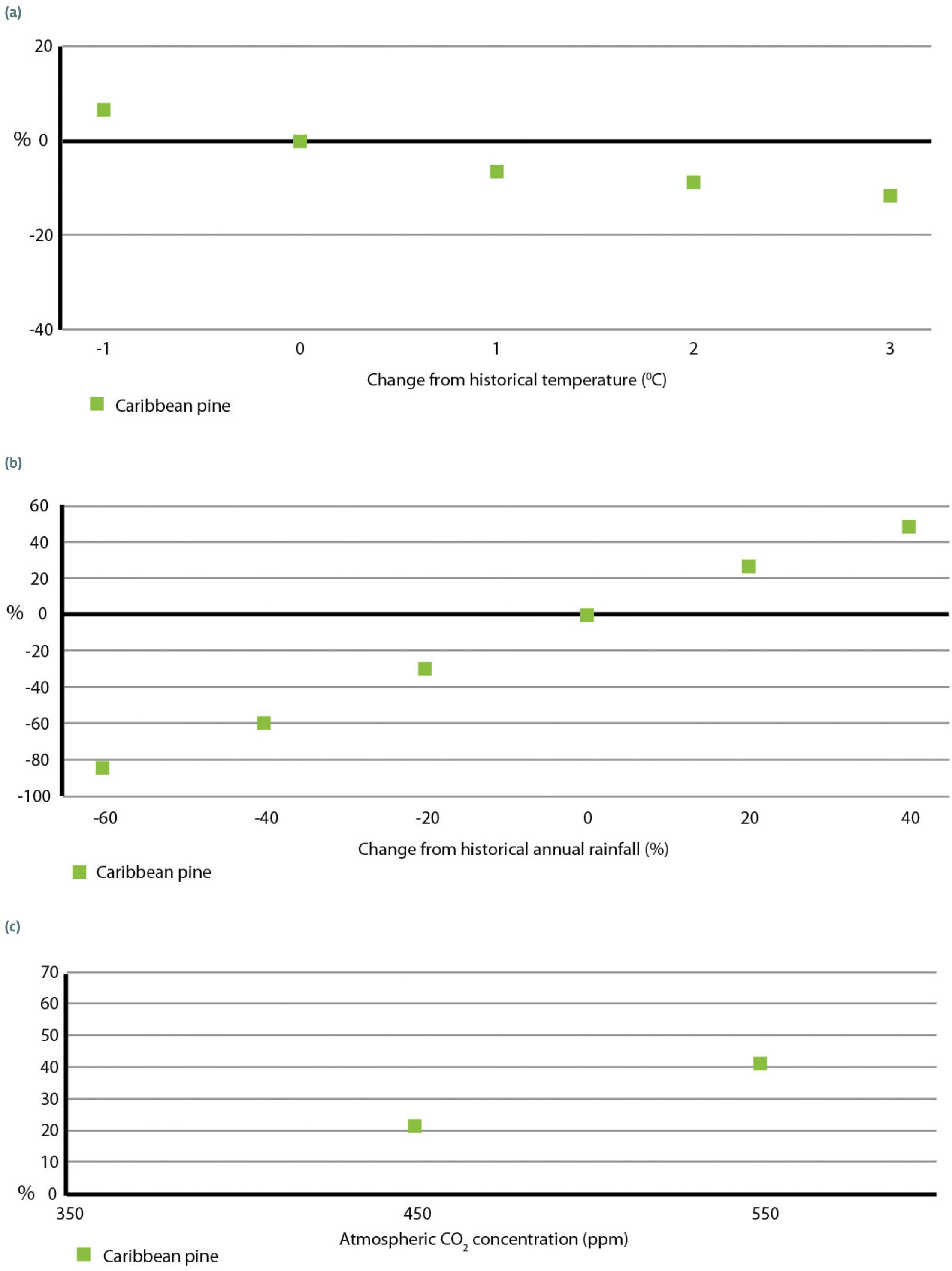
The 3PG model has a algorithm to estimate the effect of increasing carbon dioxide on forest growth reducing canopy conductance and increasing canopy quantum efficiency (Almeida et al. 2009). However to better calibrate the carbon dioxide function in the 3PG model, it would be necessary to obtain data from empirical studies where trees have been grown under artificially increased levels of carbon dioxide. Such studies are much more common for grasses and crops, as these are easy to enclose in carbon dioxide enhanced chambers, and their life spans are short enough to complete the experiment in a reasonable time period. Similar experiments for trees are much more problematic, both in the length of time required to run the experiment and the ability to mimic altered carbon dioxide conditions for the duration of the experiment and more frequent in the Northern Hemisphere. Consequently very few tree studies have been undertaken. Therefore, the carbon dioxide function in 3PG is based on best estimates of what is most likely to happen under carbon dioxide fertilisation, resulted from empirical data from pine species growing in different regions. A sensitivity analysis was undertaken as a preferred method for determining the potential effects of carbon dioxide fertilisation in this study.

A sensitivity analysis was conducted to explore the effect on tree growth of changes in temperature, rainfall and atmospheric carbon dioxide concentrations (figure 4).

Growth rates for Caribbean pine decrease as temperature increases (figure 4a). This species grows faster with higher annual rainfall (figure 4b).

The sensitivity analysis shows that growth of Caribbean pine increases with higher concentrations of carbon dioxide (figure 4c). Enhanced growth rates as a result of higher carbon dioxide may partially or fully offset projected declines in growth resulting from increased temperatures and decreased rainfall. The extent to which this occurs would depend on the interactions between carbon dioxide fertilisation and other growth parameters (see box 1).

FIGURE 4: POTENTIAL CHANGE IN AVERAGE GROWTH RATES FOR CARIBBEAN PINE PLANTATIONS IN THE NORTHERN AUSTRALIA STUDY REGION, WITH CHANGES IN (A) TEMPERATURE, (B) ANNUAL RAINFALL AND (C) ATMOSPHERIC CO_2 CONCENTRATION



6. Socioeconomic effects

The plantation resource and timber processing infrastructure of the Northern Australia region is relatively less developed than other regions, and a high degree of uncertainty surrounds the future direction of the industry in this region. Hence, ABARES has opted for a simplified Excel spreadsheet framework for the climate change impact analysis and to assess the potential for mill development and the consequent economic contribution of forestry. Therefore, the results do not represent the outcome of an optimised modelling framework as when the Forest Resource Use Model (FORUM) is used.

The supply of Caribbean pine logs in the study region is projected to be lower in 2030 and 2050 under the median growth rate estimates for both emission scenarios compared with baseline wood supply projections, which are based on 2005 data (table 5). Declining log supply would result in reduced investment in harvesting, haulage and log processing capacity and consequently in reductions in value of production (table 6) and employment (table 7). Figure 5 shows the median and range of projected climate change impacts on several socioeconomic factors in the forestry and forest products industries, relative to the reference case.

ABARES' economic analysis only covers employment in wood harvesting, log haulage and primary wood products manufacturing. Under the industry structure assumed as the baseline for this analysis, solely based on the Caribbean pine plantation resource, those activities would provide an estimated 107 jobs in the study region in 2010. It is estimated that approximately 1 400 people (both full- and part-time) were employed in the Northern Australia forestry and wood products industries in 2006 that accounts for around 0.5 per cent of the estimated 314 000[1] people employed in the study region in 2006. The employment figure of 1 400 includes all employment generated in the plantation and native forest industries of forest growing and management, wood harvesting, log haulage, primary and secondary wood products manufacturing, and other support activities. It should be noted that, of the 1 400 employees, those involved in wood products manufacturing are not necessarily dependent on timber from within the study region. In the economic modelling, inter-regional processing of logs was generally assumed not to occur. The available data were insufficient to model the socioeconomic effects of climate change for other industries of the forestry and wood products sector in the region. Such effects would be additional to those shown in the tables below.

TABLE 5: PROJECTED CHANGES IN CARIBBEAN PINE LOG SUPPLY DUE TO MEDIAN CLIMATE CHANGE EFFECTS ON FOREST GROWTH, NORTHERN AUSTRALIA STUDY REGION ('000 M^3 PER YEAR)

Log type	Reference case		Scenario A1B		Scenario A2	
Year	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Sawlogs	163	217	153	203	154	193
Pulplogs	15	15	14	14	14	13
Total	**178**	**232**	**167**	**217**	**168**	**206**
% change			–6	–6	–6	–11

Note: For the baseline, 2005 data were used to project wood supply to 2030 and 2050.

1 Based on ABS data, manipulated by Dr Jackie Schirmer, for 2006 total employment in forestry, logging, wood and paper production

TABLE 6: PROJECTED CHANGES IN VALUE OF PRODUCTION DUE TO MEDIAN CLIMATE CHANGE EFFECTS ON LOG SUPPLY

	Baseline		Scenario A1B				Scenario A2			
Year	2030 ($ million)	2050 ($ million)	2030 ($ million)	change (%)	2050 ($ million)	change (%)	2030 ($ million)	change (%)	2050 ($ million)	change (%)
Sawnwood	30.6	40.9	28.6	−7%	33.1	−19%	28.9	−6%	33.1	−19%
Log exports[1]	1.2	1.2	1.1	−6%	3.3	176%	1.1	−6%	2.4	105%
Total	**31.8**	**42.0**	**29.7**	**−7%**	**36.3**	**−14%**	**30.0**	**−6%**	**35.5**	**−16%**

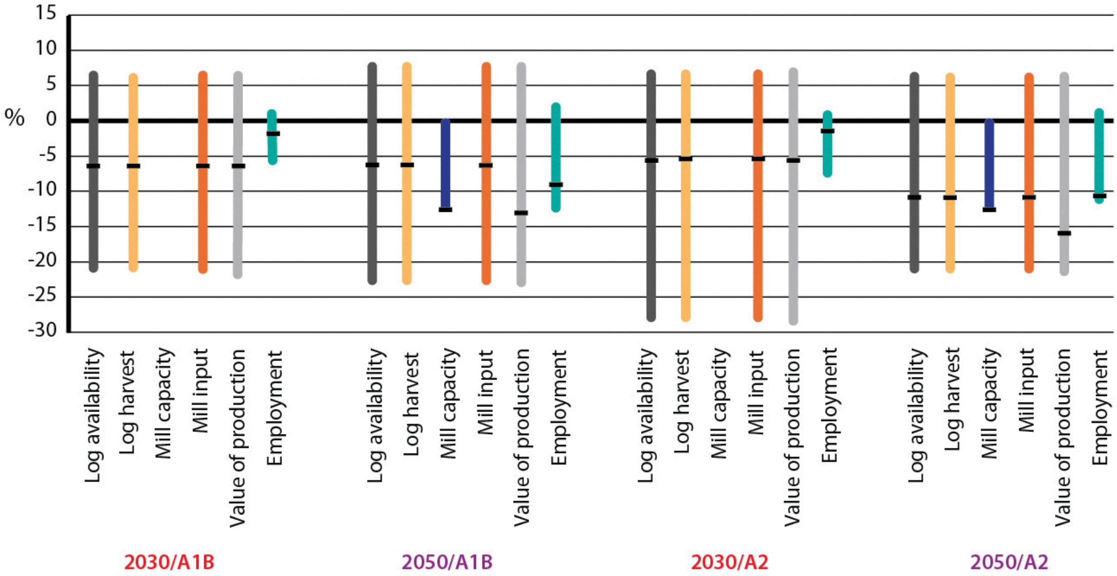
[1] Logs exported from the region.

Notes: 1. For the baseline, 2005 data were used to project wood supply to 2030 and 2050 **2.** The projected changes in value of production are expressed in current dollar terms. **3.** Changes in value of production are explained in ABARES (2011b).

TABLE 7: PROJECTED CHANGES IN EMPLOYMENT (FULL-TIME EQUIVALENT POSITIONS) DUE TO MEDIAN CLIMATE CHANGE EFFECTS ON LOG SUPPLY, NORTHERN AUSTRALIA STUDY REGION

Year	2010	2030	2050	2030	2050
Harvesting and haulage					
Employment, no climate change	14	14	19	14	19
		Scenario A1B		Scenario A2	
Employment under climate change		13	17	13	17
Difference under climate change		−1	−1	−1	−2
% difference under climate change		−6	−6	−6	−11
Wood products manufacturing					
Employment, no climate change	94	111	126	111	126
		Scenario A1B		Scenario A2	
Employment under climate change		110	113	110	113
Difference under climate change		−1	−13	−1	−13
% difference under climate change		−1	−10	−1	−10
Total					
Total employment, no climate change	107	125	144	125	144
		Scenario A1B		Scenario A2	
Total employment under climate change		123	130	124	129
Total difference under climate change		−2	−14	−2	−15
Total % difference under climate change		−2	−10	−2	−10

FIGURE 5: PROJECTED CHANGES IN SOCIOECONOMIC FACTORS DUE TO MEDIAN AND RANGE OF EFFECTS OF CLIMATE CHANGE ON LOG SUPPLY



Note: The dashes show the effects on socioeconomic factors due to median effect of climate change on log supply; the bars above and below the dashes show the range.

7. Regional community impacts and adaptation strategies

Indicators of vulnerability

An understanding of the dependence of regional communities on the forestry and forest products industries and their adaptability in the face of change helps governments and decision-makers to plan and implement strategies to ameliorate the effects of climate change on those communities. This section therefore examines:

- which communities in the region are currently most dependent on forestry and forest products industries
- factors contributing to a community's adaptive capacity
- which communities are potentially most vulnerable to the projected changes in the forestry and forest products industries
- factors influencing the ability of workers in those industries to adapt to changes in their employment status.

Employment in the forestry and wood products industries in the northern Australia study region is generally low. There are only three local area's with more than one per cent of total employment in the industries. Table 8 shows, for each of those local areas, the proportion of the labour force employed in the industries and three indicators of adaptive capacity, which together provide an indication of community vulnerability. Local areas that have a high dependence on the forestry and forest products industries for employment compared with other local areas, as well as relatively high socioeconomic disadvantage, low economic diversity and a high degree of remoteness, may be most vulnerable to the impacts of climate change.

Table 8 presents a composite index of vulnerability based on a conceptual model used by the Allen Consulting Group (2005) where vulnerability is a function of a local areas sensitivity and adaptive capacity. The model uses proxy indicators for sensitivity and adaptive capacity. Sensitivity is measured through dependence on forest and forestry industries for employment while adaptive capacity is a composite measure of Socio Economic Index For Areas (SEIFA) relative disadvantage, economic diversity index and remoteness score. Vulnerability index scores are rated as follows:

- Very low (0.00 – 0.21)
- Low (0.22 – 0.41)
- Moderate (0.42 – 0.61)
- High (0.62 – 0.81)
- Very high (0.82 – 1.00)

The data suggest that Tablelands (R) – Herberton and Tiwi Islands (CGC) local areas are the most vulnerable to changes in access to forest resources within the Northern study region. Tablelands (R) – Herberton has the highest dependence on forestry and forest products industries for employment coupled with a relatively high degree of socioeconomic disadvantage, moderate economic diversity.

TABLE 8: DEPENDENCY OF LABOUR FORCE ON THE FORESTRY AND FOREST PRODUCTS INDUSTRIES, AND INDICATORS OF ADAPTIVE CAPACITY, IN THREE LOCAL AREAS IN THE NORTHERN AUSTRALIA STUDY REGION

Statistical Local Area[1]	Dependency (%)[2]	SEIFA index[3]	Economic diversity[4]	Remoteness[5]	Vulnerability index[6]
Tablelands (R) — Herberton	3.14	2	0.6	Outer regional – remote	Very high (1.00)
Hinchinbrook (S)	1.35	3	0.5	Outer regional – remote	Very low (0.00)
Tiwi Islands (CGC)	0.93*	3	0.4	Very remote	High (0.71)

Notes: 1. Statistical Local Areas are general-purpose spatial units used by the Australian Bureau of Statistics in the collection of statistical data. **2.** Total labour force employed in the forestry and forest products industries as a proportion of total employment, 2006. Only local areas with a dependency value of ≥ 1 per cent have been included. **3.** ABS Socio-Economic Index for Areas for relative disadvantage (state decile ranking), based on 2006 data, where 1 is the most disadvantaged and 10 is the least disadvantaged. Rankings between 4 and 7 are considered neutral. **4.** As calculated using the Hachman Index of Economic Diversity, based on 2006 data. The Hachman Index is a comparative measure of industry diversity; 0 indicates the lowest economic diversity and 1 the highest economic diversity. **5.** Assessed based on the distance by road to the nearest service centre with a population of >1 000 people. There are five classes: major cities, inner regional, outer regional, remote and very remote. (ABS 2001). **6.** Vulnerability index is a comparative measure for the local areas of interest within the forestry region, they are not comparable across forestry regions.

Factors influencing the ability of workers to adapt

The key variables that have a potentially negative influence on the ability of workers in the forestry and forest products industries to adapt to changes in their employment status are age, education, income and occupation. Thus, workers generally considered less able to adapt:

- are older
- lack a post secondary school qualification
- earn less than $400 per week (the median individual income for all persons aged 15 years and over in 2006 was $466 per week for whole of Australia)
- are employed in unskilled occupations.

TABLE 9: COMPARISON BETWEEN THE CHARACTERISTICS OF WORKERS IN THE FORESTRY AND FOREST INDUSTRIES, STUDY REGION AND AUSTRALIAN AVERAGE, 2006

Statistical Local Area[1]	Workers aged 50 years or older	Workers without post secondary school qualification	Workers earning < $400/week	Workers in unskilled occupations
	(Percentage of total forestry and forest industries workforce)			
Tablelands – Herberton	45.6	61.4	19.3	43.9
Hinchinbrook	38.8	53.7	17.9	35.8
Tiwi Islands	0	100	57.1	71.4
Australia[2]	**24.3**	**53.6**	**11.6**	**18.5**

Notes: 1. Statistical Local Areas are general-purpose spatial units used by the Australian Bureau of Statistics in the collection of statistical data. **2.** Total forestry and forest product industries workforce includes; workers in forestry, logging, forestry support services, wood product manufacturing and paper, and converted paper product manufacturing.

8. Adaptation measures

The productivity and protection of forest plantations can be improved by a range of silvicultural and other measures. For example, species that are more tolerant of warmer and drier climatic conditions could be planted as existing stands are harvested, and thinning regimes could be adjusted to reduce competition for water within stands.

The choice of adaptation measures for sustainable management of plantations and native forests would require evaluation of their efficacy in addressing impacts of climatic change. The identification, characterisation and management of risks to forests associated with climate change, such as those posed by pests, diseases, weeds, drought and fire, are essential for reducing the vulnerability of forests to climate change. The combination of increasingly accurate climate and forest growth modelling and effective monitoring and surveillance systems will enable a better appreciation of threats and adoption of anticipatory adaptation measures (Singh et al. 2010). An early recognition of a need to adapt to changing climatic conditions will improve the adaptive capacity of forest industries.

Box 1: Assumptions

Two of several global IPCC emission scenarios were used in this study. Emission scenarios prepared by the IPCC are based on greenhouse gas and sulphate aerosol emissions over the 21st century and incorporate assumptions about future demographic, economic and technological factors. Greenhouse gas levels inherent in these emission scenarios are one of the key variables that drive global climate models and enable us to derive climate projections at future points in time and space. In this study, the A1B emission scenario was selected to generate climate projections that assume a moderate increase in atmospheric greenhouse gas levels over the 21st century and the A2 emission scenario was selected to generate climate projections that assume a more substantial increase in greenhouse gas levels over the same time period.

Adapting those global scenarios (scale of about 125 to 400 kilometres) for regional scale analyses (scale of 25 kilometres) increases the level of uncertainty but was necessary to produce the inputs for growth modelling. The various global climate models employed in this study produced a wide range of results, the highest and lowest and median of which are reported here. The tree growth model used in this study (3PG) is one of many available models for simulating growth of forest trees and its results may differ from those of other models.

When determining baseline log supply, it was assumed that current growth rates continue, existing plantations will be replanted with the same species following harvesting and native forests currently managed for timber production will continue to be managed for timber production. Long-term historical average effects of wildfire, storms, drought and other factors are assumed. Changes to incidences of those factors under climate change scenarios were not assumed.

Our sensitivity analysis and recently published work (Almeida et al. 2009) suggests that the effects of projected climate change reported in this study may be offset by potential increases in atmospheric carbon dioxide. This study and Almeida et al. (2009) did not consider interactions between increased levels of atmospheric carbon dioxide and soil fertility which is a known area of complexity. Projected increases in carbon dioxide fertilisation benefit are dependent on assumptions about the nature of tree species responses to increases in atmospheric carbon dioxide. The potential benefits of carbon dioxide in a changing climate must be regarded with caution because of uncertainty about its interaction with other factors, including temperature, rainfall distribution and soil fertility.

The projected effects on log supply do not take into account any adaptation measures that could be adopted.

Overall, this study used a range of models with varying reliability and many inputs and assumptions as described in ABARES (2011b). These factors need to be considered when interpreting the results.

Glossary

carbon dioxide	A naturally occurring gas. Also, fossil fuel and biomass burning and various industrial processes, among other things, release carbon dioxide into the atmosphere that contributes to climate change. Carbon dioxide is essential for tree growth and survival.
carbon dioxide fertilisation	Increase in growth rates of trees in response to increasing concentration of carbon dioxide in the atmosphere.
climate change	Change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period of decades or longer.
climate projection	A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases, among other things, often based upon simulations by climate models.
emission scenario	A representation of the future of greenhouse gas emissions based on a range of assumptions about key drivers, including demographic and socioeconomic development and technological change. The Intergovernmental Panel on Climate Change (IPCC) has presented a number of emission scenarios, including A1B and A2 used in this study.
growth rate	Mean annual increment defined as the total log volume growth (in cubic metres) of a unit area (hectare) of plantation or forest averaged over the planned rotation (years), expressed in cubic metres per hectare per year.
hardwood	Timber from flowering trees, such as eucalypts, irrespective of the physical hardness of the timber; also used to refer to the trees that have such timber.
plantation	Stands of trees of native or exotic species, created by the regular placement of seedlings or seeds.
pruning	Removing the branches from the lower part of the tree trunk so subsequent bole growth is free from knots.
pulpwood	Logs used to manufacture fibreboard, particleboard, paper products, and small-diameter logs used for posts and poles.
sawlogs	Logs used to manufacture veneer, plywood and sawn timber.
silviculture	The science and technology of managing forest establishment, composition and growth.
softwood	Timber from cone-bearing trees, such as pines, irrespective of the physical softness of the timber; also used to refer to the trees that have such timber.
thinning	Removing a proportion of the trees in a stand so remaining trees have more growing space and are therefore likely to increase in diameter.
yield	The volume of logs harvested, often expressed in cubic metres per hectare.

Bibliography

ABARES 2011a, *Potential effects of climate change on forests and forestry in Australia*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

ABARES 2011b, *Potential effects of climate change on forests and forestry: technical report for northern Australia*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

ABS 2001, ABS *views on remoteness 2001*, Cat. no. 1244.0, Australian Bureau of Statistics, Canberra.

Allen Consulting 2005, *Climate Change Risk and Vulnerability*, Report to the Australian Greenhouse Office, Department of the Environment and Heritage, Canberra.

Almeida, AC, Sand, PJ, Bruce, J, Siggins, AW, Leriche, A, Battaglia, M and Batista, TR 2009, *Use of a spatial process-based model to quantify forest plantation productivity and water use efficiency under climate change scenarios*, 18th World IMACS / MODSIM Congress, Cairns, Australia, 13-17 July 2009, http://mssanz.org.au/modsim09 (accessed 6 June 2011).

Battaglia, M, Bruce, J, Brack, C and Baker, T 2009, *Climate change and Australia's plantation estate: analysis of vulnerability and preliminary investigation of adaptation options*, prepared for Forest and Wood Products Australia, CSIRO, Hobart.

CSIRO 2007, *Climate change in Australia*, CSIRO and Bureau of Meteorology, Melbourne.

Gray, J, King, K, Barrett, G, Nikolova, S, Miller, M, O'Keefe, M and Laughlin, G 2011, *Climate modelling and impacts on forests and forestry: northern Australia*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

MIG (Montreal Process Implementation Group for Australia) 2008, *Australia's state of the forests report 2008*, Montreal Process Implementation Group for Australia, Bureau of Rural Sciences, Canberra.

Parsons, M, Frakes, I and Gavran, M 2006, *Australia's plantation log supply 2005–2049*, National Forest Inventory, Bureau of Rural Sciences, Canberra.

Gavran, M and Parsons, M, 2010, *Australia's plantations 2010 inventory update*, National Forest Inventory, Bureau of Rural Sciences, Canberra.

Pinkard, EA, Kriticos, DJ and Potter, K 2010, *Implications of climate change for Australia's plantation forests: weeds, insects and fungal pests*. Prepared for the Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Singh, S, Davey, S and Cole, M 2010, 'Implications of climate change for forests, vegetation and carbon in Australia', *New Zealand Journal of Forestry Science*, 40: 141–152.