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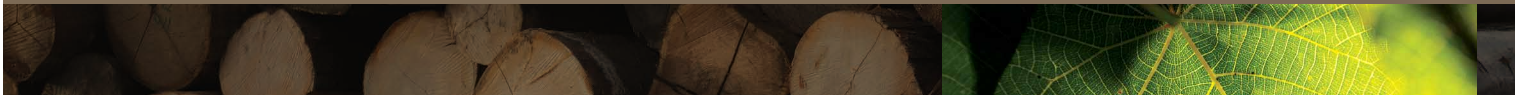

Potential effects of climate change on forests and forestry: summary for south-western Western Australia

August 2011

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Potential effects of climate change on forests and forestry: **summary for south-western Western Australia**

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Key Points

one. Climate and tree growth modelling were used to project the potential effects of climate change on forests and forestry in the south-western Western Australia region by 2030 and 2050, under two greenhouse gas emission scenarios devised by the Intergovernmental Panel on Climate Change.

two. Under both emissions scenarios, rainfall is projected to decline and temperatures increase across the region due to climate change, which would reduce the growth rates of blue gum and radiata pine plantations and of native forest species 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. The median projected effects between 2030 and 2050 indicate little change in growth rate of maritime pine, declines of 14 to 24 per cent in growth rate of blue gum and declines of 30 to 39 per cent in growth rate of radiata pine as compared with the baseline. The median projected effect for a surrogate used to model growth of native forests is a decrease in growth rate of up to 16 per cent as compared with the baseline.

five. Uncertainty remains around the interaction of high carbon dioxide and tree growth. However, a fertilisation effect may partially or fully offset modelled declines in tree growth with future warmer and drier climates.

six. Log supply in the study region is projected to increase in the next few years because more plantations and native forests are reaching harvest age. Log supply in 2030 and 2050 is still projected to be higher than the 2010 baseline level but not as high as was expected before allowing for climate change effects on tree growth. The median projections are for log supply to be 15 to 25 per cent lower than the projected higher baseline.

seven. A smaller increase in log supply under climate change than the projected increase in baseline without climate change would reduce the potential to increase investment in harvesting, haulage and log processing capacity. All or most of the potential increases in employment arising from more plantations and native forests reaching harvest age will be lost due to the effects of climate change on tree growth. These estimates do not take into account any adaptation measures that could be adopted.

eight. Within the study region, the Nannup and Manjimup communities may be most vulnerable to changes in employment in the forestry and forest products industries because of their relatively high dependence on those industries and other factors.

nine. A range of climate change adaptation measures could be taken to improve the productivity and protection of plantations in the region. These include selection of suitable species and silvicultural regimes.

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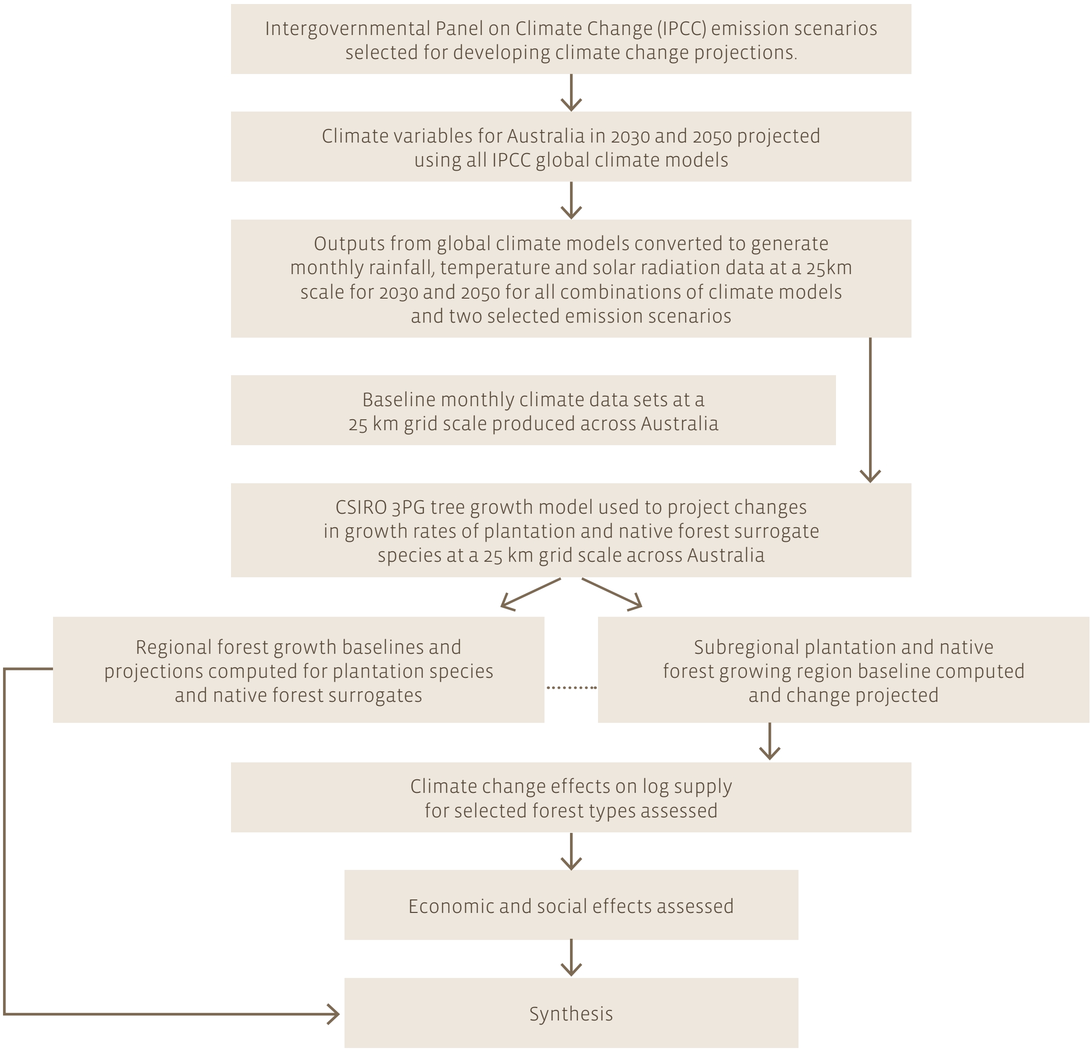
1. Introduction

This is a summary of a more detailed assessment of the potential effects of climate change on forests and forestry in south-western Western Australia (ABARES 2011b). That more detailed assessment, in turn, is part of a larger assessment of the potential effects of climate change on forest growth in six regions across Australia and estimates the consequent 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 24) 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: METHODS USED IN THE STUDY OF POTENTIAL EFFECTS OF CLIMATE CHANGE ON FORESTS AND FORESTRY



2. Region overview

The south-western Western Australia study region (depicted in map 1) covers an area of about 19 million hectares. The climate is temperate in the region's western and southern coastal areas and grades to semi-arid in the east and north-east. Average annual rainfall ranges across the region from 400 mm to 1100 mm. Average daily maximum temperature for the region is 22.4 °C. Representative mean maximum temperatures across the region include; Albany (January 23°C, July 16°C); Bunbury (January 30°C, July 17°C); and Perth (January 31°C, July 18°C).

The main plantation forest species used in the region are blue gum (*Eucalyptus globulus*), radiata pine (*Pinus radiata*) and maritime pine (*P. pinaster*). The major native forest wood production species are jarrah (*E. marginata*) and karri (*E. diversicolor*). They were assessed using spotted gum as a surrogate species. Map 1 shows the distribution of forest types, map 2 displays the distribution of forests potentially available for wood production (MIG 2008), and table 1 shows the current area of forest potentially available for wood production, by forest type.

TABLE 1: CURRENTLY AVAILABLE WOOD PRODUCTION FORESTS IN THE SOUTH-WESTERN WESTERN AUSTRALIA STUDY REGION, BY FOREST TYPE

Production forest type	Area ('000 hectares)
Eucalypt tall open	94
Eucalypt medium closed	4
Eucalypt medium open	1 038
Eucalypt tall closed	2
Hardwood plantation	314
Softwood plantation	111
Total	**1 563**

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

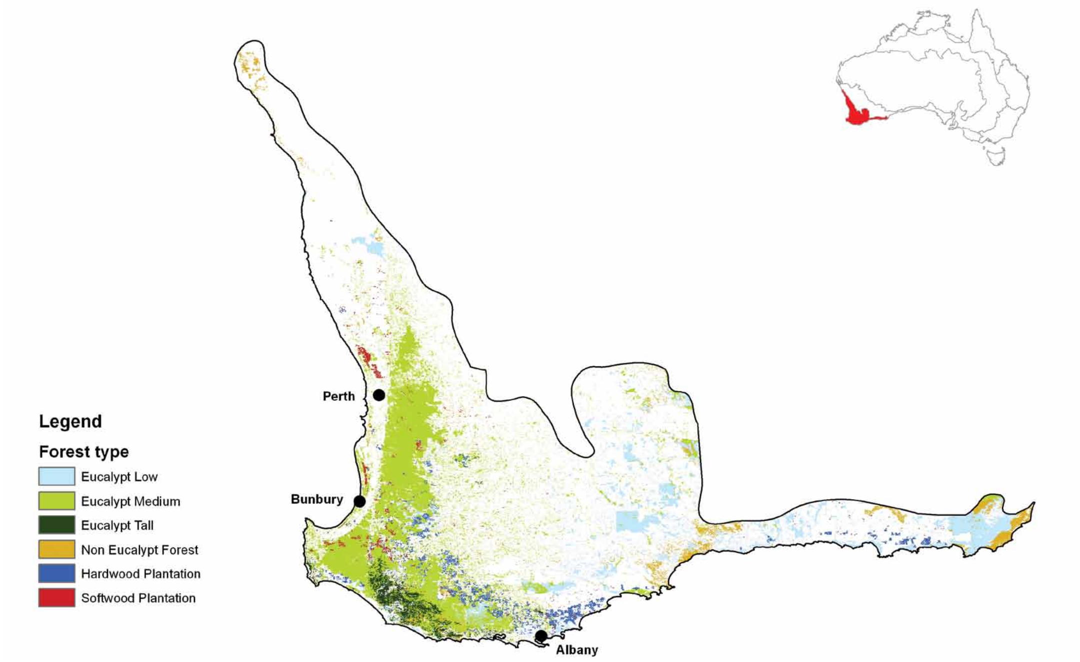
The region hosts a number of forest-based industries, including many small scale sawmills. The largest volume forest products are hardwood woodchips primarily from blue gum plantations and hardwood and softwood sawnwood. The total volume of logs harvested in 2009–10 was 4 million cubic metres, with a total value of $308 million (table 2).

TABLE 2: WESTERN AUSTRALIAN LOG HARVEST, 2009–10

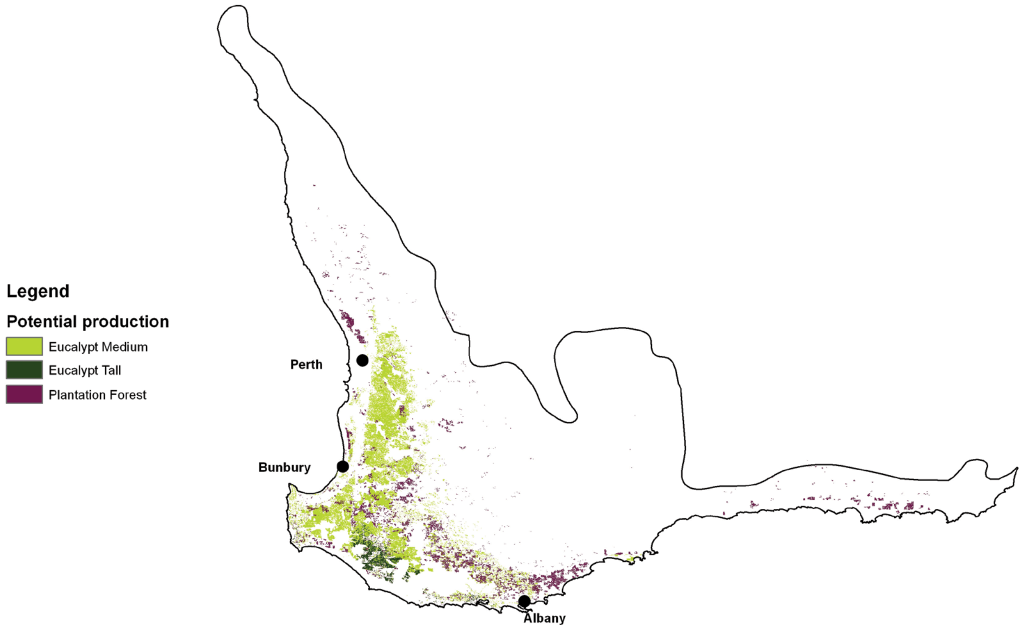
	Volume ('000 m³)	Value[1] ($ million)
Native hardwood		
Hardwood sawlogs	226	25
Hardwood pulpwood	148	11
Minor log products	62	4
Total native hardwood	**437**	**40**
Plantation hardwood		
Hardwood sawlogs	1	0
Hardwood pulpwood	2 637	215
Total plantation hardwood	**2 639**	**216**
Softwood		
Softwood sawlogs	571	37
Softwood pulpwood	300	12
Minor log products	31	4
Total softwood	**901**	**53**
Total log harvest	**3 977**	**308**

[1] When delivered to the mill
Note: Totals may not tally due to rounding.
Source: ABARES datasets

MAP 1: FOREST TYPES, SOUTH-WESTERN WESTERN AUSTRALIA STUDY REGION



MAP 2: FORESTS CURRENTLY POTENTIALLY AVAILABLE FOR WOOD PRODUCTION, SOUTH-WESTERN WESTERN 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 3), 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 3: ESTIMATED GLOBAL CHANGE IN MEAN ANNUAL TEMPERATURE (AND RANGES) RELATIVE TO 1990 UNDER TWO EMISSION SCENARIOS, 2030 AND 2050

	2030	2050
Emission scenario		**°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 4 presents the highest, lowest and median changes in rainfall and maximum temperature for all models used in each emission scenario for the south-western Western 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.

Species' growth data are required to calibrate 3PG. For some species grown in the study region, such as blue gum and radiata pine, considerable growth data are available; model projections for those species will therefore be more reliable than for species for which fewer data are available. However, 3PG is not calibrated for native forest. An alternative species for which growth data were available was therefore needed as a surrogate to assess the growth rates of jarrah and karri in those native forests in the study region currently available for wood production. Spotted gum (*Corymbia maculata*) was selected as the surrogate for native forests because, of the plantation species for which data were available, its growth characteristics were considered more similar to those of native forests.

TABLE 4: RANGE OF MODEL RESULTS FOR PROJECTED CHANGES IN RAINFALL AND MAXIMUM TEMPERATURE, SOUTH-WESTERN WESTERN 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	+26	+20	+2.9	+3.1	+9	+24	+2.7	+3.3
Lowest	−30	−34	+1.3	+1.0	−40	−35	+1.3	+1.3
Median	−14	−17	+1.8	+2.3	−16	−10	+1.9	+2.4

Notes: 1. Average baseline annual rainfall ranges across the region from 400 mm to 1100 mm. 2. Average baseline daily maximum temperature is 22.4 °C.

Table 4 shows that all climate models, 22 for the A1B and 17 for the A2 emission scenario, project similar increases in temperature in the study region. There is, however, a wide range of results for rainfall: most models project decreases in rainfall but some project increases, with the medians of model projections decreasing for specified years and scenarios.

4. Tree growth projections

Maps 3–6 show the estimated growth rates of the main plantation species and native forest species (as per the spotted gum surrogate) across the south-western Western Australia study region in 2005, as well as the actual distribution of plantations and native forests. Table 5 presents these growth rates numerically; they are used as the baseline for estimating the effect of climate change on growth rates in 2030 and 2050.

TABLE 5: BASELINE (2005) GROWTH RATES OF FOREST SPECIES IN THE SOUTH-WESTERN WESTERN AUSTRALIA STUDY REGION

Species	Average growth rate (m^3 per hectare per year)		Final harvest age (years)
	Whole region	Plantation subregion	
Blue gum (pulplog)	10.7	16.7	12
Maritime pine (sawlog)	7.3	9.7	40
Radiata pine (sawlog)	8.6	14.9	30
Spotted gum (sawlog)	5.4	5.8	30*

* While this final harvest age was used for 3PG modelling for the spotted gum surrogate for native forests, harvest ages in native forests vary typically from 80 to 200 years, depending on forest community.

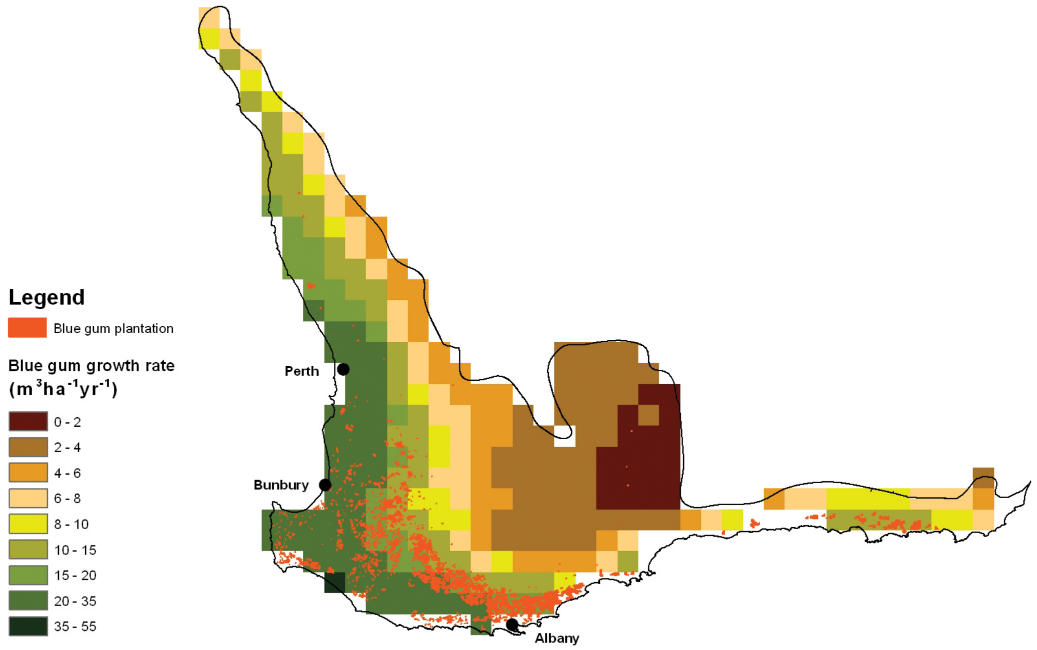
Figure 2 shows, for both emission scenarios, the projected effects across the whole region of climate change on the growth of plantation species and the surrogate used for native forest species. Figure 3 shows the projected effects of climate change on the growth of plantation species within the subregions where plantations currently occur, and figure 4 shows those effects on the surrogate used for native forest species in the six native forest subregions.

The study indicates that the reduced rainfall and increased temperatures projected to occur by 2030 and 2050 due to climate change would affect the growth rates of both forest plantation species and native forest species, although such effects would vary both by species and across the study region. On average across the whole region, growth rates for radiata pine, blue gum and native forest are projected to decline against the 2005 baseline growth rates, while the growth rate of maritime pine may increase slightly. These results correspond to the relative sensitivity of each species to changes in temperature and, to a lesser extent, rainfall.

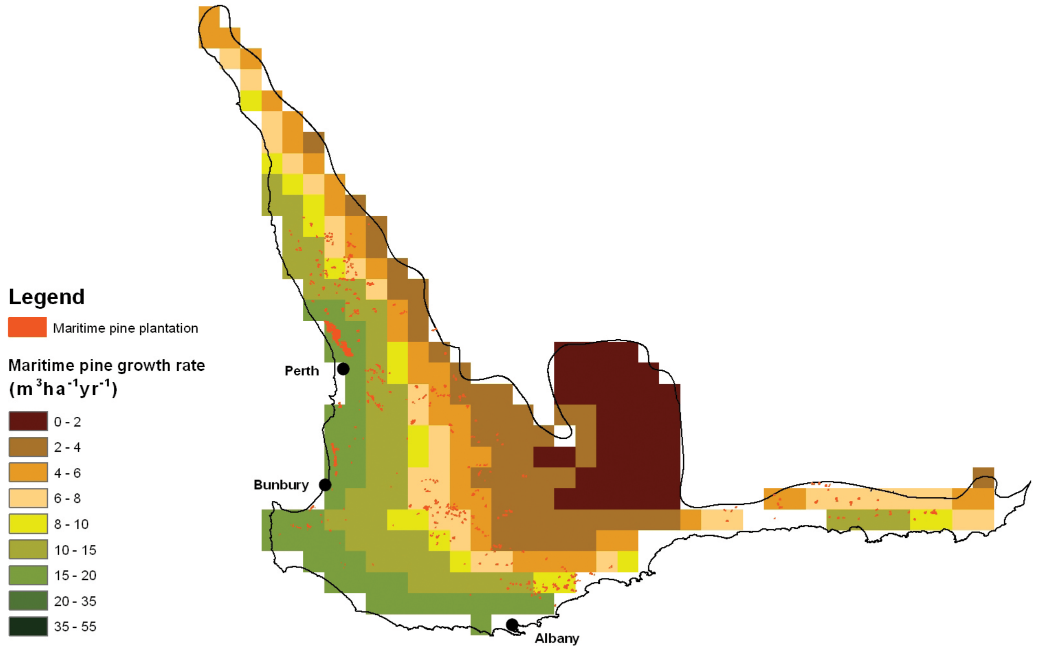
Radiata pine and blue gum plantations are projected to suffer a large reduction in wood yield compared with baseline projections (which use 2005 data to project wood supply to 2030 and 2050), while wood yield from maritime pine plantations is projected to remain virtually unaffected. The productivity of native forests is projected to decline.

Increases in atmospheric carbon dioxide (CO2), which have not been modelled in 3PG, may compensate to some extent for the losses in wood yield by providing a fertilisation effect (see figure 5 and associated discussion). Such yield gains may be offset, in turn, by changes in the distribution, incidence and severity of pests, diseases and weeds (Pinkard et al. 2010).

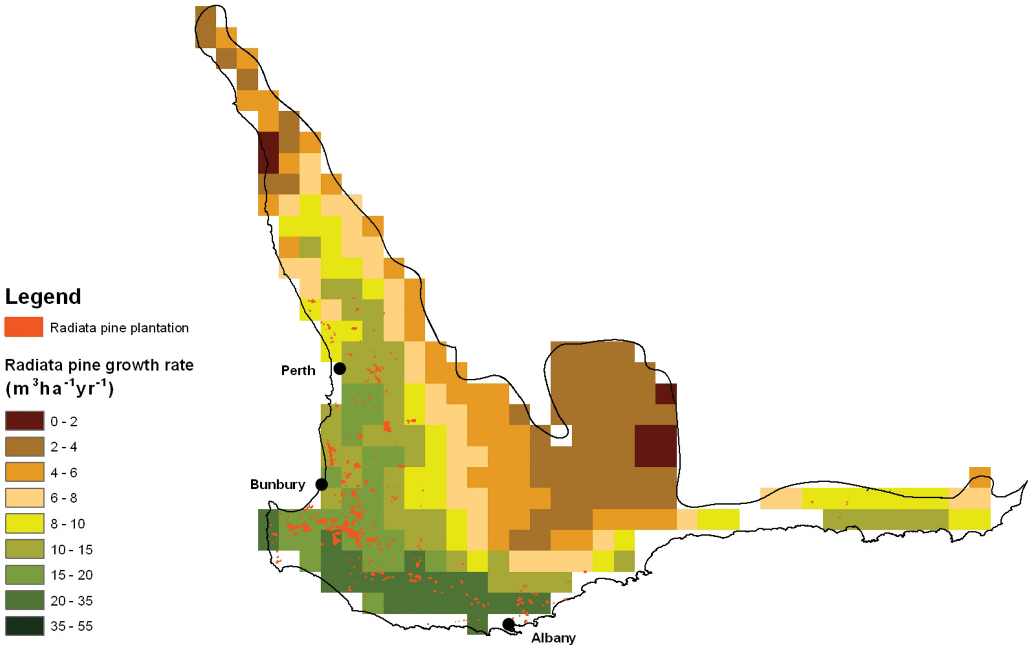
MAP 3: BLUE GUM PLANTATION DISTRIBUTION AND ESTIMATED GROWTH RATES, 2005



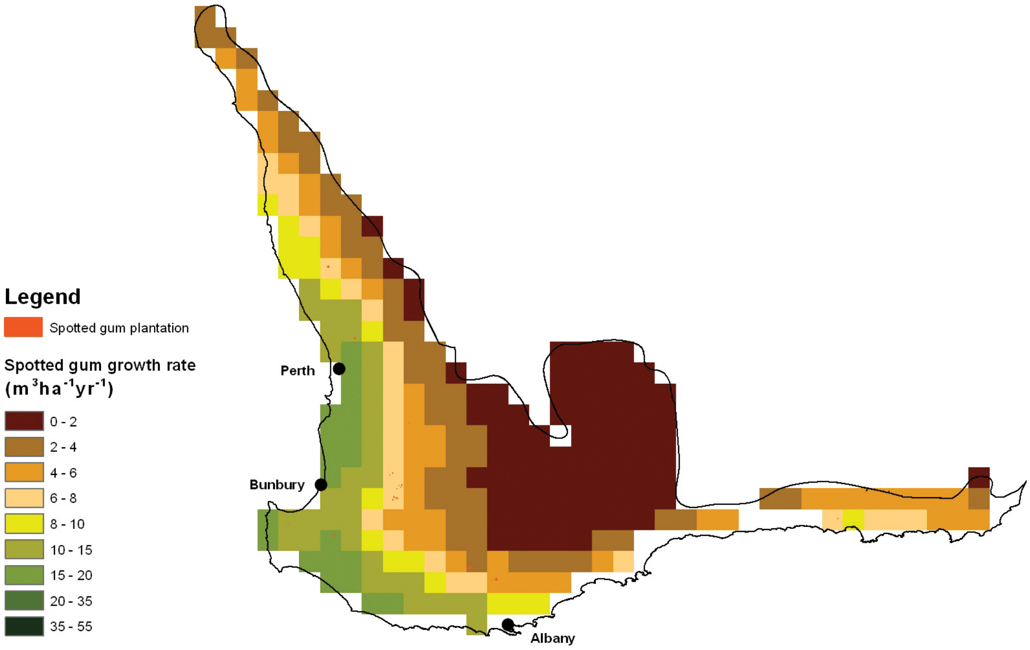
MAP 4: MARITIME PINE PLANTATION DISTRIBUTION AND ESTIMATED GROWTH RATES, 2005



MAP 5: RADIATA PINE PLANTATION DISTRIBUTION AND ESTIMATED GROWTH RATES, 2005



MAP 6: SPOTTED GUM ESTIMATED GROWTH RATES, 2005



Notes: 1. The 3PG model is not calibrated for native forest. **2.** Spotted gum was used as a surrogate to estimate growth rates for native forest tree species.

Potential effects of climate change on growth rates of forest species at subregional level are described below and shown in figures 3 and 4.

Effect on blue gum growth rates

Of the 22 climate models used in projections of growth rates under the A1B scenario, the 3PG outputs for 21 indicate an overall decline in blue gum growth rates in those areas where the species is currently grown by 2030 and, for all climate models, a decline by 2050. Under the A2 scenario, the 3PG outputs for 13 of the 17 climate models indicate a decline by 2030 and for 16 a decline by 2050.

Under the A1B scenario, the median projected effect is a 14 per cent decline in growth rates averaged for those areas where the species is currently grown by 2030 and a 24 per cent decline by 2050. For 2030, the best projected effect is a 0.5 per cent increase in growth rates and the worst projected effect is a 29 per cent decline. For 2050, the best projected effect is a 6 per cent decline in growth rates and the worst projected effect is a 44 per cent decline.

Under the A2 scenario, the median projected effect is a 14 per cent decline in growth rates averaged for those areas where the species is currently grown by 2030 and a 21 per cent decline by 2050. For 2030, the best projected effect is a 12 per cent increase in growth rates and the worst projected effect is a 38 per cent decline. For 2050, the best projected effect is a 2 per cent increase in growth rates and the worst projected effect is a 33 per cent decline.

In summary, the median projections indicate significant reductions in growth of blue gum (figure 3).

Effect on maritime pine growth rates

Of the 22 climate models used in projections of growth rates under the A1B scenario, the 3PG outputs for 15 indicate an overall increase in maritime pine growth rates by 2030 and for 17 a decline by 2050. Under the A2 scenario, the 3PG outputs for five of the 17 models indicate a decline in growth rates by 2030 and for nine a decline by 2050.

Under the A1B scenario, the median projected effect is a 5 per cent increase in growth rates averaged for those areas where the species is currently grown by 2030 but a 3 per cent decline by 2050. The best projected effect is about a 14 per cent increase in growth rates by 2030 and 2050; the worst projected effect is about a 15 per cent decline.

Under the A2 scenario, the median projected effect is a 6 per cent increase in growth rates averaged for those areas where the species is currently grown by 2030 but a 2 per cent decline by 2050. For 2030 the best projected effect is a 22 per cent increase in growth rates and the worst projected effect is a 6 per cent decline. For 2050 the best projected effect is a 12 per cent increase in growth rates and the worst projected effect is a 17 per cent decline.

In summary, while some models indicate significant reductions in growth of maritime pine and some indicate significant increases, the median projected effects indicate little change in growth.

Effect on radiata pine growth rates

For all climate models, 3PG projects an overall decline in the future growth rates of radiata pine. Under both scenarios the decline increases between 2030 and 2050.

Under the A1B scenario, the median projected effect is a 30 per cent decline in growth rates averaged for those areas where the species is currently grown by 2030 and a 39 per cent decline by 2050. For 2030 the best projected effect is a 12 per cent decline in growth and the worst projected effect is a 46 per cent decline. For 2050 the best projected effect is a 25 per cent decline in growth rates and the worst projected effect is a 55 per cent decline.

Under the A2 scenario, the median projected effect is a 28 per cent decline in growth rates averaged for those areas where the species is currently grown by 2030 and a 37 per cent decline by 2050. For 2030 the best projected effect is a 2 per cent increase in growth and the worst projected effect is a 46 per cent decline. For 2050 the best projected effect is a 12 per cent decline in growth rates and the worst projected effect is a 53 per cent decline.

In summary, the projections indicate significant reductions in growth of radiata pine. This result is consistent with that found by Simioni et al. (2009).

Effect on native forest growth

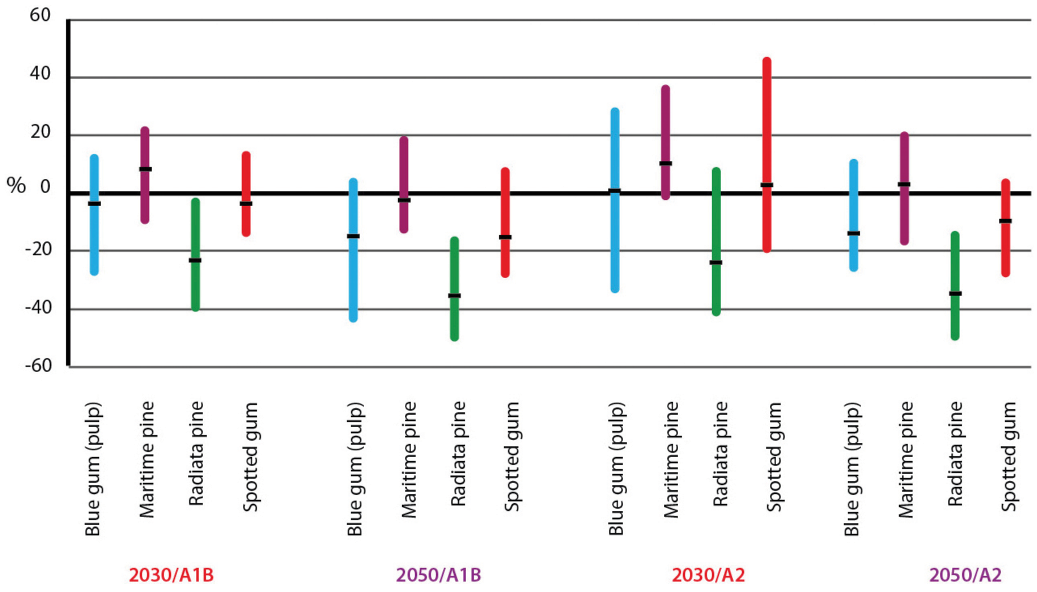
For most climate models, 3PG indicates an overall decline in the growth rates of native forest species (using spotted gum as a surrogate) by 2030, with the decline increasing by 2050. Of the 22 models used for the A1B scenario, the 3PG outputs for 14 indicate a decline in growth by 2030 and for 20 suggest a decline by 2050. Under the A2 scenario, the 3PG outputs for eight of the 17 models indicate a decline in growth by 2030 and for 13 a decline by 2050.

Under the A1B scenario, the median projected effect is a 6 per cent decline in growth rates averaged for those native forest subregions currently available for wood production by 2030 and a 16 per cent decline by 2050. For 2030 the best projected effect is a 10 per cent increase in growth and the worst projected effect is a 16 per cent decline. For 2050 the best projected effect is a 6 per cent decline in growth and the worst projected effect is a 29 per cent decline.

Under the A2 scenario, the median projected effect is a 1 per cent increase in growth rates averaged for those native forest subregions currently available for wood production by 2030 but a 10 per cent decline by 2050. For 2030 the best projected effect is a 39 per cent increase in growth rates and the worst projected effect is a 21 per cent decline. For 2050 the best projected effect is a 1 per cent increase in growth rates and the worst projected effect is a 30 per cent decline.

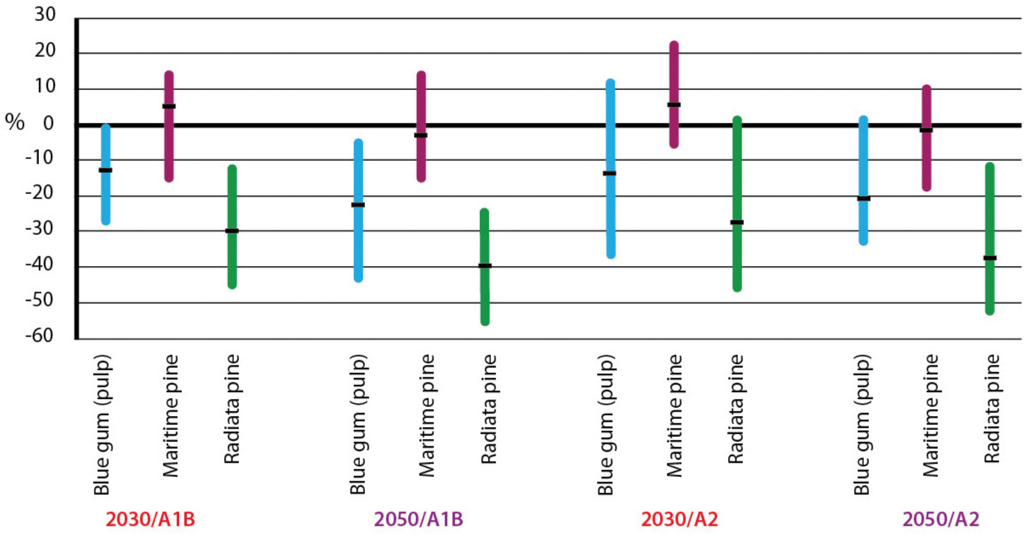
In summary, while some models indicate significant reductions in growth and some indicate significant increases, the median projected effects indicate that the growth rate of the native forest surrogate species is likely to decrease by 2050.

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



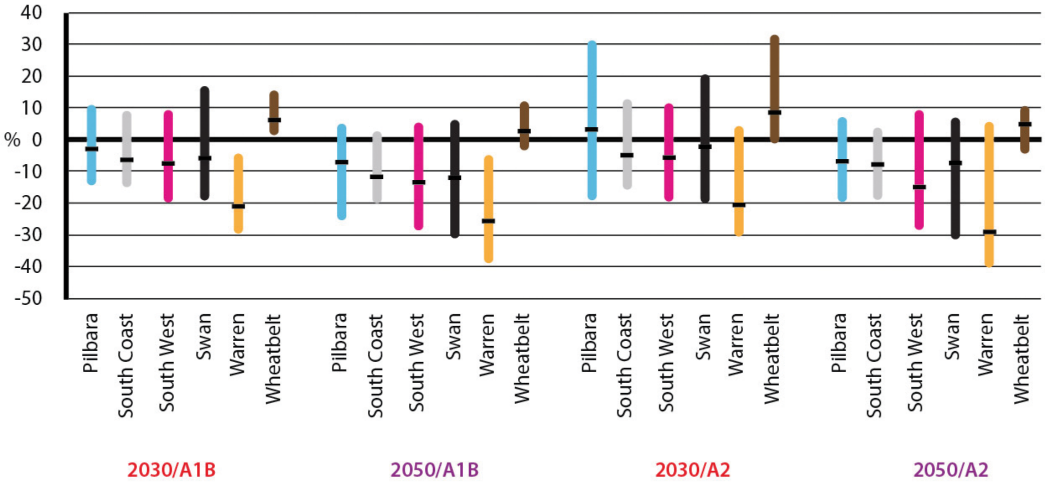
Notes: The dashes show the median projected effect and the bars above and below the dashes show the range.
Spotted gum is used as a surrogate for native forest species because 3PG is not calibrated for native forest.

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



Notes: The dashes show the median projected effect and the bars above and below the dashes show the range.
Results are for those subregions where the species is currently grown.

FIGURE 4: PROJECTED PERCENTAGE CHANGE IN GROWTH RATES DUE TO CLIMATE CHANGE, NATIVE FOREST SUBREGIONS BASED ON AVERAGES FOR THOSE SUBREGIONS



Notes: The dashes show the median projected effect and the bars above and below the boxes show the range. Spotted gum is used as a surrogate for native forest species because 3PG is not calibrated for native forest.

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 an 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 such experiments are 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, based on empirical data from pine species growing in different regions. A sensitivity analysis was undertaken as a preferred method to test the potential effects of carbon dioxide fertilisation in this study.

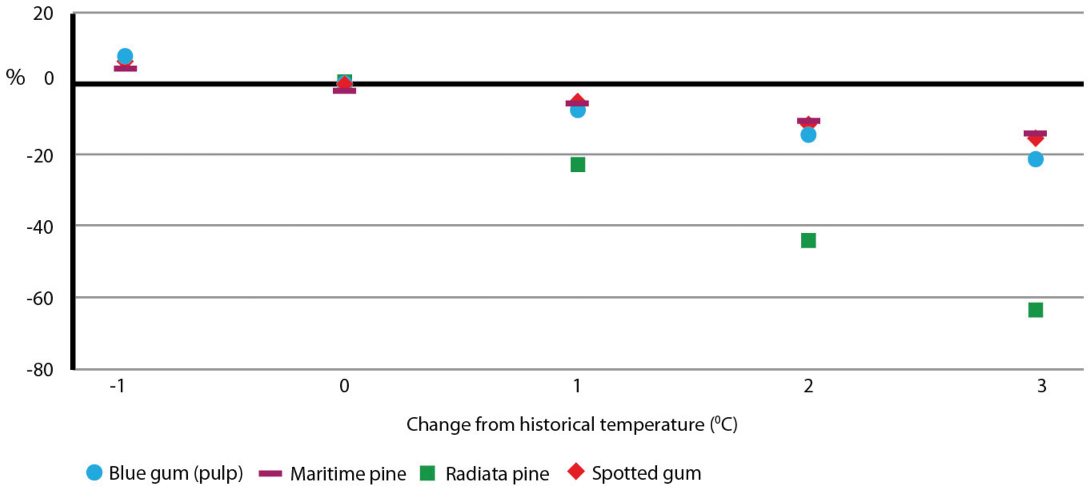
A sensitivity analysis was conducted to explore the effect on tree growth of changes in temperature, rainfall and atmospheric carbon dioxide concentrations (figure 4).

Growth rates for all tree species decrease as temperatures increase, although the extent of the effect varies between species (figure 4a). The decrease is largest for radiata pine, which grows faster at lower temperatures than do the other species. The optimal temperature for growth of spotted gum (the surrogate used for native forest) is greater than the historical mean annual temperature for this study region. It is possible that decreased water availability prevents this species from taking advantage of increases in temperature. All species grow faster with higher annual rainfall (figure 4b). The rate of increase in growth rate is greatest for blue gum and least for spotted gum.

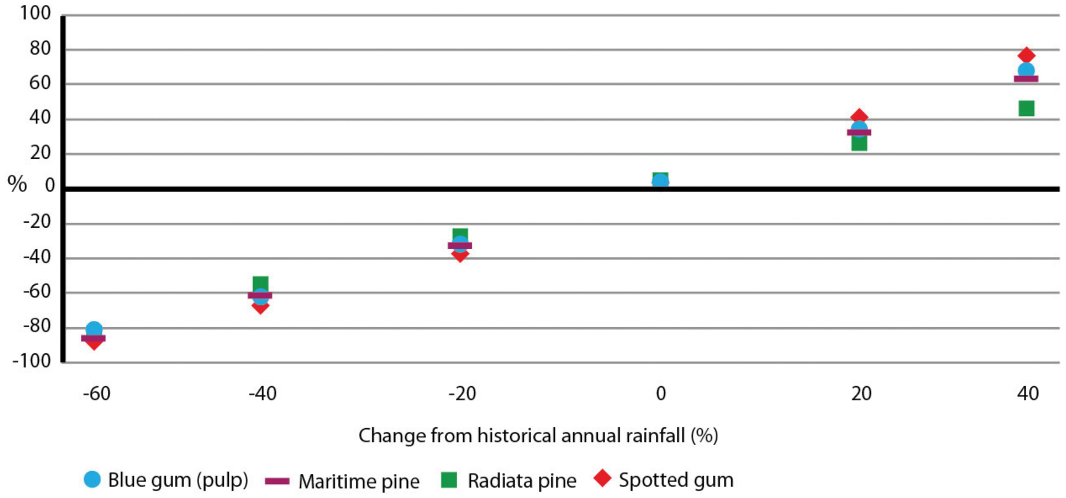
The sensitivity analysis shows that growth for all species increases with higher concentrations of carbon dioxide (figure 4c). The extent of this effect varies between species. Enhanced growth rates as a result of higher carbon dioxide may partially or fully offset projected declines in growth resulting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

FIGURE 5: POTENTIAL CHANGE IN AVERAGE GROWTH RATES FOR PLANTATION SPECIES IN THE SOUTH-WESTERN WESTERN AUSTRALIA STUDY REGION, WITH CHANGES IN (A) TEMPERATURE (B) ANNUAL RAINFALL AND (C) ATMOSPHERIC CO2 CONCENTRATIONS

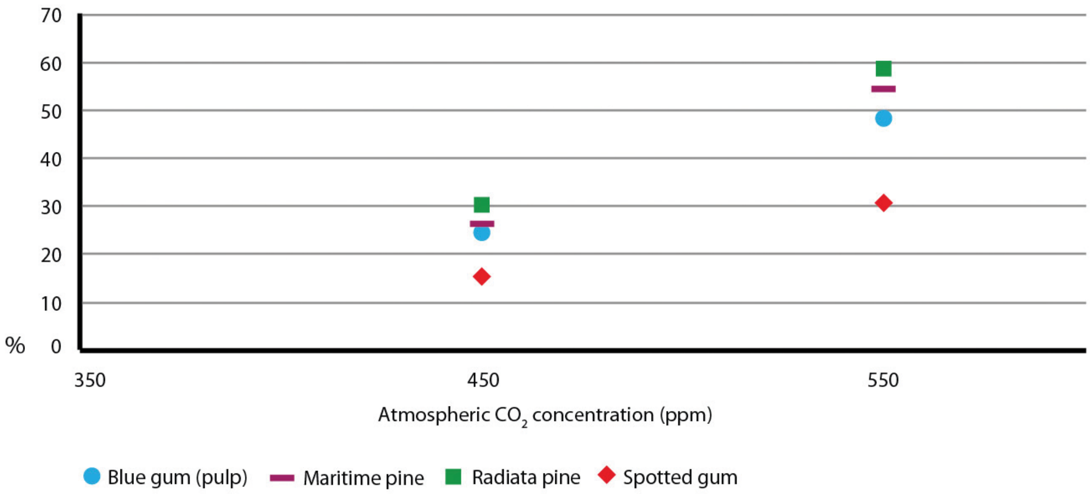
(a)



(b)


100
80
60
40
20
% 0
-20
-40
-60
-80
-100
-60
-40
-20
0
20
40
Change from historical annual rainfall (%)
Blue gum (pulp)
Maritime pine
Radiata pine
Spotted gum

(c)


70
60
50
40
30
20
10
% 0
350
450
550
Atmospheric CO2 concentration (ppm)
Blue gum (pulp)
Maritime pine
Radiata pine
Spotted gum

6. Socioeconomic effects

Baseline projections of wood supply to 2030 and 2050 in the absence of climate change effects on tree growth are based on 2005 data. Those projections show increasing log supply as the large areas of new plantations established in the past 10–15 years reach harvest age. Log supply is still projected to be higher than current levels in 2030 and 2050 under the median estimates of both emission scenarios, but not as high as the baseline projections (table 6).

It is assumed that a smaller potential increase in log supply would result in smaller potential increases in investment in harvesting, haulage and log processing capacity and consequently also in the value of production (table 7) and employment (table 8) in forest industries. Under both climate change scenarios, employment is projected to increase between 2010 and 2030, but then decline to 2050, compared with a steady increase from 2010 to 2050 in the baseline. This reduction in the potential increased employment observed in the baseline case is estimated to be between 14 and 15 per cent at 2030, increasing to between 20 and 22 per cent at 2050 (Table 8). The median and range of projected climate change effects on several economic factors, relative to the baseline, are shown in figure 6.

TABLE 6: PROJECTED CHANGES IN LOG SUPPLY DUE TO MEDIAN CLIMATE CHANGE EFFECTS ON FOREST GROWTH, SOUTH-WESTERN WESTERN AUSTRALIA STUDY REGION ('000 M3 PER YEAR)

	Baseline			Scenario A1B		Scenario A2	
Log type	**2010**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Sawlogs							
Softwood plantation	551	551	551	408	374	418	380
Hardwood plantation	0	0	0	0	0	0	0
Native forest	215	268	290	228	228	231	223
Pulplogs							
Softwood plantation	344	344	344	256	235	262	239
Hardwood plantation	2 813	4 679	4 679	4 047	3 570	4 038	3 719
Native forest	173	271	320	216	238	217	229
Total	**4 097**	**6 112**	**6 183**	**5 154**	**4 646**	**5 165**	**4 790**
Reduction compared with baseline				16%	25%	15%	23%

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

In 2006, the forest industries in the south-western Western Australia study region employed an estimated 5 400 people (both full-time and part-time) that accounted for less than 1 per cent of the estimated 847 000[1] people employed in the study region in 2006. In 2010, an estimated 1 123 (21 per cent) of those 5 400 jobs were in wood harvesting, log haulage and primary wood products manufacturing and the remainder were in forest establishment and management, secondary wood products manufacturing, and other support activities. It should be noted that, of the 5 400 employees, those involved in wood products manufacturing are not necessarily dependent on timber from within the study region. However, the economic modelling generally did not take into account inter regional transport of wood. The Forest Resource Use Model (FORUM) used to estimate employment considers only jobs in wood harvesting, log haulage and primary wood products manufacturing; that is, the implications of climate change for regional forest industry employment are estimated for only around 21 per cent of the necessary workforce. Flow on effects in other parts of the industry would be additional to those shown in table 8.

TABLE 7: PROJECTED CHANGES IN VALUE OF PRODUCTION DUE TO MEDIAN CLIMATE CHANGE EFFECTS ON LOG SUPPLY FOR VARIOUS PRODUCTS, SOUTH-WESTERN WESTERN AUSTRALIA STUDY REGION

	Baseline		Scenario A1B				Scenario A2			
Product	2030 ($ million)	2050 ($ million)	2030 ($ million)	Change (%)	2050 ($ million)	Change (%)	2030 ($ million)	Change (%)	2050 ($ million)	Change (%)
Softwood sawnwood	95	95	61	−36%	53	−45%	63	−33%	54	−43%
Hardwood sawnwood	130	141	111	−15%	111	−21%	112	−14%	109	−23%
Panels	143	143	133	−7%	127	−12%	135	−5%	128	−11%
Logs and poles	20	20	15	−24%	15	−24%	15	−24%	15	−24%
Woodchips	279	283	223	−20%	187	−34%	223	−20%	198	−30%
Bioenergy	152	152	152	0%	152	0%	152	0%	152	0%
Total	**819**	**834**	**695**	**−15%**	**644**	**−23%**	**700**	**−14%**	**655**	**−21%**

Notes: For the baseline, 2005 data were used to project wood supply to 2030 and 2050. The projected changes in value of production are expressed in current dollar terms.

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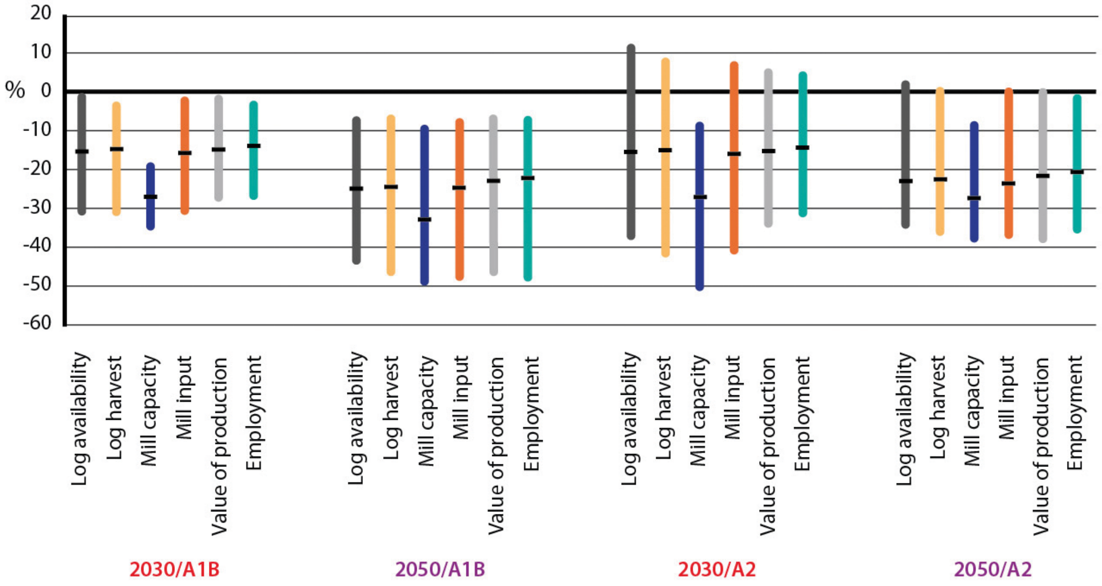
[1] Based on ABS data, manipulated by Dr Jackie Schirmer, for 2006 total employment in forestry, logging, wood and paper production

TABLE 8: PROJECTED CHANGES IN EMPLOYMENT (FULL-TIME EQUIVALENT POSITIONS) DUE TO MEDIAN CLIMATE CHANGE EFFECTS ON LOG SUPPLY, SOUTH-WESTERN WESTERN AUSTRALIA STUDY REGION

Year	2010	2030	2050	2030	2050
Harvesting and haulage					
Employment, no climate change	397	592	601	592	601
		Scenario A1B		Scenario A2	
Employment under climate change		495	447	496	460
Difference under climate change		−97	−153	−95	−141
% difference under climate change		−16%	−25%	−16%	−23%
Wood products manufacturing					
Employment, no climate change	725	774	781	774	781
		Scenario A1B		Scenario A2	
Employment under climate change		671	637	678	644
Difference under climate change		−103	−144	−95	−138
% difference under climate change		−13%	−18%	−12%	−18%
Total					
Total employment, no climate change	1 123	1 366	1 382	1 366	1 382
		Scenario A1B		Scenario A2	
Total employment under climate change		1 166	1 085	1 175	1 104
Total difference under climate change		−200	−297	−191	−278
Total % difference under climate change		−15%	−22%	−14%	−20%

Notes: Totals and differences may not tall due to rounding

FIGURE 6: 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 vulnerability assessment

Indicators of vulnerability

An understanding of the dependence of regional communities on the forestry and forest products industries and their ability to adapt to impacts such as those presented by climate change helps governments and decision-makers to plan and implement strategies to ameliorate the effects of climate change on those industries.
This section therefore describes:

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

Table 9 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 area's 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 the Nannup (S) and Manjimup (S) local areas are most vulnerable to changes in access to forest resources within the south-western Western Australia study region. Both have a high dependence on forest industries for employment compared with other local areas as well as relatively high socioeconomic disadvantage, low economic diversity and a high degree of remoteness.

TABLE 9: PROPORTION OF LABOUR FORCE EMPLOYED IN THE FORESTRY AND FOREST PRODUCTS INDUSTRIES AND INDICATORS OF COMMUNITY VULNERABILITY FOR TEN LOCAL AREAS IN THE SOUTH-WESTERN WESTERN AUSTRALIA STUDY REGION

Statistical Local Area[1]	Dependency (%)[2]	SEIFA index[3]	Economic diversity[4]	Remoteness[5]	Vulnerability index[6]
Nannup (S)	11.1	4	0.4	Outer regional	Very high
Manjimup (S)	8.4	3	0.5	Remote	Very high
Bridgetown-Greenbushes (S)	7.5	5	0.6	Outer regional	High
Dardanup (S)–Pt B	4.6	9	0.7	Inner regional	Low
Donnybrook-Balingup	4.1	6	0.5	Outer regional	Moderate
Boyup Brook (S)	3.1	6	0.1	Outer regional	Moderate
Dardanup (S)–Pt A	2.7	8	0.8	Inner regional	Very low
Collie (S)	2.6	2	0.3	Inner regional	Moderate
Capel (S)–Pt A	2.1	10	0.8	Inner regional	Very low
Albany (C) Bal	1.9	8	0.8	Outer regional	Very low

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 10 compares some socioeconomic characteristics of forestry and forest industries' workers in the study region's 10 local areas to those of the total Australian forestry and forest product industries' workforce. It shows that the communities in the 10 local areas vary considerably in their adaptive capacities and thus their vulnerability to change. They are therefore likely to respond in different ways to changes in the forestry and forest industries.

TABLE 10: 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)			
Nannup (S)	27.0	81.0	19.0	57.1
Manjimup (S)	30.3	66.3	6.8	43.9
Bridgetown-Greenbushes (S)	24.1	68.4	15.0	40.6
Dardanup (S) Pt B	30.5	62.7	5.1	20.3
Donnybrook-Balingup	35.1	58.5	12.8	26.6
Boyup Brook (S)	16.7	66.7	0.00	38.9
Dardanup (S)–Pt A	16.8	59.4	9.9	9.9
Collie (S)	10.2	69.3	13.6	52.3
Capel (S) – Pt (A)	21.1	45.6	10.5	22.8
Albany (C) Bal	13.5	58.9	12.1	25.5
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.

To simulate the effects of projected climate change on native forests, a surrogate species (spotted gum) was used; the accuracy with which that species reflects growth rates for native species is unknown.

Log supply from native forests in Western Australia may also be affected by the interaction between the changing climate and dieback (a disease caused by the fungus Phytophthora cinnamomi that affects a number of native plant species) and how well the moister native forest types respond to a warmer drier climate.

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.

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