

Carbon balance calculations for forest industries – a review

Justin B. Ford-Robertson*

Abstract

Managed afforestation has been proposed as a method of reducing net carbon dioxide emissions. In light of this proposal, the article reviews the issues of carbon emissions and sequestration, and how these relate to afforestation. A number of different factors are considered, including carbon sequestration in forests, forest soils and forest products, avoidance of carbon emissions from fossil fuels through product substitution and the use of biomass for energy. A model is developed to identify important elements in the carbon balance of the plantation forest industry in New Zealand. The results show that carbon sequestration in forest biomass is a major contributor to the net carbon balance in New Zealand compared with carbon sequestration in forest products.

Introduction

The total New Zealand land area of 27 Mha includes 7.9 Mha of forest cover. Indigenous forest accounts for 6.4 Mha (24%) compared with a plantation forest estate of approximately 1.5 Mha (5%). The plantation forest area is increasing: areas of pasture and scrubland recently planted were estimated to be 61,600 ha in 1993 (Ministry of Forestry, 1995); 98,200 ha in 1994, and 70,900 ha in 1995 (Anon, 1996).

The young and expanding plantation forest estate in New Zealand is seen as an effective carbon sink (Maclaren and Wakeelin, 1991). Expansion of the total plantation forest area has been proposed as a method of reducing net CO₂ emissions in New Zealand (Ministry for the Environment, 1995). The majority of new planting is anticipated to be with exotic species, predominantly radiata pine. There is potential, however, to use indigenous species in plantations or even to allow natural regeneration of forests on abandoned farmland.

It is expected that processing industries will expand in response to the increased forest production. The total amount of energy used by the forest industry could therefore be expected to rise, and hence increase the total gross carbon emissions. This does not necessarily imply that the carbon emissions per unit of output will increase, nor that the increase in energy demand will be met primarily through the increased consumption of fossil fuels and electricity.

There have been few attempts to calculate a carbon balance of the forest industry in New Zealand. This paper will review some of the published overseas results as well as the work in New Zealand.

Carbon sequestration under different forestry options

The estimates of carbon sequestration for different species and rotation ages in New Zealand are given in Table 1. In each case the value represents the quantity of carbon in the forest stand in live trees (stems, branches, roots etc), understorey and forest floor. The carbon contained in the mineral soil horizons is not included. The values are relatively simple to calculate for commercial plantations, since models have been developed based on extensive empirical measurements.

* NZ Forest Research Institute, Private Bag 3020, Rotorua, New Zealand.

Table 1. Carbon sequestered for different species and rotation ages in New Zealand

	tC/ha	Reference
Plantations		
radiata pine (30 years)	231 ^{1,2}	Maclaren, 1995
Douglas fir (40 years)	262 ¹	Maclaren <i>et al.</i> , 1991
Natural stands		
mature kauri	507	J.W. Herbert <i>et al.</i> , unpublished
beech/podocarp	351	Beets, 1980
beech	424	P.W. Clinton <i>et al.</i> , unpublished
podocarp	425	Tate <i>et al.</i> , 1993

¹ Total carbon in the plantation at the rotation age indicated.

² Weighted average for all National Exotic Forest Description regimes.

The forest type with the highest carbon content at maturity is not necessarily the best choice for carbon sequestration management, since the amount of carbon stored is also dependent on the growth rate. Nabuurs and Mohren (1993) emphasised the importance of identifying the net annual carbon flux and the ability to retain carbon (in soil, litter, biomass and wood products) for each forest type, as well as the time period of interest. For example, the Caribbean pine forest described in Figure 1 had a relatively high net annual carbon flux over one rotation (rapid growth rate) but a relatively low total carbon content at the end of one rota-

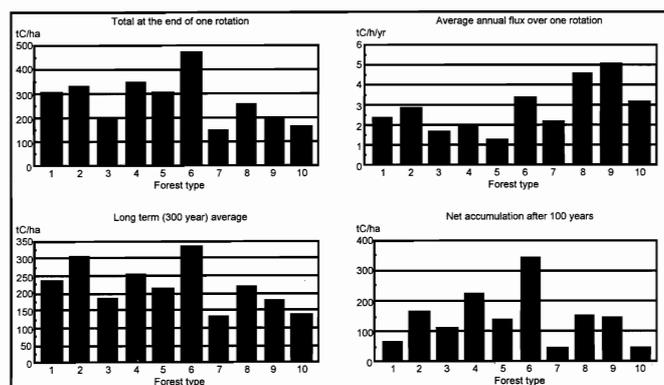


Figure 1. Carbon (t/ha) in forest and forest products under different forest management systems:

1. Heavily logged evergreen rainforest
2. Selectively logged evergreen rainforest
3. Afforestation of wasteland
4. Norway spruce in central Europe
5. Mixed deciduous in central Europe
6. Douglas-fir in northwest USA
7. Poplar on former agricultural land
8. Radiata pine in NZ and Australia*
9. Caribbean pine in Brazil & Venezuela
10. Loblolly pine in southeast USA

Source: Nabuurs and Mohren (1993).

* Values derived for an "average" regime on a 40 year rotation.

Bioenergy

A conventional forest industry produces considerable volumes of 'waste'. Much of this material could be viewed as an energy resource. In the forest, wood in the form of prunings, thinnings and harvesting waste is commonly either left in the forest to rot, or is burned to waste. Forest processing industries vary in their conversion ratios, but in some cases mill waste is utilised on site. The New Zealand forest industry as a whole consumed 52.5 PJ of energy in 1990, of which approximately 40% was generated internally, primarily through the use of black liquors from the pulp sector (15 PJ) and hog fuels (7 PJ) such as bark, reject chips and fines (Ministry of Commerce, 1992). All products will eventually reach the end of their useful life and some will be wasted. Royds Consulting Ltd (1994) suggests that a typical landfill in New Zealand contains approximately 37% paper and wood.

Wood and wood products can be utilised to produce energy (as heat, electricity, liquid fuels etc) via a number of conversion routes. Using biomass fuels for energy is not necessarily going to reduce fossil fuel consumption, particularly in less developed countries (Marland *et al.*, in press). However, in New Zealand it could be argued that biomass fuels would be used to avoid fossil fuel use. Marland *et al.* (in press) use a displacement factor of 0.6 for fossil fuels substitution, indicating that every 1 tC consumed in biomass fuels avoids the emission of 0.6 tC from fossil fuels. Schlamadinger and Marland (1995) recognised that increased efficiencies may be achieved in the future and that the displacement factor could rise to 1.

There are, of course, economic constraints to utilisation of all wood wastes, and there are also environmental ones. For example, the removal of harvesting residues from the forest, while facilitating replanting, can lead to a decline in site productivity (Smith, 1995). This might be ameliorated by the application of inorganic fertilisers, or by returning the biomass ash to the forest. The use of treated or painted forest products for energy would require caution to avoid pollution (Hustad *et al.*, 1995).

All the wood produced in forests could theoretically be used as an energy source. The merchantable stem volume produced by radiata pine at age 36 (maximum mean annual increment of a minimum tending regime) is reported to be 763 m³/ha (Neumann, 1992). Assuming plantations of radiata pine can be grown to produce 800 m³/ha of recoverable biomass with an average basic density of 400 kg/m³ (Cown *et al.*, 1991), and a net calorific value of 19.2GJ per oven-dry tonne (Miller and Young, 1993), the annual cut from a plantation estate of 2.5 million hectares could satisfy all the primary energy requirements met by fossil fuels in New Zealand in 1994. This forest area would also represent a long-term carbon reservoir of over 300 MtC. In comparison, a short rotation coppice cropping system producing 20 odt/ha/yr (Ministry of Commerce, 1993) would need to be planted on an area of 1.1 million hectares to replace the fossil energy requirements, and this would represent a reservoir containing 28 MtC. Maclaren (1995) has estimated that up to five million hectares may currently be available in New Zealand for afforestation. Use of part of this land for biomass fuel production would help to sequester carbon (in biomass) and reduce carbon emissions (fossil fuel substitution).

Carbon balance studies

Several carbon balance studies have been conducted overseas. Nabuurs (1994) classifies them into two main types of study: those focusing on the carbon storage potential of forests and forest products, and those which quantify the present and/or future situation from estimates of stocks and fluxes. The carbon sequestration in the New Zealand plantation estate is calculated annually (e.g. Maclaren *et al.*, 1994; Wakelin and Te Morenga, 1995), but a full organic carbon life-cycle assessment has not been conducted for the New Zealand forest industry.

Ford-Robertson (1996) integrated estimates of carbon sequestration in an average radiata pine stand (Maclaren *et al.*, 1993), estimates of the amount of carbon stored in wood products (Maclaren and Wakelin, 1991), and his own estimates of carbon emissions from the forest industry into a simple model used to identify major carbon sinks and sources in the New Zealand forest industry. It was assumed that all harvesting residues decayed instantly. Substitution (and hence avoided carbon emissions) of non-wood products or fossil fuels was not considered.

Emissions factors for electricity production can be updated using information from Ministry of Commerce (1996a and 1996b): in 1990, 3.8 Mt CO₂ were emitted to generate 114 PJ of electricity, which is equivalent to 9.1 kgC/GJ; this can be used as a lower emissions estimate. An upper estimate can be taken as the "ECNZ marginal emission factor (calculated based on the time that fossil fuel power stations operate at the margin)" which is 624 tCO₂/GWh (Ministry of Commerce, 1995) or 47.3 kgC/GJ. Electricity accounted for only 11.5 PJ of the 30.5 PJ total external energy used by the forest industry (Ministry of Commerce, 1992). The carbon emissions for the other fuels used can be taken from Baines (1993). Total emissions from the forest industry range from 344 to 783 GgC for the lower and higher electricity emissions factors respectively. Since 13.0 Mm³ was harvested in New Zealand in the year to March 1991 (Ministry of Forestry, 1993), the carbon emissions range from 26 to 60 kgC/m³. Assuming an average clearfell yield of 576 m³/ha (Ministry of Forestry, 1993) this would be equivalent to a range of emissions from 15 to 35 tC/ha.

If the model is modified to include decay rates for forest residues and the displacement factors of Marland *et al.* (in press), the effect of changing variables (such as pre-planting vegetation and emissions rates) on the carbon balance of the forest industry can be estimated. The impacts of two afforestation scenarios were examined in this way: Scenario 1 specified pasture planted with radiata pine. Soil carbon content was held constant, and fossil carbon emissions during harvesting, transport and processing were set at 19 tC/ha. Scenario 2 specifies scrubland cut and burned and then planted with radiata pine. Here carbon loss to the atmosphere during burning was set at 27 t/ha (L. Fogarty, pers. comm. ¹); soil carbon content was set at 0.1% of the amount of carbon in the vegetation; and carbon emissions during harvesting, transport and processing were set at 38 tC/ha. Table 2 shows the assumptions used in both of the afforestation scenarios. In each case energy is arbitrarily assumed to be derived from 50% of the short-lived products only, with all harvesting residues

Table 2. Assumptions in modelling the carbon balance of the forest industry

Rotation age	30 years		
Stand biomass (tC/ha)	1 st rotation	2 nd rotation	each subsequent rotation
- initial	0	114	116
- maximum	231	234	234
Initial vegetation	Carbon lost at planting tC/ha		
- pasture	0		
- scrub	27		
Products	proportion	longevity	product displacement factor*
- long-lived	2.2%	80 years	1
- medium-lived	20.5%	50 years	0.5
- short-lived	77.3%	1 year	0
Fossil fuel displacement factor*	0.6		
Emissions from energy use (tC/ha)			
- harvesting and transport	3.3		
- processing (low)	15.3		
- processing (high)	34.7		
Proportion used for energy %	(arbitrary values)		
- long-lived products	0		
- medium-lived products	0		
- short-lived products	50		

* After Marland *et al.* (In Press)

¹ L. Fogarty, Forest and Rural Fire Research, NZ FRI, Rotorua.

tion and a low long-term average. Forest systems with slower growth rates tend to have a higher carbon carrying capacity and may be used to yield large volumes of quality timber. If plantations are harvested on a regular rotation, the long-term average sequestration in the forest will be about one-half of the total carbon content of a stand at the age of harvest (Maclaren *et al.*, 1993). The long-term average carbon content of stands which are not harvested is likely to remain approximately constant once it reaches maturity.

Soil carbon

Tate *et al.* (1993) estimate that there is almost twice the quantity of carbon in New Zealand's soils (to 1m depth) as there is in vegetation, which indicates the importance of this carbon reservoir. However, it is the *change* in soil carbon over time (e.g. as land use changes) that is important for atmospheric carbon concentrations – is the soil a sink or source? This is difficult to ascertain, since carbon fluxes in and out of the soil are dependent on the nature of the decaying material, the physical soil environment and the abundance of decay organisms (Cannell, 1995). Soil carbon is often omitted from calculations of carbon sequestration in forests due to the great uncertainty.

Comparison of values for soil carbon content requires care, since estimates are not always based on the same assessment methods. Soil carbon is defined here as carbon contained in the small (<2 mm) fragments of organic matter which are incorporated in the mineral soil horizons. The fragments consist of decaying components of trees, understorey plants, and the organisms responsible for decay processes. In some studies the definition of soil carbon includes carbon contained in the litter/humus layers, and sometimes the live roots.

The international standard for estimating soil carbon is down to a depth of 1m (Tate, 1995). However, tree roots tend to extend to much greater depths, with roots of radiata pine found several metres below the ground (Madgwick, 1994). The majority of fine root turnover is reported to occur within the top 1m of soil, but when trees die or are harvested, the roots die and their carbon is released. Some of this carbon may be incorporated into the <2 mm soil fraction.

Tate (1995) has preliminary estimates of soil carbon levels for a central North Island site that was mostly cleared of native forest (by burning) in 1927, converted to pasture in 1955, and some of the pasture planted with radiata pine in 1976. Results suggest a steady decline in soil carbon since the native forest was cleared, but a small apparent increase in soil carbon (litter plus soil to 20 cm depth), recorded during the period since reforestation, was found to be statistically non-significant. Recent results for the same area (Ford-Robertson *et al.*, unpublished data) indicate that soil carbon levels (<2 mm fraction, excluding litter) are very variable across the site and at different depths. More intensive sampling work is therefore required to produce conclusive results.

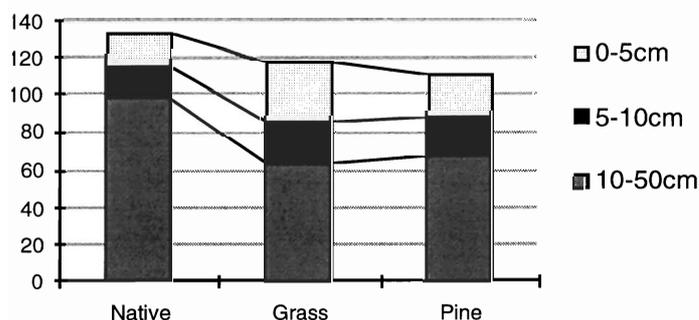


Figure 2. Mean soil carbon at a central North Island pumice site (Puruki) at different depths under three vegetation types

Results from the preliminary study (Figure 2) show that the mean quantity of carbon in the surface 5 cm is highest in the pasture ($p=0.001$), and that there is more carbon under native forest at 10-50 cm than the other vegetation types ($p=0.017$). This indicates that the total soil carbon to 50 cm is lower for pine than pasture. However, there is an accumulation of carbon in the soil profile lower than 50 cm when pasture is converted to pine.

It is also important to identify longer-term changes over successive rotations. In a study currently in progress sequential soil cores were taken from a 4m soil profile to compare the soil carbon content at different depths under pasture and a neighbouring pine plantation (now in its second-rotation) 69 years after the trees were planted. The samples are being analysed and results should be available in late 1996.

Carbon in forest products

Carbon in forest products is often cited as a substantial carbon pool (e.g. Karjalainen *et al.*, 1994). Wood products only constitute a sink if the total quantity of carbon in that pool increases, which will be affected by both the longevity of the products and by their turnover rate.

Cannell (1995) reports that equilibrium carbon storage is greatest when:

- stands accumulate biomass rapidly and for a long period before they are harvested;
- wood products have a long life; and
- forest litter decomposes slowly.

After harvesting at the end of the first rotation of an afforestation scheme, carbon is present in harvesting residues and wood products as well as the live biomass. If the products, litter and general detritus are decomposed to carbon dioxide rapidly (i.e. within one rotation), the equilibrium value of the system will be reached by the end of the second rotation. If the decay proceeds more slowly, it may be many rotations before equilibrium is achieved. This does not include any impacts of displacing other products, product recycling or using biomass for energy and thus avoiding fossil fuel emissions.

It is difficult to assess the longevity of wood products. Dewar and Cannell (1992) suggest that a reasonable assumption is that average product life is the same as the rotation age. Schladinger and Marland (1995) and Maclaren and Wakelin (1991) classify products into three classes, and estimate the proportion of products which fall into each. In both studies the carbon in the products with the shortest life is assumed to be released back into the atmosphere within one year. Several studies (e.g. Hollinger *et al.*, 1993) conclude that the wood products carbon pool is small compared to that in living biomass. However, Marland *et al.* (in press) suggest this is not necessarily true if carbon emissions are reduced through the substitution of wood products for items requiring higher energy consumption during manufacture. They propose the use of a 'displacement factor' when the carbon balance of products is under consideration. In the case of long-lived products for example, they allocated values between 0.5 and 1 to the displacement factor, which means that for every 1 tC in wood products, between 0.5 and 1 tC is not emitted. This implies a reduction in total carbon emissions that is equivalent to more than 50% of the carbon contained in the wood products themselves.

Karjalainen *et al.* (1994) include the fate of products once they have reached the assumed end of their useful life. This analysis suggests that 'used' products can be separated into three equal categories, destined to be recycled, burnt (some proportion of which will yield useful energy), or sent to the landfill. The latter category then assumes a decay rate of 0.5% per year. The study concluded that the carbon stored in the products is more sensitive to the landfill decay rate and burning than to product lifespan.

allowed to decay in the forest. Other products are assumed to decay steadily to carbon dioxide.

The effect of Scenario 1 on the carbon balance of forest industry activities is shown at the stand level in Figure 3 and at the forest² level in Figure 4. Figures 5 and 6 show the effect of Scenario 2 on the carbon balance of the forest industry activities at the stand and forest level respectively.

The legends in Figures 3 to 6 use terms which are explained below:

Energy	Carbon emissions avoided through use of forest biomass fuel for energy
Avoided	Carbon emissions avoided through manufacture of wood products rather than other materials
Products	Carbon sequestered in wood products (new products pool)
Stand	Carbon sequestered in the stand (including roots, litter and understorey)
Forest	Carbon sequestered in the forest (including roots, litter and understorey)
Soil	Carbon accumulated in mineral soil horizons (<2 mm fraction)
Net Value	Sum of all the above elements, minus the forest industry emissions from harvesting, transport, and processing.

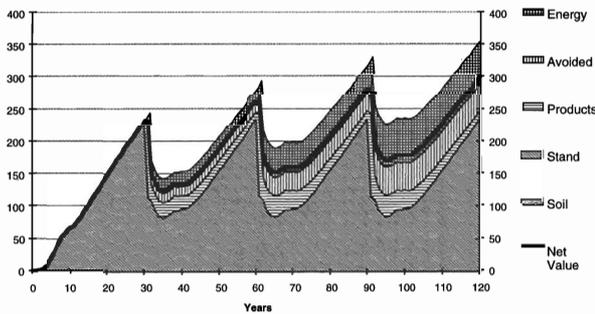


Figure 3. Carbon balance for a Scenario 1 forest **stand** and its wood products

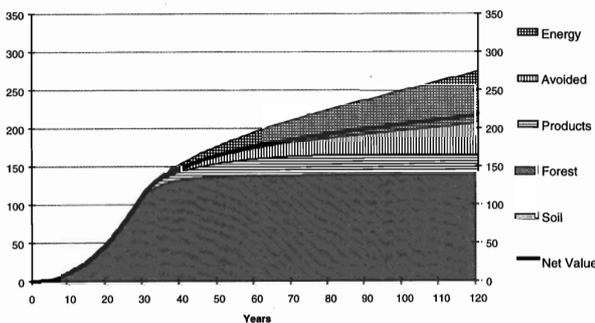


Figure 4. Carbon balance for a Scenario 1 **forest** and its wood products

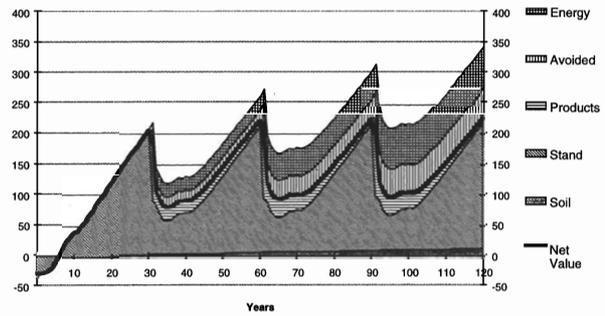


Figure 5. Carbon balance for a Scenario 2 forest **stand** and its wood products

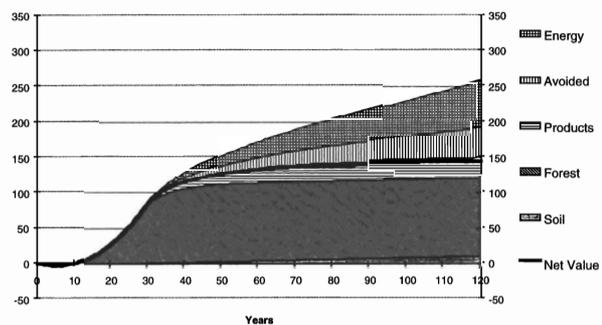


Figure 6. Carbon balance for a Scenario 2 **forest** and its wood products

Discussion and Conclusions

Figures 3-6 show clearly that, regardless of planting scenario, more carbon is stored in the forest than in wood products. Avoided emissions are also a significant contributor, but unless there is an increase in the use of bioenergy, high industry emissions will eventually erode the carbon benefit of afforestation. This demonstrates that although the forest is in equilibrium, the harvesting and processing emissions continue and, if all electricity is assumed to be generated at the marginal rate (high emissions), the emissions are greater than the sum of sequestration and avoidance.

The modelling approach outlined here gives an indication of the roles played by different aspects of the forest industry in influencing atmospheric carbon dioxide levels. More precise results could be gained if forest estate models were used in forest industry case studies incorporating specific combinations of forest data, downstream processing options and forest products.

There are numerous factors which will play a role in deciding which mix of production forests and conservation forests is selected in a particular region or country. Timber must be harvested to provide revenue for rural communities and to satisfy the growing global demands for wood (Sathaye *et al.*, 1995). The competition for fibre is likely to play an increasing role in determining the efficiency of conversion of trees to various wood products, and the availability of residues for energy.

There is also the question of time preference, i.e. is a tonne of carbon sequestered now better than a tonne sequestered 100 years from now? Can a tonne of carbon emitted this year be offset by a tonne of carbon sequestered 30 years from now? Not accounting for timing makes forestry options which are capable of retaining carbon in long-term carbon reservoirs appear most favourable (Fearnside, 1995). Perhaps traditional economic

² Equal areas established annually over a 30 year period.

methods (such as discounting) should be practised to assist in decision-making about timing of emissions and sequestration.

These and many other points will probably be argued repeatedly over the next few years. For the present it is clear that conversion of pasture or scrub to forest will result in an accumulation of carbon on site. Manufacture of wood products will increase the size of the forest industry carbon reservoir slightly, as long as the market for them expands. Emissions of carbon can be reduced by the use of biomass fuels to avoid direct fossil fuel use, and by the substitution of wood products for those which cause higher fossil fuel consumption in their manufacture.

Acknowledgements

Thanks are due to Piers Maclaren, Steve Wakelin and Wayne Hennessy for their helpful and constructive comments during the preparation of this paper. The assistance of Ruth Gadgil has been invaluable during the final editing.

References

- Anon. 1996. Small forest owners dominate plantings. NZ Forestry, February 1996, p11.
- Baines, J.T. (ed) 1993. New Zealand Energy Information Handbook. Taylor Baines and Associates, Christchurch.
- Beets, P.N. 1980. Amount and distribution of dry matter in a mature beech/podocarp community. NZ J.For.Sci. 10(2):395-418.
- Cannell, M.G.R. 1995. Forests and the global carbon cycle in the past, present and future. European Forest Research Institute, Research Report 2. 66pp.
- Cown, D.J., D.L. McConchie, and G.D. Young. 1991. Radiata pine wood properties survey. FRI Bulletin No. 50.
- Dewar, R.C. and M.G.R. Cannell. 1992. Carbon sequestration in the trees, products and soils of forest plantations: an analysis using UK examples. Tree Physiology 11:49-71.
- Fearnside, P.M. 1995. Global warming response options in Brazil's forest sector: comparison of project-level costs and benefits. Biomass and Bioenergy 8(5):309-322.
- Ford-Robertson, J.B. 1996. Estimating the net carbon balance of the plantation forest industry in New Zealand. Biomass and Bioenergy 9(1):7-10.
- Hollinger, D.Y., J.P. Maclaren, P.N. Beets, and J. Turland. 1993. Carbon sequestration by New Zealand's plantation forests. NZ J For. Sci. 23(2):194-208.
- Hustad, J.E., Ø. Skreiberg, and O.K. Sønju. 1995. Biomass combustion research and utilisation in IEA countries. Biomass and Bioenergy 9(1-5):235-255.
- Karjalainen, T., S. Kellomäki, and A. Pussinen. 1994. Role of wood-based products in absorbing atmospheric carbon. Silva Fennica 28(2):67-80.
- Maclaren, J.P. 1995. Plantation forestry - its role as a carbon sink: conclusions based on New Zealand's planted forest estate. In: M. Apps and D. Price (eds) The role of global forest ecosystems and forest resource management in the global carbon cycle. NATO ASI Series, Vol. XX. Springer-Verlag.
- Maclaren, J.P. and S.J. Wakelin. 1991. Forestry and Forest Products as a Carbon Sink in New Zealand. NZ For. Res. Inst., Rotorua, NZ. FRI Bulletin No. 162.
- Maclaren, J.P., G.P. Horgan, N.J. Ledgard, I. Nicholas, G.F. Pardy, and D. Whitehead. 1991. Carbon offset forestry. Scoping paper prepared for the Electricity Corporation of New Zealand.
- Maclaren, J.P., L. Te Morenga, and P.N. Beets. 1994. Carbon sequestration by plantation forests (Calculations revised as at April 1994). Ministries of Forestry, Commerce, the Environment, and Foreign Affairs and Trade, Wellington, NZ.
- Maclaren, J.P., S.J. Wakelin, and P.N. Beets. 1993. Projected carbon sequestration by forestry plantings commencing in 1991. Ministry for the Environment, Wellington, NZ.
- Madgwick, H.A.I. 1994. *Pinus radiata* - Biomass, Form and Growth. Madgwick (Publ.), Rotorua, New Zealand.
- Marland, G., B. Schlamadinger, and P. Leiby. In Press. Forest/biomass based mitigation strategies: does the timing of carbon reductions matter? Environmental and Resource Economics.
- Miller, W.R. and G.D. Young. 1993. Wood properties of firewood. In:

R.G. Shula, A.E. Hay and G.L. Tarlton (eds) The Firewood Venture. NZ FRI Bulletin No. 137.

- Ministry for the Environment. 1995. Climate Change - the New Zealand Response. New Zealand's first national communication under the Framework Convention on Climate Change. Ministry for the Environment, Wellington, NZ.
- Ministry of Commerce. 1992. An Energy Baseline Forecast to 2020: Supply and Demand Interactions in New Zealand's Energy Markets. Ministry of Commerce, Wellington, NZ.
- Ministry of Commerce. 1993. Renewable Energy Opportunities for New Zealand. Ministry of Commerce, Wellington, NZ.
- Ministry of Commerce. 1995. Technical guidelines for establishing and reporting voluntary agreements to reduce carbon dioxide emissions in New Zealand. Second Issue, Feb 1995. Ministry of Commerce, Wellington, NZ.
- Ministry of Commerce. 1996a. Energy Greenhouse Gas Emissions. May 1996. Ministry of Commerce, Wellington, NZ.
- Ministry of Commerce. 1996b. Energy Data File. July 96. Ministry of Commerce, Wellington, NZ.
- Ministry of Forestry. 1993. A National Exotic Forest Description (as at April 1, 1992). Ministry of Forestry, Wellington, NZ.
- Ministry of Forestry. 1995. A National Exotic Forest Description (as at April 1, 1994). Ministry of Forestry, Wellington, NZ.
- Nabuurs, G.J. 1994. State-of-the-art in the field of forest sector carbon balance studies (with reference to the European situation). European Forest Institute, Working Paper No. 2. EFI, Joensuu, Finland.
- Nabuurs, G.J. and G.M.J. Mohren. 1993. Carbon fixation through forestation activities. Study for the FACE (Forests Absorbing Carbon dioxide Emissions) Foundation. Institute for Forestry and Nature Research, Wageningen, Netherlands.
- Neumann, A. 1992. A national exotic forest description - yield tables as at April 1, 1991. Ministry of Forestry, Wellington.
- Royds Consulting Ltd. 1994. Estimate of methane production from NZ landfills. Report for Ministry of the Environment, Wellington.
- Sathaye, J., W. Makundi, and K. Andrasko. 1995. A comprehensive mitigation assessment process (COMAP) for the evaluation of forestry mitigation options. Biomass and Bioenergy 8(5): 345-356.
- Schlamadinger, B. and G. Marland. 1995. Carbon implications of forest management strategies. In: M. Apps and D. Price (eds) The role of global forest ecosystems and forest resource management in the global carbon cycle. NATO ASI Series, Vol. XX. Springer-Verlag.
- Smith, C.T. 1995. Environmental consequences of intensive harvesting. Biomass and Bioenergy 9(1-5):161-179.
- Tate, K. 1995. Soil carbon uptake. In: R.E.H. Sims (ed) Trees as carbon sinks. Proc. workshop at Massey University, May 1995. Dept Agricultural Engineering, Massey University, Palmerston North, NZ.
- Tate, K., D.J. Giltrap, J.J. Claydon, P.F. Newsome, I.A.E. Atkinson, and R. Lee. 1993. Estimation of carbon stored in New Zealand's terrestrial ecosystems. Manaaki Whenua - Landcare Research NZ. ISBN 0-478-04516-6.
- Wakelin, S.J. and L. Te Morenga. 1995. Carbon sequestration by plantation forests (Calculations revised as at June 1995). Contract report for Ministries of Forestry and the Environment, Wellington, NZ.

Continuing professional development opportunities

- | | |
|---------------------|---|
| May 29, 1997 | FIEA Conference "Pruned Radiata - Is the Future Clear?" in Dunedin |
| May 30, 1997 | NZIF field day to CHH Ashley Forest and MDF mill organised by Canterbury section. Contact Hugh Stevenson (03) 318-8311. |
| August 28, 1997 | NZIF seminar on GIS in Forestry organised by Canterbury section. Contact Owen Springford (03) 348-4933. |
| October 25-26, 1997 | NZIF field trip to the West Coast organised by Canterbury section. Contact Peter Allen (03) 332-3251. |

To add conferences, meetings and local NZIF section events which are relevant to CPD to this list, contact the Editor. The journal is published quarterly, so plan accordingly.