CSIRO Submission 11/409

Inquiry into the Australian Forest Industry

House Standing Committee on Agriculture, Resources, Fisheries and Forestry

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Enquiries should be addressed to:

Ms Kerry Miles
CSIRO Ministerial and Parliamentary Liaison
PO Box 225
Dickson ACT 2602

email: kerry.miles@csiro.au
Ph: (02) 6276 6115

Main Submission Author:

Dr Chris Harwood
CSIRO Ecosystem Sciences
Private Bag 12
Hobart, Tasmania 7001

email: chris.harwood@csiro.au
Ph: (03) 6237 5664

Executive summary

The Australian forestry industry is important nationally through the wood products it produces, and the influence of native and planted forests on water security, biodiversity and carbon storage.

Scientific knowledge helps to drive innovation to underpin a viable forestry industry. This submission reviews current scientific knowledge and its application, and priority areas for further research.

Key points made in our submission, in relation to the inquiry's terms of reference are as follows:

Opportunities for and constraints upon production

- Water availability is the most important limiting factor to plantation productivity across most of the plantation estate.
- The role of informed management in sustaining site resources of soil carbon, nutrients and water is emphasised. Current research is addressing second rotation productivity decline in Western Australian blue gum plantations.
- There is evidence that in some instances, plantation site selection, establishment and management have been disconnected from longer term stewardship of sustainable productivity.
- Forest growth modelling is helping us to understand the potential impacts of rising carbon dioxide levels and changing climates on forest ecosystems, but many uncertainties remain.
- Tree breeding provides genetically improved planting stock that delivers substantial improvements in wood production, wood quality and value. Ongoing genetic improvement research can support further genetic improvement and better matching of improved breeds to plantation site types.
- Plantation grown hardwood sawlogs are now becoming available from the small proportion of plantations that have been thinned and pruned. Their successful processing into high value sawn products will require significant investment in modified sawing and drying equipment and procedures.
- Native forests remain an important source of timber for some sections of the Australian forestry industry and there is a strong scientific basis for their sustainable management for multiple uses and values including wood production.
- Ongoing research into processing is needed to develop profitable options for processing unpruned, smaller-diameter plantation logs into veneered or engineered wood products.

Environmental impacts of forestry

- Water use of forest plantations is higher than that of crops and grassland (per unit of land area), and guidelines have been developed for estimating the impact of plantations on water availability.
- A recent analysis of the impacts of forests on water resources concluded that at a national scale, the impacts of plantations on water security and availability had been overstated and the importance of the much larger area of natural forests on water availability for urban catchments needs to be emphasised.
- Access of plantations to groundwater may result in increased water use, but enable more efficient use of water for wood production, indicating the potential for optimising land allocation among plantations and agriculture.
- Plantations can be a tool for management of land and water salinity, the trade-off of recharge reduction to saline groundwater versus flow reduction must be considered.

Creating a better business environment for forest industries

- Future plantation establishment can now use best available data and modelling tools to help predict plantation growth rates and impacts on water resources.

Potential energy production from the forestry sector

- Biomass from existing forest industries and from dedicated new plantings could contribute substantially to an Australian energy future with reduced greenhouse gas emissions.
- Technical, environmental, policy and economic constraints limit forest biomass availability for biomass energy, biofuel and biochar industries, and should be considered in planning to reduce potential for conflict.
- The national Carbon Accounting System has been developed to predict the impacts of land use, management and climate on net emissions of greenhouse gases.
- Potential land availability for new forest plantings to sequester carbon depends on many factors including establishment costs, growth rates and possible carbon pricing.
- Large scale planting of new forests for carbon sequestration would require the development of suitable infrastructure in the planting regions. With annual planting rates unlikely to exceed 100,000 hectares, new plantings would be unlikely to make a significant contribution to national 2020 emission reduction targets, although their contribution could increase in subsequent decades.

Land use competition between the forestry and agriculture sectors

- Improved biophysical and economic spatial modelling can give better estimates of the trade-offs between food production and carbon sequestration following the introduction of market-based climate and forestry policy.
- Incorporating tree belts, woodlots and plantations into farming landscapes can improve water quality, increase biodiversity and carbon sequestration and provide shelter to livestock, while providing an additional income stream to farmers.
- Within farms, trees compete for resources with crops, but research has identified designs for efficient integration of tree plantings that minimise competition impacts while delivering co-benefits.

Introduction

The Australian forestry industry is nationally important, not only for the forest products it produces but because of the significant role of both native and planted forests in providing ecosystem services and influencing water and carbon cycles.

Innovation, through the application of scientific knowledge, has played and can continue to play a vital role in underpinning the productivity, profitability and sustainability of the forestry industry and improving the integration of forestry and agriculture. A recent analysis (Turner and Lambert 2009) indicates that total Australian investment in research to support the forestry and wood products industries, has remained constant in cost-adjusted terms over the course of the last decade, during a period of the rapid expansion of, and investment in, plantation forestry involving new species and new planting environments where the research base is limited.

Our submission focuses on scientific knowledge relevant to the forestry sector, and concentrates primarily on the forest plantation estate, currently about 2 million hectares (Mha) in area, which supplies an increasing proportion (already more than 70%) of the nation's forest products. Australia's 147Mha of natural forests continue to play a vital role in biodiversity protection and the maintenance of water and carbon cycles, and in wood production for some industry sectors. An understanding of this role, predicting changes in the future, and examining impacts of management (for example fire management) remain the focus of important scientific research.

This submission aligns with the Inquiry terms of reference, addresses most of the terms, reviews scientific knowledge relevant to each term, and highlights the opportunities where application of existing knowledge and the conduct of further research to address knowledge gaps can contribute.

Terms of Reference

Opportunities for and constraints upon production

Understanding constraints to the productivity of native forests and plantations in Australian environments has been a focus for CSIRO and its partners for more than 40 years. Most of this research has been undertaken in southern Australia where the majority of plantations are located. The softwood estates are dominated by one species, *Pinus radiata* and the hardwood estates by two species, *Eucalyptus globulus* and *E. nitens*. It is these three species that have been the focus for most research, although the subtropical pines planted primarily in SE Queensland are also relatively well studied.

In mature Australian plantation systems such as the temperate and sub-tropical pine plantations there is a well developed empirical understanding of growth potential across different site types, based on repeated measurements from one or more harvests across many site types (O'Hehir and Nambiar 2010). There is a shorter history of management for wood production in the eucalypt plantations, most of which have been established since the 1990s and are now approaching, or have recently delivered, their first harvest for pulpwood. Concerns have been raised about the sustainable management of this estate (Nambiar 2010).

Some analysis of productivity at the national scale has been carried out by CSIRO and others. In Tasmania, the Green Triangle and Western Australia, average hardwood plantation productivity equates to mean annual increments (MAI) in log volume of about 15 cubic metres per hectare (m^3 ha^{-1}). Substantially higher MAI (over 30 m^3 ha^{-1}) has been recorded on sites in these regions with abundant rainfall, high soil fertility and mild temperatures, while slower-growing plantations (less than 10 m^3 ha^{-1}) are not uncommon.

The most fruitful approach to understanding the limits to productivity is to research the response of fundamental growth processes (light interception and conversion efficiency) to environment and management. This effort commenced in earnest in the early 1980s and has resulted in the development of process-based models of plantation production (Battaglia *et al.* 2004). These models are being used in Australia and around the world to predict productivity in new environments, under changed management regimes or under future climates.

Water availability sets an upper limit to tree growth potential for most Australian plantations, with the exception of small areas of high-altitude sites in Tasmania, Victoria and NSW where low temperatures limit growth (White *et al*. 2009a). However, site index (the capacity of a particular site to support plantation growth) is not a fixed, unchanging value. It can be increased with careful management of soil and nutrient reserves and judicious fertilizer application and conversely it can deteriorate with poor management that results in soil erosion and decline in soil organic matter, nitrogen, phosphorus and other nutrient elements, and reduced soil water availability.

While genetically improved planting stock matched to the planting site produced by tree breeding (discussed below under value-adding), can deliver much greater wood volumes and more valuable harvests on a given site than can unimproved stock, tree breeding cannot overcome major declines in site quality. Genetic improvement and sustainable site management are best seen as complementary activities that together underpin plantation viability.

Sustaining productivity and managing risk across multiple plantation rotations is a key challenge. In the 1970s much of the radiata pine estate was faced with the widely-known second-rotation growth decline. Research by CSIRO and others led to an understanding of management for sustainable yields, resulting in changes to harvesting and replanting practices that reduced soil disturbance and increased levels of conservation of nutrients on site. Productivity decline in radiata pine was subsequently reversed, and average site index in the Green Triangle region of South East Southern Australia and South West Victoria, has now increased from that observed in the first rotation (O'Hehir and Nambiar 2010).

Research to address a similar decline in second-rotation blue gum plantations in Western Australia is currently under way (Mendham *et al*. 2008). It is likely that some practices adopted in the pine plantation sector to sustain site productivity, such as harvest residue retention to prevent nutrient loss, will also be best practice in the hardwood sector. CSIRO, in partnership with industry through the Cooperative Research Centre (CRC) for Forestry, is seeking to develop the tools, practices and understanding to sustain production through successive plantation rotations.

The potential for climate change to impact on productivity of plantations is unclear. Emerging data from the Hawkesbury Forest Experiment suggests that productivity gains from elevated carbon dioxide in plantation species may be slight, though some gains in increased water-use efficiency may be observed. Analyses using forest growth models carried out to date by CSIRO (Battaglia *et al.* 2010) suggest that under such a scenario production in some parts of Australia's plantation estate (such as the Hume region of NSW, the Green Triangle and south-west Western Australia), may be affected adversely by projected climate change. However, longer term responses of forest production to predicted climate change remain poorly understood and is an area requiring ongoing research.

Forest plantations are long-rotation crops, with a minimum of approximately 10 years for pulpwood and 25 years for high-value sawlog rotations, and most plantations will therefore be exposed to damaging events during the rotation. Building resilient forest plantations is an important part of sustaining productivity. Resilience refers to the ability to withstand and recover from the inevitable challenges of drought, pests, storm and fire. Resilience can be built through the germplasm (breeds of trees) and the plantation management methods used. For example, plantation management options such as wider tree spacing have been shown to reduce vulnerability of *E. globulus* plantations to drought damage, while avoiding major reductions in productivity (White *et al.* 2009b). Equally important are the institutional structures that promote forestry development and lead to wise investment and appropriate levels of management and technology inputs.

There may be perverse outcomes if forest plantation establishment and management are disconnected from longer term stewardship of sustainable yield. In this regard the recent expansion of plantation area has included establishment on land that is not well-suited to viable plantation forestry, as evidenced by recent write-offs and yield downgrades of substantial plantation areas in Queensland and Western Australia (Saunders 2010).

Many new plantations for wood production, carbon storage or bio-energy will likely be established in environments that differ from those of the existing plantation estate, and using different species. There are new challenges to understand and manage the relationships between production and risk in these new planting environments, where knowledge from the existing estates cannot be directly applied. This is evidenced by the relatively poor performance observed in recent hardwood plantation trials in subtropical environments, recently summarised by Lee *et al*. (2010).

Although production from native forests has declined as a proportion of the total Australian wood harvest, they remain an important source of timber for some sections of the Australian forestry industry. Current State Codes of Practice for native forest management provide a strong scientific basis for sustainable management which maintains forest values in perpetuity, and are supported by decades of research on the impacts of forest management on biodiversity, forest growth, forest soils and many other areas (Connell et al. 2001, Connell et al. 2004, Forest Practices Authority 2010). Native forest logs have wood properties that differ from those of plantation-grown logs, and native forests yield speciality logs from species that cannot be grown economically in plantations (Harwood 2010).

In summary, the performance and profitability of plantations can be improved through a combination of tree breeding and silvicultural management that aims to i) increase the water use efficiency of dry matter production, ii) increase the proportion of biomass directed to the harvest (usually the harvested log) and/or iii) improve the quality and value of the harvest, while maintaining the site quality. Using existing knowledge and conducting targeted research and development to achieve this improvement is a key challenge for the forest industry.

Opportunities for diversification, value adding and product innovation

CSIRO and other research agencies have carried out research to underpin breeding for the major plantation tree species in Australia. Starting with the undomesticated genetic resources of the wild species, tree breeding programs have produced improved varieties better suited to plantations, to supply wood and other products for the forest products industries. Australian pine plantations have benefited greatly from genetic improvement over the last 50 years, with harvestable log volumes estimated to have increased by up to 40% from the first two generations of breeding for radiata pine. The softwood industry now plants trees that combine fast growth with fine branching and improved wood properties, enabling higher product recovery and value from sawing. The estimated nation-wide net return on investment, from radiata pine breeding alone, exceeds $1 billion (Sullivan 1999, Agtrans 2008).

Eucalypt plantations grown for pulpwood similarly now benefit from breeds with increased wood density and pulp yield in addition to faster growth. Research on molecular genetics is now refining our understanding of genetic control of key value traits. CSIRO recently identified the first molecular markers for selecting eucalypts with higher pulp yield (Thumma *et al*. 2010). Application of this knowledge should improve the rates of genetic gain from breeding, particularly for wood quality traits such as wood stiffness and pulp yield which are expressed late in the life of the tree and are expensive to measure. Tree breeding will also focus on achieving improved matching of different breeds to particular site types to maximise plantation production, and improving the adaptability of trees to more marginal site conditions, which are predicted to increase in some regions with climate change.

Research undertaken over the last decade on sawn timber processing of plantation eucalypt logs has confirmed that pruning and thinning of plantations is required for the production of clearwood for high-value, knot-free appearance-grade boards and veneers from the two major temperate plantation eucalypts *E. globulus* and *E. nitens*. Research has supported the development of pruning and thinning schedules for sawlog regimes to meet these requirements, but pruning and thinning have only been applied to date to some 30,000 hectares of hardwood plantations, primarily in Tasmania (Beadle *et al*. 2008).

Processing research has shown that, because of the different sawing and drying characteristics of fast-grown plantation eucalypt sawlogs, existing sawmills optimised for native forest logs will struggle to profitably process plantation logs if they switch to the latter because of declining native-forest log availability (Washusen *et al*. 2009a). Substantial investment is required to modify sawing equipment and drying methods. Appropriately modified processing systems should be able to operate profitably while paying an acceptable log price to plantation growers (Washusen *et al*. 2009b). However, access to large volumes of plantation sawlogs is required to justify the investment in retrofitting existing systems or constructing new ones. Effective marketing of the new plantation-grown sawn products will be needed to ensure success.

There is a need for ongoing research to develop processing and product options that can profitably use (i) unpruned plantation eucalypt logs, and (ii) smaller volumes of pruned plantation sawlogs. One Australian company has developed commercial structural timber production from unpruned *Eucalyptus nitens* plantations. Veneered and engineered wood products may offer good prospects for product diversification. Using modern veneering equipment, smaller log diameters can be processed, at smaller scales of production than can be achieved for pulping and sawmilling of plantation eucalypts.

In 2010, CSIRO terminated most of its capability in wood processing and forest products research, primarily because of the industry's inability to contribute sufficient financial support to this research area. Other Australian research providers will continue to carry out research to support processing and product innovation, to the extent that research funding is available.

Environmental impacts of forestry, including:

Impacts of plantations upon land and water availability for agriculture; and

Plantations generally use more water, per unit land area, than grasslands and many agricultural crops. This difference in water use increases with increasing rainfall (Zhang *et al*. 2001). Consequently, large-scale land use change such as plantation development has been identified in the National Water Initiative as an intercepting activity that that would require inclusion in water sharing plans. Guidelines for the assessment of impact of plantation establishment have been developed (Gilfedder *et al*. 2010). However, a recent analysis (Polglase and Benyon 2009) of the impacts of plantations on water resources concluded that, at a national scale, the impacts of plantations on water security and availability had been over-emphasized. Plantations can have local, rather than regional, impacts on water resources and there may be specific areas of particular interest, such as in the lower limestone coast of South Australia.

Plantations can affect groundwater resources through direct groundwater use and reduced recharge to groundwater. In general, the interactions of plantations with groundwater are poorly quantified; however when plantations are established over highly transmissive, shallow aquifers with good water quality, rates of plantation water use can potentially be high. The spatial extent of this situation nationally is not well understood and the interactions of plantations with groundwater are rarely examined in detail; an exception is the lower limestone coast of South Australia (Benyon *et al*. 2006). Here, there is evidence that plantations accessing groundwater may use water more efficiently that is they produce more timber per unit of water than plantations without access to groundwater. This suggests that careful siting of plantations in the landscape can maximise timber production while minimising impacts on catchment water yield.

Plantations can also impact on salinity and have been suggested as an attractive tool to help manage salinity in land and rivers. Plantations established in salt source catchments such as those in the headwaters of major river systems, may have a net positive impact on freshwater supplies. This has been demonstrated in the Denmark catchment in South West Western Australia. In some such cases wood production from plantations as the sole financial return may not be attractive. In the Denmark, effort is being made to create incentives for ongoing plantation activity to avoid increased river salinity.

At the national scale, the potential impacts on water availability of the much larger areas of native forests, for example those located in the major urban catchments, are much more profound than are plantation impacts (Polglase and Benyon 2009). Risks include the direct impacts of changing climate, for example increased temperature and carbon dioxide levels which can affect the physiology of trees, and indirect impacts of fire which can change forest structure and alter water use. However, the importance of native forests seems to be not well recognised and should be a focus of further research.

The development of win-win outcomes in balancing environmental costs with economic opportunities.

Plantations may have benefits (provide 'ecosystem services') and trade-offs when established on agricultural land. There are two issues here:
(i) *quantifying* versus *valuing*, the benefits and trade-offs of plantation establishment, and (ii) *regional* versus *local* (*paddock-scale)* assessments. Quantification of impacts is often more readily achieved than is valuation, particularly at a regional scale. Many of the benefits, such as enhanced biodiversity, are externalised and as such do not have a market value. Further research is needed to better quantify impacts at paddock-scales on, for example, productivity of agricultural land and water run-off.

Creating a better business environment for forest industries, including:

Investment models for saw log production;

We have noted the importance of research that underpins the effective growing and processing of sawlogs into high-value products, both for conventional sawn timber and other products such as veneer-based products. More profitable processing will improve the prices payable for sawlogs and hence the attractiveness of sawlog plantations as an investment. Development of technology for local processing options such as veneering that can profitably process sawlogs from a small scale plantation resource would increase the viability of investment in sawlog plantations.

New business and investment models for plantation production; and

Use of the best available data and tools for prediction of plantation growth rates and impacts of plantations on regional water resources should be an integral part of future plantation investment planning.

Superannuation investment in plantations.

Nil response.

Social and economic benefits of forestry production

CSIRO is not currently conducting research in this area, which has been addressed by the CRC for Forestry (Schirmer *et al*. 2010).

Potential energy production from the forestry sector, including:

Biomass, biofuels and biochar;

Research by CSIRO Energy Transformed Flagship indicates that the use of biomass, and in particular forestry biomass, for stationary energy and biofuels production can contribute substantially to an Australian energy future with reduced greenhouse gas emissions (Farine *et al*. submitted).

Only a fraction of the total biomass produced by agricultural and forestry industries can be diverted to bioenergy and biofuels. Technical, environmental, policy and economic constraints restrict the quantities of biomass that are realistically available. For example, removal of leaves, bark and fine branches from the site during plantation harvest has been shown to compromise productivity of subsequent rotations because of the negative effects on soil organic matter and nutrients (Raison 2006). Current residue estimates are based on use of coarse woody harvest residues only, with bark, twigs and leaves left on site. Research to ensure the appropriate application of these constraints during planning will reduce the potential for conflict and adverse outcomes in the development of biomass and biofuel industries.

CSIRO has made detailed studies of biomass availability in several regions. Similar studies in other regions are needed to improve the precision of estimates at the national scale. In the Green Triangle region, small-scale (60 ML year^{-1}) ethanol factories making use of low-cost, locally-available lignocellulosic residues from timber processing may be close to break-even under current economic and policy settings. Taxation regimes for bio-ethanol production and petroleum fuels, and uncertainties associated with future petroleum prices, will strongly influence investment decisions (Rodruigez *et al.* 2011).

Significant potential exists for a bioenergy/biofuel industry based on trees grown in belts on farms in the lower rainfall, cereal cropping regions of southern Australia. Belts would occupy less than 10% of the farm and be designed to be integrated with conventional agriculture. Tree crops utilising native species well adapted to low rainfall (for example mallee eucalypts), could offer a mechanism for farmers to diversify their sources of income, improve environmental outcomes through better water and carbon balance, potential biodiversity benefits, and produce significant amounts of commercial energy. CSIRO, in partnership with the CRC for Future Farm Industries, is currently conducting research to demonstrate that such short rotation tree cropping systems can efficiently and sustainably deliver biomass, and ensure that site nutrient capital and productive potential is maintained or improved.

Forest residues such as sawmill residues are ideal sources for combined biochar and bioenergy production (CBBP) as they are pure (unprocessed and uncontaminated) materials that have a high carbon content. The methodology for CBBP can be achieved either through fast or slow pyrolysis with the latter being the preferred option for biochar production. While other bioenergy production processes such as Fischer-Tropsch, gasification and fermentation that are specialised for energy production alone, often require materials of a specific chemical composition or size. CBBP through pyrolysis is a process that is easily adaptable to various materials.

CSIRO is currently undertaking research into the potential application of biochar to agricultural soils. This research is addressing both the role of biochar in soil carbon sequestration and as an amendment to improve soil health. An important aspect of the work is assessing differences in the physical and chemical properties of biochar produced from different feedstock sources, including various types of wood based biomass, and how they behave in soil. A recent CSIRO review discusses the potential role of biochar in addressing climate change and discusses scenarios for the uptake of biochar for use in soil (Sohi *et al.* 2010). Understanding the characteristics of biochar is key in matching biochar products to their end-use. There is currently no information available as to the effects of biochar applied to forest soils. This is an important area that needs to be investigated as it would be of interest to avoid large transport distances for biochar made from plantation harvest residues and instead apply it close to its source and production.

Further work is required in following areas to better estimate the potential contribution of the forestry industry to biomass energy, biofuels and biochar:

- Identification of the most cost-effective methods of harvesting and transporting of various biomass feedstocks.
- The potential impact of biorefineries producing high-value petrochemical compounds in addition to energy.
- Further research on the physical and chemical properties of different biomass types, which determine feedstock quality.
- Characterisation of chemical, physical and biological properties of biochar products from different types of forestry residues that relate to their potential end uses.

Cogeneration; and

Nil response.

Carbon sequestration.

CSIRO has worked closely with the Commonwealth in helping to develop and test the forestry (and soil) component of National Carbon Accounting System (NCAS). The NCAS predicts the impacts of land use, management, natural disturbances and climate on net emissions of greenhouse gases (Raison and Squires, 2009). Further work is required to refine the NCAS for native forests which are likely to be included in future more comprehensive greenhouse gas accounting frameworks, and for new “carbon forests”. CSIRO has also made a considerable investment into better quantifying the potential for new forests to off-set greenhouse gas emissions in Australia. Some of the main points to emerge include:

- The extent to which land is available depends on a range of factors, including land value (or opportunity cost), establishment costs of the plantations, community attitudes, environmental considerations, opportunity costs of alternative use, rate of growth (carbon sequestration), any possible carbon pricing, and discount rate used in modelled scenarios and whether there are payment streams for environmental benefits such as biodiversity.
- Depending on the assumptions used in economic modelling, the area for financially viable new plantings may range from nil to tens of millions of hectares. However, the potential rate of planting is constrained by such factors as available supply of tree planting stock, labour, capital investment, acceptability of land use change and competition for land and water resources.
- If carbon plantings are to be used as partial off-set mechanisms, it is unlikely that more than about 100,000 hectares could be planted annually (this being equivalent to the maximum annual expansion rate achieved for commercial wood-producing plantations), and large-scale planting could not commence until infrastructure was developed in the planting regions: this would take several years. Trees planted would take some time to establish and store carbon at their maximum rates. New plantings would thus be unable to make a significant contribution to national 2020 emission reduction targets. Rather, over a period of some decades, incremental establishment of new plantings could derive some biodiversity benefit while making a contribution to emission reductions.
- As with the issue of forests and water impacts discussed above, there is a case for more focus on native forests, the very large amounts of carbon they currently store and keep out of the atmosphere, and the implications of changes in that store on national emissions. Australian native vegetation stores approximately 24 GtC in living biomass, with over 80% of this occurring in forests and woodlands. This is equivalent to over 150 years worth of Australia's current annual emissions (Department of Climate Change, 2010). Because of the large land area covered by native forest, even small relative changes in carbon stock (due to for example climate change impacts on tree growth, decomposition, or altered fire regimes) could lead to large absolute emissions (or sequestration) when aggregated over the whole continent. Our current ability to predict the direction and magnitude of these changes is limited, however new research by CSIRO has begun to address this gap through the development of analysis tools for integrating native forest carbon cycling, water cycling and fire dynamics (Roxburgh et al. 2010).

- **Land use competition between the forestry and agriculture sectors:**

Land is subject to competing demands from forestry, agriculture, urban development and other land uses. The trade-off from all conversion of agricultural land to forestry is the reduced capacity to produce food. Some work has been done on the land use competition between agricultural uses for food production and for bioenergy production for abating greenhouse gas emissions in Australia (Bryan *et al.*, 2010a, b).

Several authors have identified the potential for carbon and ecosystem service market policies to alter the relative profitability of alternative land uses and thereby motivate large scale land reforestation (Polglase *et al.*, 2008). On a large enough scale, this direct competition for a finite resource creates a tight link between carbon sequestration and agricultural commodities, and policies designed to mitigate climate change by promoting re-forestation can put upward pressure upon food prices (Wise *et al.*, 2009).

Improving the detail of biophysical and economic modelling, including the capture of spatial heterogeneity, can lead to better estimates of the trade-offs between food production and carbon sequestration following the introduction of market-based climate and forestry policy. Several studies have confirmed landscape-scale spatial heterogeneity in levels of carbon sequestration and agricultural production (Bryan *et al.* 2009), and land use profitability (Bryan *et al.* 2011).

Harmonising competing interests

Two main techniques have been used to quantify and map trade-offs between competing land uses at a landscape scale. Scenario analysis has been used to quantify spatially-explicit trade-offs between food production and greenhouse gas mitigation through bioenergy land uses, (Bryan *et al.*, 2010a, 2011), but only for a limited number of spatial and policy options. Other authors have found that by optimising the spatial distribution of land uses, they could improve a range of outcomes such as biodiversity, economic production, carbon sequestration and other ecosystem services across a spectrum of policy options (Higgins *et al*. 2008, Crossman *et al*. 2009). In this way, and in theory, co-benefits may be maximised and trade-offs may be minimised. It is yet to be demonstrated how policy can be designed to achieve these optimal outcomes when land use is controlled by multiple independent agencies in the landscape. No studies have assessed the food-carbon trade-offs of reforestation under alternative market-based policies on a landscape scale for informing policy.

Opportunities for farm forestry

Incorporating tree plantations into the farming landscape can improve water quality, increase biodiversity and carbon sequestration and provide shelter to livestock, while providing an additional income stream to farmers. As an example, the buffering effect of riparian plantations on grazing properties may improve water quality of streams and rivers in farming landscapes, while well managed harvesting of riparian trees need not adversely affect water quality (Neary *et al*. 2010).

Within paddocks, trees compete for resources with crops both on the planted area and in a ‘competition zone’ beyond the tree canopies. This competition has been much studied, and its implications for optimum ways to integrate tree plantings on farms are relatively well understood. For example, in South

West Western Australia, belts of trees and mallees are planted to provide wood/forest products and salinity mitigation in lower-rainfall zones (Ellis and Hatton 2005; Oliver *et al*. 2005).

Farm woodlots may displace crops, and the growth of tree roots into neighbouring fields can result in significant production losses outside of the tree block (Huth *et al.*, 2010). Case studies for a range of woodlot configurations in the subtropics have showed that there may be ways to plant trees that minimise crop losses (Huth 2010). This increase in efficiency can be used to increase the area planted to trees by up to a factor of eight for a given level of crop impact. Furthermore, this more extensive tree planting provides greater hydrologic, ecological and shelter benefits at no extra cost in terms of crop losses. Finally, this study also showed that efforts to increase one benefit will automatically provide increases in all other benefits in most situations. Such an outcome greatly simplifies decisions for farm managers.

CSIRO and others have invested in testing and domesticating tree species suited for farm forestry beyond the traditional plantation regions over the last 15 years, especially in the temperate wheat-sheep belt. Parallel work has been carried out to develop appropriate silviculture, and to match the species under development to different site types. Improved breeds of trees now exist that are suited to a diverse and geographically large area of farmland in southern Australia (Harwood *et al*. 2007).

Further biophysical research is needed to better define plantation growth obtainable with a range of species outside the traditional plantation regions of Australia. Establishment of planted forests in subtropical and tropical rangelands requires further research to underpin success. Rainfall in these zones is more variable than in southern Australia, both year-to-year and in its seasonal distribution, posing greater challenges for plantation establishment.

Some research is needed to better define the scale and design of farm forestry investment models, for example on the efficient operation of markets for co-payments for biodiversity and hydrological benefits which, together with returns on commercial wood production and carbon farming, could provide favourable financial returns.

Further information (online resources)

Forest and Wood Products Australia (FWPA) reports are available at:
http://fwpa.com.au/latestreports.aspx

CRC Forestry information can be found at:

http://www.crcforestry.com.au/

CRC Future Farm Industries can be found at:
http://www.futurefarmonline.com.au/

CSIRO information can be found at:

http://www.csiro.au

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