

4. Regeneration of Eucalypts

Issues and relevance to ESFM

Extraction of fuelwood will lower the available fuel loads (especially the larger fuel components) and consequently will reduce fire intensity and residence time. This has consequences for nutrient loss in smoke from fuels and the surface organic layers of the soil, preparation of new seedbed and eucalypt regeneration, and impacts on understorey vegetation regenerating from rootstocks. The most important for ESFM would be any significant reduction in regeneration and early growth of eucalypt and understorey species.

State of knowledge

The dependence of the wet eucalypt forests on fire for regeneration in nature has been emphasized by Ashton and Attiwill (1994): 'It seems paradoxical that the forests which produce vast amounts of fuel and generate the most fires, consist of fire-sensitive species. That they need to be burned down at some time in their seed-bearing life (if they are to be perpetuated) is axiomatic'.

Following pioneering ecological and silvicultural studies in Victorian and Tasmanian wet eucalypt forests, clear-felling followed by high-intensity burning of the logging residues and broadcast sowing of seed has been extensively and successfully used to achieve regeneration after logging (reviews by Campbell 1997; Attiwill 1994).

High intensity slash burns remove much (40-95 t/ha) of the fine fuels and a significant amount of larger fuels (Slijepcevic 2001). This significantly lowers subsequent fire risk, and results in successful regeneration of eucalypts (confirmed by regeneration surveys).

Low intensity burns can be achieved operationally but are less reliable and require more personnel to conduct them (Marsden-Smedley and Slijepcevic 2001). They also create less ashbed and lower levels of eucalypt regeneration (unpublished findings from WARA LTER studies). Future fire risk is higher, although there may be lower quantities of *Gahnia* after low-intensity fire. *Gahnia* also competes strongly with regenerated eucalypts and other understorey plants.

In wet eucalypt forest, adequate eucalypt regeneration has been obtained with low-intensity burns or with mechanical clearing (Raison 1981; Hickey et al. 2001; King et al. 1993 for *E. regnans*; Lockett 1998 for Tasmanian wet forests). However, reliability of regeneration is likely to be reduced. Harvesting of larger biomass components (e.g. logs or branches > 20 cm small end diameter) for energy will create some additional seedbed by mechanical disturbance of the soil.

There is very little operational experience in wet eucalypt forests of the adequacy of regeneration following low-intensity fire, mechanical site preparation, or biofuel harvesting. Sufficient fine (<25 mm diameter) fuel and other 'available' fuel could be retained after biofuels harvesting to enable a moderate intensity burn to be conducted (Slijepcevic 2001). This requires that very 'complete' harvesting of biofuels not be conducted on coupes that are to be regenerated to native forest, but such harvest could be applied on areas to be converted to plantation. Such a

moderate intensity burn is likely to ensure adequate eucalypt regeneration but this needs to be confirmed by monitoring in the field.

Nutrient conservation is greater with low-intensity fire (Raison et al. 1993), but initial rates of growth of eucalypt regeneration are less due to less ash-bed effect (e.g. King et al. 1993). Slow early growth can contribute to increased seedling loss from frost, disease and browsing.

Current approach and its adequacy for ESFM

The Forest Practices Code refers to appropriate silvicultural prescriptions (manuals), specifies stocking standards for eucalypt regeneration, and requires that a regeneration survey be conducted 12 months after harvesting. Reference is made to Forestry Tasmania Technical Bulletins No. 6 (Regeneration surveys and stocking standards) and No. 12 (Monitoring and protecting eucalypt regeneration). Regeneration success at the coupe level is recorded in the coupe history database. Regeneration is assessed as part of Forestry Tasmania's Quality Standards System and EMS. It is reported annually by FT.

Audits of compliance with the Code cover regeneration. The audit is based on whether the necessary work has been done to suggest that regeneration will succeed. Where remedial action is required, the success of this is also determined and reported. Systematic surveys of the success of regeneration date back to the mid-1960s.

The adequacy of regeneration of understorey species (including N-fixing species which will be critical for replacement of large quantities of N lost in slash burns) is not routinely assessed and reported. However, research (Hickey, 1994) has shown all but a few late successional plant species return within a 100-year forest rotation.

Options for addressing perceived weaknesses

The success of regeneration during the earlier period of very heavy pulpwood removals (early to mid-1980s) could be assessed to help build confidence that good regeneration could also be obtained following the proposed harvest of biofuels. This assumes that biofuel harvests and the earlier intensive pulpwood harvest would have similar impacts on regeneration. Soil physical damage is likely to be much less under contemporary harvesting and this should favour more successful regeneration of eucalypts.

Detailed monitoring of regeneration success should be conducted on all coupes subjected to biofuel harvest. This will enable harvest/regeneration practices to be adapted if required in the early phase of the new operations.

Summary and Recommendations

Harvest of fuelwood has the potential to create two sets of conditions that may prevent the successful regeneration and early growth of eucalypts: greater soil physical damage as a result of increased harvesting traffic, and lower fire intensities because of fuel removal. There is no field experience against which to judge the possible consequence of these.

Recommendation 4. *Regeneration success on areas subjected to very high pulpwood removals in the 1980s be reviewed and used as a guide to the possible effects of proposed harvest of fuelwood on regeneration. Further, regeneration success be carefully monitored on areas subjected to harvest of fuelwood, especially those areas where harvest is most intensive, so that measures can be quickly taken to remedy any problems that may arise.*

References

- Ashton, D.H. and P.M. Attiwill (1994). Tall open-forests *In Australian Vegetation*. (Ed. R.H. Groves) Second Edn. pp. 157-196. Cambridge Univ. Press, Cambridge.
- Attiwill, P.M. (1994). Ecological disturbance and the conservative management of eucalypt forests in Australia. *For. Ecol. Manag.* 63, 301-346.
- Campbell, R. (1997). Evaluation and development of sustainable silvicultural systems for multiple purpose management of mountain ash forests. VSP Tech. Report No. 29. Dept. Nat. Resources and Environ., Victoria.
- Hickey, J.E. (1994). A floristic comparison of vascular species in Tasmanian old growth forest with regeneration resulting from logging and wildfire. *Aust. J. Bot.* 42, 383-404.
- Hickey, J.E., Neyland, M.G. and O.D. Bassett (2001). Rationale and design for the Warra silvicultural systems trial in wet *Eucalyptus obliqua* forests in Tasmania. *Tasforests* 13, 155-182.
- King, M., Rab, M.A. and T. Baker (1993). The regeneration of *Eucalyptus regnans* under alternative silvicultural systems. 5. Effects of seedbed on seedling growth. VSP Intern. Rep. No. 24. Dept. Conserv. Nat. Res., Victoria.
- Lockett, E.J. (1999). Slash burning – its implications for 20-year height growth of eucalypt regeneration in Tasmania. *Aust. For.* 61, 159-162.
- Marsden – Smedley, J.B. and A. Slijepcevic (2001). Fuel characteristics and low intensity burning in *Eucalyptus obliqua* wet forest at the Warra LTER site. *Tasforests* 13, 261-279.
- Raison, R.J. (1981). More on the effects of intense fires on the long-term productivity of forest sites : Reply to comments. *Search* 12, 10-14.
- Raison, R.J., Keith, H., Khanna, P.K. and A.M. O'Connell (1993). Effects of repeated fires on nitrogen and phosphorus budgets and cycling processes in forest ecosystems. In 'Fire in Mediterranean Ecosystems'. (Ed. L. Trabaud and R. Prodon). Rep. No. 5 Ecosystem Research Report Series, Commission of the European Communities, Brussels.
- Slijepcevic, A. (2001). Loss of carbon during controlled regeneration burns in *Eucalyptus obliqua* forest. *Tasforests* 13, 281-290.

5. Nutrient cycling and forest growth

The issue, and why it is important for sustainable forest management

Organic matter in forest soils (SOM) is fundamentally important in maintaining soil fertility. More than 95% of total nitrogen and more than 50% of total phosphorus in surface soils of forests is in organic combinations. SOM accounts for a major part of cation exchange capacity in surface soils, and plays a key role in maintaining soil structure.

When a forest is harvested, the surface soil is disturbed to a greater or lesser extent depending on harvesting procedures. Nutrients are removed from the site in the harvested wood. The bared soil becomes wetter and warmer. Leaching of some nutrients from the surface layers (and possibly to drainage waters – e.g. the loss of N as nitrate-N) increases. The rate of respiration by soil micro-organisms increases, with a consequent decrease in the soil organic matter. A regeneration burn oxidizes much of the logging slash and litter, and some nutrients (particularly N) are lost from the system by volatilisation and the convection of particulate matter. Where the regeneration burn is most intense, organic matter within the surface centimetre or more of soil is also oxidized.

The state of knowledge

Timber harvesting and nutrient removals

There are many studies of the nutrient content of forests around the world (e.g. Cole and Rapp 1981; Federer *et al.* 1989) and in Australia (some of which are reviewed by O'Connell 1996 and Attiwill *et al.* 1996). Many of these studies have been directed toward an assessment of one of the questions that is fundamental to forest management for sustained timber yield: Can we predict the effects of nutrient removal on long-term, sustained productivity of forest ecosystems? In summary (from Attiwill *et al.* 1996) we know that, for a typical wetter forest of south-eastern Australia:

- Leaves account for 1-2% of the total biomass of the trees above-ground, but for 20% of the N and P contents;
- Stembark accounts for 10% of the total mass of the trees above-ground, but for 25-40% of the N, P and Mg and up to 60% of the K and Ca contents;
- Stemwood is nutrient-poor relative to other components of the tree; stemwood accounts for almost 80% of tree biomass but contains 10-20% of the K, Ca and Mg and 30-40% of the N and P content;
- The subordinate vegetation (understorey, shrubs and ground-layer) is nutrient-rich relative to the overstorey. Although the subordinate vegetation accounts for <5% of above-ground mass, it accounts for 10% of N and Ca and 14% of the P content;
- The litter layer is also relatively nutrient-rich (except for potassium). The forest floor accounts for 6% of above-ground mass, but accounts for 14-16% of the P, Ca and Mg, and for 24% of the N.

We know of no Australian data for the mass and nutrient content of coarse woody debris (CWD) in the wet forests of south-eastern Australia.

Calculations of nutrient removals

Mass data (oven-dry weight) for mature, mixed-age and regrowth forests in Tasmania were provided by Forestry Tasmania (Table 1b). These data give merchantable and non-merchantable mass, dead standing mass, understorey mass and mass of 'downers'. The merchantable + non-merchantable mass (assumed here to be measured under-bark) was the basis for estimating other components of the stand using mass and nutrient content of a 100-year-old stand at Retreat, Tasmania (Attiwill and Adams 1988), and including mass of litter layers from Attiwill and Weston (2001).

Grove *et al.* (2002) provide estimates of the areas to be harvested for sawlogs and pulpwood (current practice of clearfall burn and sow, CBS) and for energy-wood over the 35-year life-span of the proposed power station. On average, 43% of the CBS area will be harvested for energy-wood. However, this average requires further comment; over the first 24 years, 37% of the CBS area will be harvested for energy-wood, but in years 25-35, 84% of the CBS area will be harvested for energy-wood (Figure 1). This large increase in the intensity of energy-wood harvesting in native forest in the later years is due to the fact there will be a marked decrease in the CBS area as plantations come on stream to supply significant quantities of wood for pulp, other fibre and fuelwood.

Required energy-wood removal (from Southwood Catchment Residue Assessment) to meet the requirements of the proposed power station is 375,000 green tonnes per year, 10,000t/year of which is expected to come from sawmill residues. Suppose dry weight = 0.42*green weight. Then dry weight required from harvested energy-wood = 0.42*365,000 = 153,300 t/year. Over the first 35 years (from data used by Grove *et al.* (2002), 26, 979 ha will be harvested, so that the average harvest of energy-wood will be (153,000 t year⁻¹ *25year)/26979 ha = 198 t ha⁻¹. However, the area harvested each year varies greatly from 1554 ha in 2005 to 321 ha in 2034, giving the range of proportions of CBS areas that must be harvested for energy-wood shown in Figure 1. Energy-wood removal calculated on an annual basis is 237 t ha⁻¹, and this was used in calculating average nutrient removal. Calculation in this way is therefore conservative in that it is biased toward maximum (rather than mean) rates of removal

Summarized outputs from the spreadsheets are given in Table 2.

Table 2 Summary table for biomass and nutrient content of mature, mixed and regrowth forests in southern Tasmania.

MATURE FOREST	Mass (t ha ⁻¹)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Ca (kg ha ⁻¹)	Mg (kg ha ⁻¹)
Total in stand	822	1089	63	541	854	203
Losses						
Sawlog + pulp	255	148	7	37	35	15
Sawlog + pulp + energy-wood	492	260	12	64	67	28
Sawlog + pulp + energy-wood + energy-wood bark	514	317	17	147	182	45
Regeneration burn		401-592				

MULTI-AGED FOREST	Mass (t ha ⁻¹)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Ca (kg ha ⁻¹)	Mg (kg ha ⁻¹)
Total in stand	713	941	54	462	722	171
Losses						
Sawlog + pulp	243	141	7	35	33	15
Sawlog + pulp + energy-wood	480	245	11	60	65	27
Sawlog + pulp + energy-wood + energy-wood bark	498	291	15	127	157	40
Regeneration burn	334-499					

REGROWTH FOREST	Mass (t ha ⁻¹)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Ca (kg ha ⁻¹)	Mg (kg ha ⁻¹)
Total in stand	614	781	45	382	601	143
Losses						
Sawlog + pulp	216	125	6	31	30	13
Sawlog + pulp + energy-wood	440	221	10	54	60	25
Sawlog + pulp + energy-wood + energy-wood bark	455	260	13	110	137	36
Regeneration burn	276-413					

Figure 1. Proportion of the proposed area of sawlog and pulp harvest (CBS silviculture) to be harvested for energy-wood. The marked increase after 25 years is due to hardwood plantations becoming available as sources of energy-wood.

The calculated quantities of potential energy-wood (Table 3) exclude residual downers, and they are all less (but most probably not significantly) than the quantities assessed by Mannes (2002).

Table 3 Estimates of the quantity of fuelwood in forest types of the southern catchment

Forest type	Calculated potential energy-wood (t ha ⁻¹) ¹	Residual downers (t ha ⁻¹) ²	Assessed fuelwood (t ha ⁻¹) ³
Mature	322	51	372
Multi-aged	269	41	330
Regrowth	224	41	244

¹Calculated in this report, and excluding residual downers

²From Forestry Tasmania's 'best estimates'

³From conversion factors for the southern catchments (Mannes 2002); the conversion factors are based on assessments, and give residual wood as a multiplier of total merchantable volume (sawlog + pulpwood).

On average, 237 t ha⁻¹ over 771 hectares per year is required to supply the power station. This average can be met from mature and multi-aged forest, but cannot be met from regrowth forest alone (Table 3). Energy-wood harvesting will remove on average 64% of total available energy-wood in mature forests and 72% of total available energy-wood in multi-aged forests. We do not have the relative areas of mature, mixed and regrowth forest to be harvested, and so the analysis cannot be taken further.

Discussion of nutrient removals

Harvesting for energy-wood will on average, double the removal of wood (and therefore double the nutrient removal) compared with CBS. (Table 4). If energy-wood is taken unbarked, the removals of K, Ca and Mg will be increased significantly (up to 5 times for Ca, Table 4). The current practice of leaving bark on site in the forests of the southern catchment will not change with energy-wood harvesting; nevertheless, these data (Table 4) illustrate the magnitude of redistribution of the nutrient content of bark to centralized log landings.

Table 4. Increases in mass and nutrient removal due to energy-wood harvesting relative to mass and nutrient removal by sawlog and pulp removal (CBS).

Forest type	Increase in removal (CBS + energy-wood)/(CBS)					
	Mass	N	P	K	Ca	Mg
Mature						
<i>Wood only</i>	1.9	1.8	1.7	1.7	1.9	1.8
<i>Wood + bark from energy-wood</i>	2.0	2.1	2.4	4.0	5.2	2.9
Multi-aged						
<i>Wood only</i>	2.0	1.7	1.7	1.7	2.0	1.9
<i>Wood + bark from energy-wood</i>	2.0	2.1	2.2	3.6	4.7	2.8
Regrowth						
<i>Wood only</i>	2.0	1.8	1.7	1.7	2.0	1.9
<i>Wood + bark from energy-wood</i>	2.1	2.1	2.2	3.5	4.6	2.8

The loss of N in regeneration burning

Much of the N in organic matter is lost when the organic matter is burned, and this loss is of concern to sustainable management of forests (Raison 1979;1980;1981). Estimated losses by regeneration burning for Southland forests (median figures, Table 2) are of the order of 350 kg ha⁻¹ (regrowth forest) to 500 kg ha⁻¹ (mature forest). These estimates are similar to those for 100-year-old forest elsewhere (Attiwill and Leeper 1987).

Will increases in nutrient losses of these magnitudes lead to a decrease in soil fertility such that forest growth is adversely affected?

In fact, we know of no definitive and quantitative evidence to support the hypothesis that the loss of nutrients associated with timber removal (in Australia and in the rest of the world) cause a loss of productivity. That is primarily because concentrations of nutrients in wood are small relative to those in other parts of a tree; harvesting the wood (and leaving the bark) therefore removes a relatively small nutrient store.

These conclusions assume that the bark is left on site. If the bark is removed, the amounts of nutrients removed increase from 1.7 times for N up to 5 times for Ca (Table 4). In the gum-barked eucalypts (sub-genus *Symphyomyrtus*) the concentration of Ca in bark is so high that it has been speculated that Ca (and perhaps B) are the elements at greatest risk in managed, native eucalypt forests (Hopmans *et al* 1993; Attiwill and Weston 2001) and in eucalypt plantations (Turner and Lambert 1996).

The concentration of Ca in eucalypts such as *E. obliqua* and *E. regnans* (in the sub-genus *Monocalyptus* and the dominants of the wetter forests of the Southwood catchment) are low enough to cause little concern where the bark is left on site, as will continue to be the practice in forest operations in Tasmania's south-east. However, the bark is piled in dumps near log-landings. Most of this bark is subsequently burned, so that the nutrient return is highly localized. Is there a better way to manage this problem?

Can the losses of nutrients in timber harvesting be replaced?

N will be replaced in nature by biological N₂-fixation; if we assume a rotation of 90 years, then the rate of N₂-fixation required to replace 260 kg N ha⁻¹ in harvesting (including energy-wood) the mature plus 500 kg ha⁻¹ lost in the regeneration burn is 8.4 kg ha⁻¹ year⁻¹. This is a moderate rate given that rates of N₂-fixation as high as 30 kg ha⁻¹ year⁻¹ have been measured over the first 5 years of a regenerating, wet forest in Victoria (Adams and Attiwill 1984a; 1984b). However, it is essential to have a dense stand of wattle regenerated after harvest; and it is likely that N fixation rates decline rapidly as eucalypts begin to suppress the leguminous understorey. The question of replacing P-losses is more difficult; we cannot provide an analytical answer to the rate at which P is made available from less available to more available sources through chemical equilibria and through the weathering of parent rock.

Will the removal of energy-wood exacerbate a decrease in soil organic matter?

There have been estimates of the total amount of carbon stored in forests in Victoria (Grierson *et al.*, 1992) and the effects of forest management and utilization on net carbon storage (Grierson *et al.*, 1993). After harvesting, carbon storage in the forest initially decreases due to oxidation of carbon in residues from the harvesting and in soil organic matter. Carbon is also rapidly lost from timber taken off-site in the manufacturing of forest products (e.g. in kiln wastes) and in the oxidation of short-lived forest products (e.g. paper). We are considering here only the decrease in soil organic matter. This decrease is relatively short-lived, and is unlikely to be significantly affected by the removal of energy-wood in addition to the current harvest.

Options

The management of organic matter has emerged as a critical issue in the management of many forests and plantations. The following options are worth considering further to ensure that processes of nutrient cycling and growth are maintained following harvesting:

- Ensure that successful regeneration is achieved as soon as possible after harvesting (minimize loss of nutrients by leaching; re-establishment of nutrient cycling; replenishment of soil organic matter through litter input).
- Review the regeneration of N₂-fixing species. We can probably assume that acacias regenerate in profusion after regeneration burning in most of the wetter forests of south-eastern Tasmania. The review should consider appropriate actions for those forests where wattles are scarce.
- Aim for minimum disturbance of top-soil (top-soil has the greatest concentration of nutrients and of soil organic matter: ensure that regeneration is established in the most fertile soil; minimize the inevitable increase in rate of soil respiration).
- An aim in many forests is to conserve organic matter in logging debris after harvesting. This is impractical for the wetter eucalypt forests that regenerate best

and grow fastest after the slash has been burned. It is only through the early establishment of regeneration and subsequent rapid growth that ecosystem processes will be restored.

- The concept of leaving patches within coupes in which there is no disturbance from felling and extraction would allow some standing dead trees and some coarse woody debris to be retained *in situ*, thereby contributing to the overall retention of soil organic matter. On-going research at the Warra LTER site will provide an assessment of the value of leaving undisturbed areas.
- The return of wood ash, produced by a number of forest industries, is increasingly practised in Europe. For example, about 200,000 tonnes of wood ash is produced annually by forest industries in Finland. The application of wood ash to forests has a direct fertilizing effect, and it increases the rate of decomposition of organic matter and of nutrient mineralization. Forestry Tasmania (2002) plans to collect the ash 'for possible composting or for off-site re-use or disposal'. The return of ash to coupes would be appropriate, and the costs of handling and spreading ash should be investigated.

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Recommendations

Soil fertility and soil organic matter

More intensive harvesting, involving increased soil disturbance and increased removal of timber, has the potential to adversely affect soil fertility as a result of increased loss of nutrients due to and following harvesting. The management of organic matter has emerged as a critical issue in the management of many forests and plantations. It seems inevitable that the intensity of energy-wood harvesting on some coupes and in some years will be so great as to cause concern for the capacity to sustain soil fertility and soil organic matter. Leaving patches within coupes in which there is no disturbance from felling and extraction will reduce the area of soil disturbance and hence increase the retention of soil organic matter as well as ensuring that some standing dead trees and some coarse woody debris are retained *in situ*.

Large amounts of ash (~2000 t/yr) will be generated in the power station. This ash is high in cations (Ca, Mg) and phosphorus. In Europe, techniques have been developed for returning the ash to the forest, with associated benefits for forest nutrition.

Recommendation 5. Existing guidelines should be further developed to ensure that, in general, and particularly on the most intensively-harvested coupes:

Wood extraction continues to be planned so that soil disturbance is limited and soil organic matter is maintained over most of the coupe;

Regeneration is rapid and optimal so that nutrient cycling processes are rapidly re-established;

Nitrogen-fixing species (e.g. wattles) are established early in the regenerating forest.

Recommendation 6. *Research at the Warra LTER site should be continued so as to provide an assessment of the value, through the maintenance of organic matter, of leaving undisturbed patches in coupes harvested for energy-wood. This recommendation is in consort with Recommendations 9 and 14.*

Recommendation 7. *Practical and safe procedures be explored and developed for returning ash to forest sites.*

References

- Adams MA, Attiwill, PM (1984a) Role of *Acacia* spp. in nutrient balance and cycling in regenerating *Eucalyptus regnans* F. Muell. forests. I. Temporal changes in biomass and nutrient content. *Australian Journal of Botany* **32**, 205-215.
- Adams MA, Attiwill, PM (1984b) Role of *Acacia* spp. in nutrient balance and cycling in regenerating *Eucalyptus regnans* F. Muell. forests. II. Field studies of acetylene reduction. *Australian Journal of Botany* **32**, 217-223.
- Adams MA, Attiwill PM (1988) Nutrient cycling in forests of north-east Tasmania. 219 pp., Tasmanian Forest Research Council Inc.
- Attiwill PM, Adams MA (1993) Nutrient cycling in forests. Tansley Review No. 50, *New Phytologist*. **124**, 561-582.
- Attiwill PM, Leeper GW (1987) *Forest Soils and Nutrient Cycles*. (Melbourne University Press: Melbourne).
- Attiwill PM, Polglase PJ, Weston CJ Adams MA (1996) Productivity and nutrient cycling in eucalypt forests of south-eastern Australia. In PM Attiwill, MA Adams (Editors). *Nutrition of Eucalypts*. pp. 191-227. CSIRO, Melbourne.
- Attiwill PM, Weston CJ (2001) Forest Soils. In J Evans (Editor). *The Forests Handbook Volume 1 An Overview of Forest Science*. pp. 157-187. Blackwell Science Ltd., Oxford
- Cole DW, Rapp M (1981) Elemental cycling in forest ecosystems. In: *Dynamic Properties of Forest Ecosystems* (Ed. by D.E. Reichle), pp. 341-409. Cambridge University Press, Cambridge.
- Federer CA, Hornbeck JW, Tritton LM, Martin CW, Pierce RS (1989) Long-term depletion of calcium and other nutrients in eastern US forests. *Environmental Management* **13**, 593-601.
- Forestry Tasmania (2002) 'The Wood Centre Development, Southwood Resources – Huon. Developmental proposal and Environmental Management Plan'. Forestry Tasmania: Hobart.
- Grierson PF, Adams MA, Attiwill PM (1992) Estimates of carbon-storage in the above-ground biomass of Victoria's forests. *Australian Journal of Botany* **40**, 631-640.
- Grierson PF, Polglase PJ, Attiwill PM, Adams MA (1993) Carbon storage in Victoria's forests. In: S. Burgin (Editor), *Climate Change: Implications for Natural Resource Conservation*. University of Western Sydney, Hawkesbury, pp 81-99.
- Grove S, Meggs J, Goodwin A (2002) A review of biodiversity conservation issues relating to coarse woody debris management in the wet eucalypt production forests of Tasmania. Draft Technical Report to Forestry Tasmania.

- Hopmans P, Stewart HTL, Flinn DW (1993) Impacts of harvesting on nutrients in a eucalypt ecosystem in southeastern Australia. *Forest Ecology and Management* **59**, 29-57.
- Mannes, D (2002) Report on potential harvest residue levels following clearfelling in Tasmanian native forests. Forestry Tasmania, unpublished report. 17pp.
- O'Connell AM and Grove TS (1996) Biomass production, nutrient uptake and nutrient cycling in the jarrah (*Eucalyptus marginata*) and karri (*Eucalyptus diversicolor*) forests of south-western Australia. In PM Attiwill, MA Adams (Editors). *Nutrition of Eucalypts*. pp. 155-189. CSIRO, Melbourne.
- Raison RJ (1979) Modification of the soil environment by vegetation fires with particular reference to nitrogen transformations: a review. *Plant and Soil* **51**, 73-108.
- Raison RJ (1980) Possible forest site deterioration associated with slash-burning. *Search* **11**, 68-72.
- Raison RJ (1981) More on the effects of intense fires on the long-term productivity of forest sites: reply to comments. *Search* **12**, 10-4.
- Turner J and Lambert MJ (1996) Nutrient cycling and forest management. . In PM Attiwill, MA Adams (Editors). *Nutrition of Eucalypts*. pp. 229-248. CSIRO, Melbourne.