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Implications of climate change for forests, vegetation and carbon in Australia†

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Abstract

The Intergovernmental Panel on Climate Change predicts that the level of threats to forests and vegetation will increase in the 21st century. Rising temperatures, drought, forest fires, heavy rains, humidity and cyclones will render forests and vegetation more prone to many threats, including pests and diseases. Pests and diseases adapted to warmer conditions would extend their distribution to the southern direction and higher elevations in Australia. Drought stressed plants may become more susceptible to existing pests and diseases, including bark beetles and *Phytophthora* spp. A range of exotic pests and diseases, if introduced, may cause widespread damage in Australia. Managing sustainable productivity *inter alia* requires realistic evaluation of impacts of climate change on potential threats to forests and the ecosystem services they provide, including as a carbon sink. Such evaluations of threats will assist future planning including prudent use of silvicultural practices to mitigate possible threats. Climate models can enable: better understanding of future threats to Australia's forests and vegetation and related ecosystem services; and better preparedness to safeguard Australia's natural resources in a changing climate. Forest management systems and plans can incorporate measures for mitigating the changing risks associated with pests, diseases, weeds, drought and fire. They can include contingency plans for the emergency salvage of damaged or dead standing timber to prevent damaged forest stands from becoming a source of greenhouse gas emissions.

Keywords: forests; vegetation; drought; pests; fire.

† *Based on a paper presented at the IUFRO International Forest Biosecurity Conference, 16-20 March 2009, Rotorua, New Zealand*

Introduction

Australia has 149 million hectares of forests, comprising 147 million hectares of native forest, dominated by eucalypt (79%) and acacia (7%) forest types, and 1.97 million hectares of commercial plantations, predominantly eucalypts and pines (Montreal Process Implementation Group (MIG), 2008; Bureau of Rural Sciences, 2009). About 70% of Australia's forests are effectively under private management, with 44% on leasehold land and another 26% on land either held under freehold private title or managed by indigenous communities. A further 16% or 23 million hectares of native forest is in formal nature conservation reserves. Multiple-use public native forests, where wood production is an objective, cover 9.4 million hectares. Any changes to Australia's climate are likely to affect its forests.

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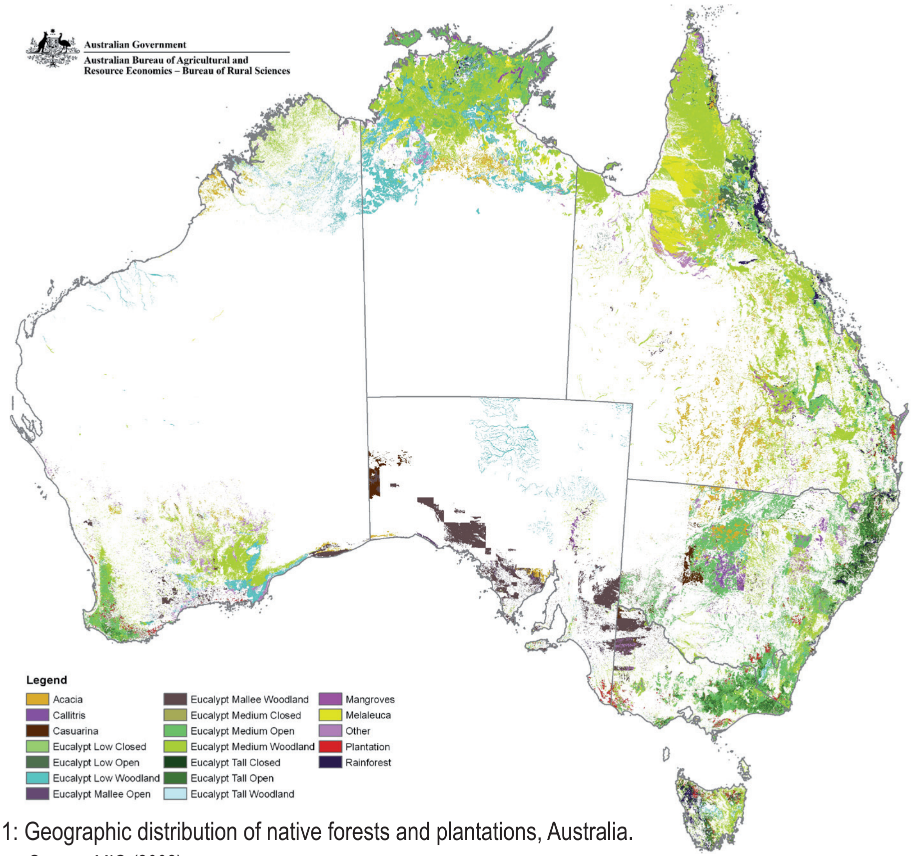

FIGURE 1: Geographic distribution of native forests and plantations, Australia.
Source: MIG (2008).

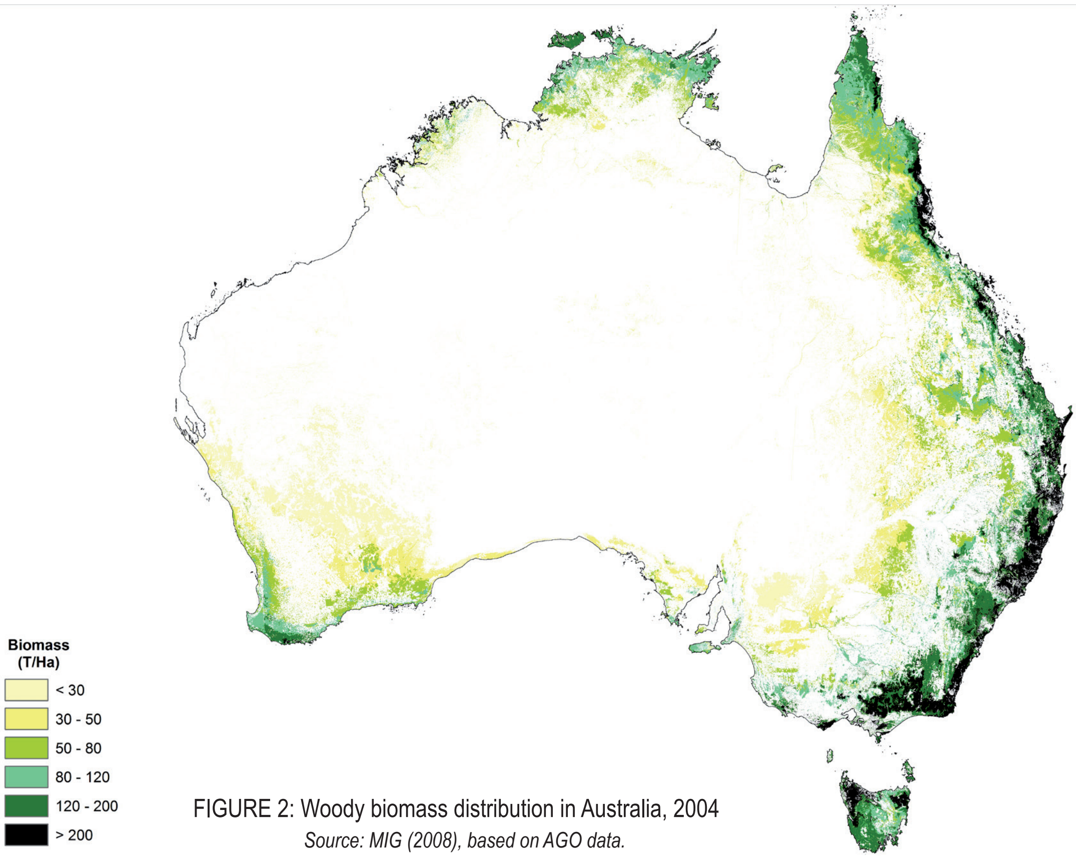

FIGURE 2: Woody biomass distribution in Australia, 2004
Source: MIG (2008), based on AGO data.

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Figure 1 shows the distribution of Australian forests and Figure 2 shows the distribution of woody biomass (tonnes/hectare) in Australia.

The primary feature of climate change is increasing atmospheric concentrations of greenhouse gases, including carbon dioxide. These lead to adverse secondary changes in climate, such as higher temperatures, more droughts and other extreme weather conditions, and rising sea levels (International Panel on Climate Change (IPPC), 2007; Kirilenko & Sedjo, 2007).

It is the secondary effects of climate change (such as weather and the levels of pests, diseases and weeds) that will have the greatest effect on Australian forests. The impacts will vary depending on the degree of climate change in a region and vulnerability or resilience of plant species to the changing climate. Australia has experienced significant climate changes over the last century, and projected climate changes include warmer and drier climatic conditions in southern Australia (Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2007; Battaglia et al., 2009). The following adverse impacts of climate change are projected for Australia's forests (IPPC, 2007):

- significant loss of biodiversity by 2020 in some ecologically rich sites, including the Queensland Wet Tropics;
- intensification of water security problems by 2030 in southern and eastern Australia;
- decline in production from forestry by 2030 over much of southern and eastern Australia due to increased drought and fire;
- increases in the severity and frequency of storms and coastal flooding by 2050; and
- north-western Australia shows areas with moderate to strong increases in annual rainfall over several decades and conditions have become wetter over northwest Australia.

It is important to protect existing forests for a range of economic and amenity uses. Rollinson (2006) formulated forest-related climate change mitigation options into three groups: (i) carbon conservation through the reduction of deforestation and promotion of sustainable management of existing forests; (ii) carbon sequestration through afforestation and reforestation; and (iii) carbon substitution through the sustainable use of forest products for replacing carbon-intensive materials (e.g. concrete, steel, aluminium and plastics) and fossil fuels.

This review focuses on: (a) various threats to Australian forests from climate change; and (b) the importance of Australian forests as carbon sinks and the use of silviculture to maximise carbon sequestration.

(A) Possible risks to Austrailian forests from climate change

Climate change may alter the extent and severity of threats to forests and other vegetation, including those posed by pests, diseases, weeds, fire and drought (IPCC, 2007; Chakraborty, 2005; Garrett et al., 2006; Dunlop & Brown, 2008; Singh & Davey, unpublished data). Each of these threats is discussed below.

Pests

The impact of climate change on pests is likely to be highly variable, with some changes favouring the spread of certain species while hindering others.

Table 1 provides a number of international examples of increases in damage to a range of forest species from arthropod pests associated with climate change based on Moore and Allard (2008).

Most severe insect attacks are associated with fire, drought and other stressors and with poor silvicultural and harvesting practices. Well-planned management actions could help reduce the spread of some pest species. Biologically diverse forests and other vegetation are generally considered to be more resilient and less prone to major pest outbreaks and the effects of climate change (Convention on Biological Diversity, 2007).

Bark beetles are a global threat to forests and other vegetation and their impacts are likely to increase with climate change. The pest population will increase as a result of a faster reproductive cycle under warmer climatic conditions and/or the availability of larger amounts of suitable plant materials following drought associated increases in the number of dead or stressed trees (Wylie et al., 1999; Ramsden et al., 2002; Wulder et al., 2006; Kurz et al., 2008). The projected warmer and drier climatic conditions in southern Australia are expected to increase the distribution and activity of pine aphid, *Essigella californica* (Essig); leaf skeletoniser, *Uraba lugens* Walker; and eucalypt weevil (*Gonipterus scutellatus* (Gyllenhal) (Pinkard et al., 2008). Warmer climatic conditions are expected to favour reproduction and survival of autumn gum moth, *Mnesampela privata* (Guenáa) but drier conditions would decrease the undesirable activities of this pest (Pinkard et al., 2008).

Diseases

As with pests, the impact of climate change on diseases is likely to be highly variable, with some changes favouring the spread of certain species while hindering others. The pathogens with short generation times, high rates of reproduction and effective dispersal

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TABLE 1: Possible Impacts of climate change on a number of arthropod pests

Scientific name	Common name	Climate change impact
Dendroctonus frontalis Zimm.	Southern pine beetle	In the USA, warming has increased geographic distribution of the pest; damage caused to trees by Hurricane Mitch in 1998 was followed by an outbreak of the pest.
Dendroctonus ponderosae Hopkins	Mountain pine beetle	In North America, warming has resulted in increases in population and geographic distribution by reducing generation time and winter mortality of the pest.
Dendroctonus rufipennis Kirby	Spruce beetle	Likely increase in attacks on weakened or wind thrown trees due to climate change impacts
Dendrolimus spectabilis (Butler)	Pine moth	In North Korea, warming has reduced winter mortality and overwintering period of time; and resulted in increased loss of native Japanese red pine (*Pinus densiflora* Siebold & Zucc.)
Ips typographus L.	European spruce bark beetle	Likely increase in attacks on stressed trees due to climate change impacts.
Thaumetopoea pityocampa (Den. & Schiff.).	Pine processionary caterpillar	In Europe, warming has increased geographic distribution of the pest.
Thaumetopoea processionea L.	Oak processionary caterpillar	In Europe, warming has increased geographic distribution of the pest.

Source: Based on Moore and Allard (2008)

mechanisms are most likely to respond directly and quickly to climate change (Pinkard et al., 2008). Again, biologically diverse forests and other vegetation are generally considered to be more resilient and less prone to major disease outbreaks and the effects of climate change (Convention on Biological Diversity, 2007).

Table 2 provides a number of international examples of increases in damage to a range of forest species from pathogens associated with climate change based on Moore and Allard (2008).

Disease-stressed trees are more susceptible to damage by high winds, storms, cyclones and fire, all of which are likely to be more prevalent under climate change (IPCC, 2007). Extreme climatic conditions of alternate wet and dry periods could exacerbate the damage caused by the root-rot fungus *Phytophthora cinnamomi*, which causes dieback in a range of eucalypt (including jarrah, *Eucalyptus marginata* Donn ex Sm. and other forest species, and could lead to large-scale tree mortality (Old & Stone, unpublished data; Australian Greenhouse Office, 2006).

Diseased trees will also sequester less carbon because of a reduction in biomass production. Moreover, they are likely to release greenhouse gases, such as methane, due to any increase in activity of decay-causing microorganisms such as *Armillaria* spp., *Ganoderma* spp., *Phelinus* spp. and *Phytophthora* spp., and stem-rots and butt-rots (Tainter & Baker, 1996).

Weeds

Weeds can severely affect the growth and survival of young plants, compete for nutrition and water with trees and other vegetation, and, in some instances, increase the risk of fire. Weeds can also form part of a vicious circle in which they invade stands of forests and other vegetation affected by drought, fire, pests, diseases or other disturbances, limiting the potential for recovery. Climate change may increase weed problems for forests including an expansion in the geographic distribution of weedy acacia species (Kriticos et al., 2009). Significant weed infestations can reduce forest stand productivity and consequently the carbon sequestration performance of afforestation and revegetation projects. Weed management is doubly important in such projects because the removal and suppression of weeds are potential sources of emissions.

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TABLE 2: Possible Impacts of climate change on a number of pathogens

Scientific name	Common name	Climate change impact
Armillaria mellea (Vahl:Fr.) P. Kumm.	Armillaria root rot	In Europe, expansion in geographic distribution is expected due to warming and associated drought stress.
Phytophthora cinnamomi Rand	Phytophthora dieback	In Europe, expansion in geographic distribution is expected due to warming.
Phytophthora ramorum Werres, de Cock, & In't Veld	Sudden oak death	Increase in populations of bark and Ambrosia beetles due to climate change may result in increased spread of the pathogen; their role in transmission of the pathogen needs to be studied.[1]
Melampsora allii-populina Kleb.	European rust	Likely to spread to northern Europe due to warming.
Mycosphaerella pini E. Rostrup	Red band needle blight	In the USA, warming has expanded geographic distribution of the pathogen; dispersal depends on moisture availability.
Ophiostoma novo-ulmi Brasier	Dutch elm disease	Vectors of the disease likely to be more active under warmer conditions.
Bursaphelenchus xylophilus (Steiner & Buhrer) Nickle	Pine wilt nematode	Warming and water stress is likely to increase geographic distribution; increased vector activity associated with climate change will enhance spread of the nematode.

Source: Based on Moore and Allard (2008)

[1] *http://www.eppo.org/QUARANTINE/Alert_List/fungi/PHYTRA.htm*

Fire

Fire poses one of the most significant risks to the diversity and productivity of Australia's forests and their role as carbon sinks. A significant amount of carbon sequestered in trees is released into the environment as a result of fires, thus making burnt forest a source of greenhouse gas emissions. Fire-damaged or dead trees often become more susceptible to wood-decay fungi and attacks by pests and diseases (see earlier sections), which releases additional greenhouse gases, including methane. Forest fires may assist dispersal of pathogen inoculum (e.g. fungal spores) over long distances (Mims & Mims III, 2004).

Between 2000 and 2006, fires burned an estimated 24.7 million hectares of forests in Australia, comprising 20 million hectares of unplanned fires and 4.7 million hectares of planned fires (MIG, 2008). Southern Australia is prone to large intense wildfires (sometimes called mega-fires). In 2002 – 03, for example, the alpine fires in New South Wales and Victoria burned more than 1.3 million hectares of forest, releasing an estimated 40 million tonnes (Mt) CO_2-e (MIG, 2008). Attiwill and Adams (2008) reported that the 2003 and 2006 – 2007 fires released an estimated 150 Mt of carbon.

Fire management will be an important consideration in the management of carbon in forests and other vegetation over the long term (Attiwill & Adams, 2008), although limited data are available on the effects of various fire management practices on carbon stocks. While planned fires (usually called prescribed burning or hazard reduction burning) emit carbon they can be used to reduce the risk of more intense fires, which emit much larger volumes of carbon and risk greater ecological change.

The combination of increased temperatures and lower rainfall predicted under climate change, particularly in southern Australia, is likely to compound the existing fire risk and present further difficulties for fire control (IPCC, 2007; Lucas et al., 2007; Campbell, 2008). By 2050, the number of extreme fire danger days is predicted to increase by10 – 50% in 'low' scenarios and by 100 – 300% in 'high' scenarios; fire seasons are likely to become longer, starting earlier in the year (Lucas et al., 2007). Fuel management and fire management planning processes, therefore, will become increasingly important for reducing the risk to forest carbon sinks posed by fire and managing likely carbon emissions from these sinks.

More positively, Australian native forests and vegetation are well-adapted to fire, and post-fire recovery

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is generally rapid. The effects of fire are incorporated in the National Carbon Accounting System using equations for greenhouse gases emitted, type of fire (prescribed or wildfire), fuel load, and volume of biomass burnt (Department of Climate Change (DCC), 2008a).

Drought

Australia is the driest inhabited continent and has a highly variable rainfall marked by cycles of severe drought and floods. In parts of Australia, climate change is expected to cause an increased frequency and intensity of drought and changed rainfall patterns (IPCC, 2007; Hennessy et al., 2008). This will lead, in turn, to lower plant growth and increased plant mortality, with associated impacts on the carbon sequestration services provided by forests and other vegetation. Increased drought will also increase the risk of fire in forests and other vegetation. By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia due to increased drought and fire (IPCC, 2007).

Drought risk management strategies will need to be applied in afforestation, reforestation and revegetation projects, including judicious species selection and stocking density practice. In some cases, existing plantations might need to be replaced with more drought-tolerant species, or their stocking reduced. In native forests, drought risk management strategies could include more intensive thinning of regrowth stands, greater investments in fire management, and the establishment and maintenance of vegetation corridors to facilitate gene flow between forest fragments.

Long-term planning is needed to adapt the management of land, forests and other vegetation to the drier conditions that are likely to prevail in southern Australia. Predicted changes in drought and rainfall patterns will need to be incorporated into the modelling used to predict timber yields and carbon sequestration. A failure to plan for climate change could leave large areas of forest and other vegetation, and their carbon stocks, highly vulnerable to increasingly hostile climatic conditions.

Future projections

The complexities of climate change mean that uncertainties exist about future projections and further information is needed to ascertain impacts of changes in certain climatic conditions, for instance, the impact of CO_2 enrichment on forest pests and forest growth (CSIRO, 2007; Battaglia et al., 2009; Chakraborty et al., 2008). As the risks to forests and other vegetation change, adaptive management systems will be particularly important for maintaining the role of forests and other vegetation.

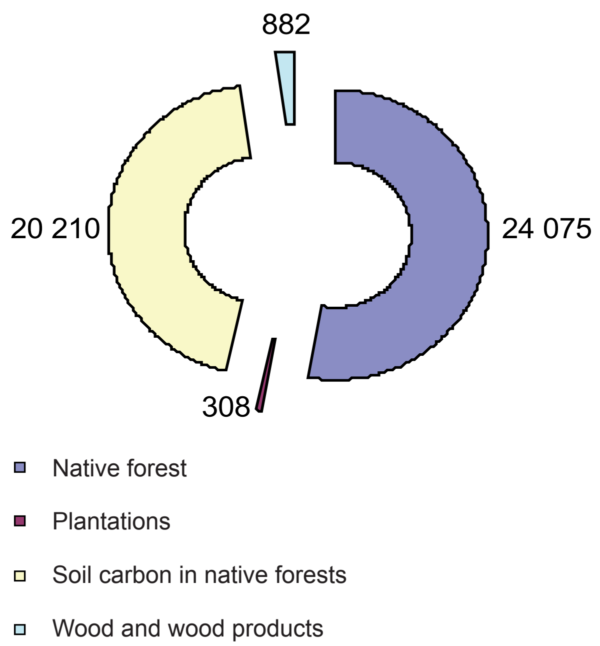
(B) Importance of Australian forests and vegetation as carbon sinks

Vegetation, particularly forest, stores substantial amounts of carbon in above-ground biomass, below-ground biomass, litter, woody debris, harvested materials, wood products and organic soil carbon. Being a net sink of greenhouse gases, forests help offset greenhouse gas emissions (Watson et al. 2000; DCC, 2008b).

Australia's plantation estate represents an important carbon store (Davidson et al., 2008). Figure 3 and Table 3 summarise carbon storage in forests and wood products in Australia. They show that about 53% of carbon stored in forest-based sinks is in native forests, 0.7% is in plantations, 44.4% is in soil in native forests, and 1.9% is in wood products in service and landfill.

Forests will play an important role in assisting Australia to meet its commitment to reduce net greenhouse gas emissions. In 2005, this sector in Australia was responsible for the net removal from the atmosphere of an estimated 51.5 Mt of greenhouse gases (measured as carbon dioxide equivalent) (MIG 2008). Forests can play a much bigger role than their current role in offsetting Australia's greenhouse gas emissions (Garnaut, 2008).

FIGURE 3: Carbon (million tonnes of carbon dioxide equivalent) stored in major forest-based sinks, Australia



Source: Derived from Table 1 (ibid).

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TABLE 3: Carbon storage in forests and wood products, Australia

Storage pool	Year	Stock (Mt)		Annual change (%)	Storage (as a percentage of Australia's total net 2005 emissions[1])
		Carbon	CO_2		
Native forests, including conservation reserves (excluding soil carbon)	2004	6 560	24 075	-0.3	4 610
Soil carbon in native forests	2004	5 507	20 210	Insufficient data	3 870
Total carbon in native forests	2004	12 065	44 285	Insufficient data	8 480
Plantations (excluding soil carbon)	2004	84	308	+4.6 (2001 – 2004)	53
Wood and wood products in service	2005	97	357	+1.5 (2001 – 2005)	61
Wood and wood products in landfill	2005	143	525	+2.3 (2001 – 2005)	90
Total		**24 456**	**89 760**		

[1] Australia's total net emissions from all sources in 2005 was 522.2 Mt CO_2-e.

Source: MIG (2008).

The use of silviculture for carbon sequestration

Silvicultural decisions and yield scheduling

The application of good silvicultural practices will be an essential element in global efforts to mitigate climate change given the limited availability of suitable land for the establishment of new forests and the possible degradation of some existing forests. Optimising the productivity of forests will also maximise the rate at which forests sequester carbon (Resource Assessment Commission, 1992; Lindner et al., 2008). It is important to note that some of the currently available silvicultural practices may no longer be effective under climate change, e.g. biocontrol agents may not function to their optimum under unfavourable climatic conditions or they may be suppressed by hyperparasites.

Silvicultural management of production native forests is critical given that they are the major type of Australian forests. An Australian modelling study of different silvicultural regimes in production native forest suggested that the application of certain silvicultural practices can improve the value of native forests as long-term carbon sinks compared to no logging, taking into account the carbon stored in above-ground biomass, coarse woody debris, and the soil (Ranatunga et al., 2008).

In plantations, the first silvicultural decisions are concerned with species selection, initial spacing between trees, plantation layout, and establishment methods. Later, the forest manager or owner must decide on the type and timing of thinning, pruning, fire management, grazing and harvesting.

Yield scheduling models support planning and decision-making by estimating the flow of sustainable timber products while balancing environmental requirements and other ecosystem services (e.g. water supply). Given the increased importance to forest management of carbon-related decisions, scheduling models will need to be adapted to consider carbon values as well as timber yields. Yield scheduling and carbon accounting approaches associated with afforestation and reforestation (i.e. plantations) will be important considerations in projecting carbon sequestration benefits and the associated application of credits/permits in emissions trading schemes (DCC, 2008c). Yield scheduling tools can be used to balance various carbon stocks (e.g. standing tree carbon, litter carbon, soil carbon, coarse woody debris, and wood products) across a plantation estate in ways that provide non-declining yields of carbon as well as an even flow of timber products (Baalman & O'Brien, 2006).

Species selection

Carbon sequestration rates vary depending on species, and an individual species is more likely to perform better on one site than another. Matching species with site conditions, therefore, is important for good carbon sequestration outcomes. The choice of species for afforestation, reforestation and

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revegetation will have an important bearing on the rate of carbon sequestration achieved and the likelihood of tree survival in the face of climate change. Forest managers should:

- be informed of the most likely climate scenarios for a given afforestation/reforestation site;
- choose species, especially natives, that are adapted to the current and predicted climate of a site and have characteristics for surviving changing and variable climates, drought and/or fire;
- maximise diversity in genetic material, including for pest and disease resistance; and
- favour species with high wood density (the wood density of a species has a significant bearing on carbon content in wood and wood products — Llic et al., 2000) and high growth rates.

In selecting species, an assessment of risk should be undertaken and, to assist future regional decisions on species selection, the reasons underpinning the choices made should be documented.

Stocking density

Stocking density over the lifetime of a forest stand significantly affects the long-term carbon sequestration and plant growth, highlighting the importance of well-timed thinning (see below). Depending on site characteristics and species, stocking densities can be manipulated to help mitigate the risk and impact of fire, drought, pests, diseases and competition from weeds.

Thinning and pruning

Done judiciously, thinning can have a significant bearing on the carbon balance of a forest (Hoover & Stout, 2007) and other ecosystem services such as streamflow. Thinning provides an opportunity for culling commercially less-desirable trees such as those that are small, diseased, damaged, malformed or otherwise unproductive. Thinning methods vary depending on silvicultural or harvesting objectives.

Changing stand structure by thinning can affect carbon sequestration and stand growth either positively or negatively. Those effects can be significant, with long-term implications for carbon sequestration and the growth of the stand. In general, thinning regimes that increase volume of production and stand productivity also increase net carbon sequestration.

The life cycle of carbon associated with thinning and pruning residues needs to be factored into carbon-related decisions. Such residues can be used in bioenergy generation, thereby helping to offset carbon emissions from fossil fuels. *In situ*, however, they will decay, producing greenhouse gas emissions (including methane) as well as carbon that, in time, will be incorporated into the soil carbon sink. If poorly managed, residues from thinning and pruning can also increase fire risk.

Grazing

Over-grazing by livestock in forests and other vegetation can degrade the resource. Reducing such grazing, therefore, will help increase carbon stocks (Orlando et al., 2002; Lunt et al., 2007). Well-managed grazing can help reduce fire risk by reducing fuel loads (particularly grasses) and is also a viable economic option in some private forests. In some cases, however, animals can damage the bark and stems of established trees by chewing, rubbing or pushing on stems, predisposing them to attack by pathogens. Thus, for grazing land management regimes to be effective in climate change mitigation, management must be well-planned at the project level.

Harvesting methods

Selecting the most appropriate harvesting technique and thereby reducing the environmental impact of logging on a stand and the associated loss of carbon is an integral part of forest management. Reducing the forest degradation associated with many current timber harvesting operations could have significant benefits for climate change mitigation (Smith & Applegate, 2002). In Australia, trees are felled either manually (i.e. with a chainsaw) or using mechanical tree-felling machines; as the harvesting of plantations and native regrowth increases, so too does the prevalence of mechanisation (National Association of Forest Industries, 2006). The use of mechanical tree-fellers and forwarders for moving logs in the forest reduces soil erosion. Forest soils are protected by mechanical forwarders 'walking over' logging debris spread deliberately on the ground. The use of cable logging systems, in which logs are suspended above the ground during extraction, allows logging on steep slopes with minimal impact on the soil. Harvesting methods and practices will be important considerations in reducing both emissions during harvesting operations and emissions associated with soil disturbance and erosion.

Managing forest health risks

The monitoring and surveillance of Australia's forests and other vegetation will be important components of risk management and must be capable of providing early warning of impending threats. Coupled with increasingly accurate climate models, an effective monitoring and surveillance system will enable a better understanding of such threats and the adoption of anticipatory risk mitigation measures. Information on threats will assist future planning, including the prudent use of silvicultural practices.

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The Intergovernmental Panel on Climate Change (IPCC, 2007) recognised that 'In the long-term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustainable mitigation benefit'. Moreover, when well designed and managed, forest-related carbon sequestration projects can provide additional socioeconomic and environmental benefits ('co-benefits') such as employment and income generation opportunities, biodiversity and watershed conservation, salinity control, the provision of timber and fibre, and aesthetic and recreational services. When determining forest management strategies for carbon sequestration, it is important to account not only for carbon sequestered in above-ground and below-ground biomass and the soil but also for the carbon stored in wood products and particularly their substitution for fossil fuels and alternative energy-intensive materials (Schmid et al., 2006).

Initiatives involving protection of forests and other vegetation from threats can potentially have other, wide-ranging benefits for rural and regional Australia. These could accrue in the form of better and complementary natural resource management outcomes such as salinity control, improved water quality and biodiversity conservation, and also in the form of increased revenue from diverse forest products, increased farm productivity, the sale of carbon credits, and associated regional development and employment potential.

Silviculture is an important factor in determining the rate at which forests sequester carbon and will also play an important role in the adaptation of forests to climate change, including through better management of forest health threats. Given the limited availability of suitable land for the establishment of new forests, and the need to minimise the risks to forests posed by climate change, the application of good silvicultural practices will be an essential element in climate change mitigation and adaptation.

Forest management systems and plans will need to take into account the changing nature of various threats, optimise carbon sequestration needs and to allow for contingencies. Plans might be needed, for example, for the emergency salvage of damaged or dead standing trees to prevent them from becoming sources of greenhouse gas emissions. The Greenhouse Gas Protocol Initiative highlights the need for direct suppression, replacement, insurance and buffering strategies to mitigate events that could turn carbon sinks into sources (World Resources Institute, 2006). Such management plans are also valuable for carbon market investors in demonstrating the quality of their forest-related carbon assets.

Considerations for tackling impacts of climate change

Forests are susceptible to damage from a wide range of agents. The risks to forests and other vegetation posed by such disturbances will change as the climate changes and will require adaptive management responses. A range of considerations for managing impacts of climate change on forests, vegetation and carbon include:

- identifying and characterising local, regional, national and international threats likely to be associated with climate change;
- monitoring impacts of climate change on forest and vegetation health;
- developing strategies and contingency plans for sustainably managing potential impacts of climate change on forest and vegetation health;
- identifying and implementing sustainable adaptation and mitigation measures;
- implementing forest and vegetation protection education and training activities; and
- integrating government and industry programmes and initiatives for sustainably managing likely impacts associated with threats of climate change to forest and vegetation health.

Well-planned management actions could help reduce the spread of some pest species. The monitoring and surveillance of Australia's forests and other vegetation will be important components of risk management and must be capable of providing early warning of impending threats. Coupled with increasingly accurate climate models, an effective monitoring and surveillance system will enable a better understanding of such threats and assist with the adoption of anticipatory risk mitigation measures.

It is important for policymakers and stakeholders to understand the role of forest health in management of carbon sinks associated with forests and other vegetation. Comprehensive national forest/vegetation inventory and reporting systems will be required to inform discussion especially in a changing climate.

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