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A cash flow model to compare coppice and genetically improved seedling options for *Eucalyptus globulus* pulpwood plantations

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Abstract

Coppice can provide a cheap alternative to replanting in the second rotation in *Eucalyptus globulus* Labill. plantations. However, replanting with genetically improved stock may provide a more profitable alternative. A discounted cash flow model was used to compare the profitablity of coppice and seedling crops in second rotation *E. globulus* pulpwood plantations, using incremental net present value (NPV). Using the model presented in this paper as a framework it is possible to say that a gain of 20% over the original seedling crop in dry matter production from second rotation seedlings through genetic improvement and provenance selection would result in equivalent NPV for second rotation seedling and coppice crops. Sensitivity analysis showed that incremental NPV is strongly affected by the level of genetic gain available (and therefore the genetic quality of the first rotation stock relative to the available genetically improved stock), and the productivity of coppice relative to the first rotation crop. Any reduction in the basic density of coppice reduces the level of genetic gain required to make replanting with improved seedlings economically justifiable.

Keywords: Coppice; Cash flow model; *Eucalyptus globulus*; Genetic improvement; Economic evaluation

1. Introduction

Eucalyptus globulus is one of the major hardwood species in temperate plantation forestry. Considerable effort has been expended on the domestication and genetic improvement of this species (Volker and Orme, 1988; Borralho et al., 1993; Greaves et al., 1997; Borralho and Dutkowski, 1998; Dutkowski and Potts, 1999; Harbard et al., 1999; Kerr et al., 2001). Genetic improvement in the form of provenance selection and breeding promises gains in productivity. Estimates of such gain in *E. globulus* range from 7 to 17% for volume (Volker et al., 1990), 20–47% for dry matter (Borralho et al., 1992) and up to 18% saving in total pulp costs (Greaves et al., 1997). Gains will be maximised where first rotation (1R) stock is based on seed collected from unselected natural stands.

E. globulus regenerates readily through stump coppice following the removal of the stem and crown at harvesting (Blake, 1983; Opie et al., 1984). This ability to coppice and the fact that second rotation establishment costs are avoided have led many plantation managers to assume that the second rotation (2R) may be managed as a coppice crop. While a coppice

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crop may be optimal in some situations, potential increases in plantation productivity through genetic improvement may argue in favour of replanting in the second rotation.

Previous economic models of eucalypt coppice have dealt with the optimum number of shoots to retain (Agnihotri and Arya, 1994) or the number of coppice rotations and rotation length for optimum economics in a plantation (Nobre and Rodriguez, 2001), or charcoal production system (Platais and Betters, 1989). No direct comparison has been made between seedling and coppice crops in *E. globulus* pulpwood plantations for coppice stands thinned to one stem per stump. Such comparisons are complicated by the need to use the same genetic material for the establishment of first and second rotation crops. In the current study, a cash flow model is developed to allow an assessment of the level of genetic gain required to produce a second rotation seedling crop that exceeds the value of a second rotation coppice crop.

2. Methods

2.1. Model description

The model was developed in Microsoft Excel®, based on cost structures for managing *E. globulus* plantations from seedlings in the first rotation, and from seedlings or coppice in the second rotation (Tables 1 and 2). All costs are in Australian dollars. Costs and the timing of costs differ between seedling and coppice crops. The model allows changes in productivity due to coppicing or genetic improvement to be investigated in terms of net present value (NPV). Incremental NPV (Irvin, 1978) was used to compare the two mutually exclusive options (Dasgupta and Pearce, 1972). A positive incremental NPV indicated that the NPV of coppice exceeded the NPV of seedlings in the second rotation, whilst a negative incremental NPV indicated that the NPV of a seedling crop exceeded the NPV of a coppice crop in the second rotation.

Two series of two 10-year rotations, representing a seedling crop established on an open paddock followed by either a seedling crop, or a coppice crop (Table 1) were considered. A lag time of 1 year

Table 1
The system used to calculate the incremental NPV of seedling and coppice crops

Year	Seedling (rotation 1, unimproved seedling)		Seedling (rotation 1, unimproved seedling)	
	Cost	Income	Cost	Income
0	Est1	1	Est1	1
1	Est2	2	Est2	2
2	Est3	3	Est3	3
3	4	4	4	4
4	5	5	5	5
5	6	6	6	6
6	7	7	7	7
7	8	8	8	8
8	9	9	9	9
9	10	H10	10	H10
	Coppice (rotation 2, coppice)		Seedling (rotation 2, improved seedling)	
	Cost	Income	Cost	Income
10	Man1	1	Fallow	0
11	Man2	2	Est1	1
12	Man3	3	Est2	2
13	4	4	Est3	3
14	5	5	4	4
15	6	6	5	5
16	7	7	6	6
17	8	8	7	7
18	9	9	8	8
19	10	H10	9	9
20			10	H10

‘Est’ indicates a cost associated with seedling establishment, ‘man’ indicates a cost associated with coppice management, ‘H’ indicates an income at harvest, ‘fallow’ the lag period of 1 year between harvest of the first rotation and establishment of second rotation seedlings, ‘PV’ the present value and ‘NPV’ the net present value. Numbers in the ‘cost’ and ‘income’ columns refer to the year in the rotation that the cost or income occurs.

Table 2
Illustrative costs for the management and establishment of *E. globulus* plantations

Activity	Cost per hectare (AU\$ ha^{-1})		
	First rotation	Second rotation	
	Paddock	Seedling	Coppice
Administration	240.00	10.00	10.00
Preparation	1018.00	1468.00	5.00
First year	206.00	176.00	21.50
Second year	256.00	256.00	696.00
Third year	58.00	58.00	241.00
Annual costs	213.00	213.00	213.00

between clearfall and replanting seedlings built into the model (Table 1) meant that the lifespan of the two crop types (coppice or seedlings) differed by 1 year at the end of two rotations. Small differences in project lifespan should not impact significantly on the performance of financial models (Brigham and Houston, 2002). This was checked by converting the NPV of coppice and seedling crops to an equivalent annuity (Zerbe and Dively, 1994). The equivalent annuities system did not alter the interpretation of the results, and the results presented remain in the form of NPV or incremental NPV.

The net present value of systems was calculated as

$$\mathrm{NPV} = I_{\mathrm{PV}} - C_{\mathrm{PV}} \tag{1}$$

where I_{PV} is the present value of all incomes and C_{PV} the present value of all costs. All costs and incomes were discounted to the time of plantation establishment (year 0). Present value was calculated using the standard formula:

$$P = V\left(1 + \frac{d}{100}\right)^{a_V} \tag{2}$$

where P is the present value of a cost or income, (V), a_V the time (year) in which V occurs, and d the annual discount rate in percentage points. A discount rate of 7% was used in a study of fibre production from *E. globulus* in Australia (Selkirk and Spencer, 1999), and was adopted as the base rate in this study. 'Present' is the time of plantation establishment (year 0).

It was assumed the enterprise was selling timber as a standing crop. Income was calculated based on the value for an oven dried tonne of wood delivered (O). This was converted to a value per green tonne delivered using the basic density of the crop, and then transport and harvest costs were removed to give the stumpage price. This system allowed changes in basic density due to genetic improvement or coppice to affect the value of the standing crop at harvest.

Basic density was calculated separately for each series (seedling or coppice) in each rotation. The basic density of the first rotation crop (D) was altered by the gain in basic density from genetic improvement in percentage points (DGAIN) in second rotation seedling crops, and reduced by a small percentage (r) in a coppice crop. The base value (first rotation mean basic density) assumed was 530 kg m^{-3} (see Macfarlane and Adams, 1998; Schimleck et al., 1999; Miranda et al., 2001 for estimates of *E. globulus* basic density). Ferrari (1993) reported that the basic density of *E. globulus* coppice was up to 8% lower than the basic density of the original stem on the same stumps. A decrease in basic density was also reported in *E. camaldulensis* coppice (Sesbou and Nepveu, 1991).

The gross value per green tonne delivered was calculated as G_1, G_{2_s}, and G_{2_c}, in first rotation, second rotation seedling and second rotation coppice crops, respectively. The green specific gravity (S) was assumed to equal 1 t m^{-3} (Albertson et al., 2000).

$$G_1 = \frac{OD}{S} \tag{3}$$

$$G_{2_s} = \frac{OD(1 + \mathrm{DGAIN}/100)}{S} \tag{4}$$

$$G_{2_c} = \frac{OD((1 - r)/100)}{S} \tag{5}$$

The stumpage (net income per green tonne for the grower, I) was calculated by removing the harvest cost per green tonne (h) from the gross income per green tonne. The harvest cost (AU$ 17 per green tonne) given by Albertson et al. (2000) was used as the base value in this case. The number of stumps with multiple stems and form problems such as hooking towards the base of the stem will increase the cost of extraction and transport of a coppice crop. A penalty (f) was applied to reflect potential difficulties associated with the harvest of coppice material

$$I = G - h(1 + f) \tag{6}$$

Yield in metric tonnes (Y) for the first rotation was calculated as

$$Y = \mathrm{MAI} \times a_{\mathrm{R}} \tag{7}$$

MAI is the mean annual increment (merchantable volume) calculated as m^3 ha^{-1} per year, and a_{R} the rotation length in years. The base value applied for MAI was 20 m^3 ha^{-1} per year. Yield of a second rotation coppice crop (Y_{c}) was calculated as

$$Y_{\mathrm{c}} = \mathrm{MAI}\left(1 + \frac{\mathrm{CPROD}}{100}\right) a_{\mathrm{R_c}} \tag{8}$$

where $a_{\mathrm{R_c}}$ is the rotation length (years) for a coppice crop, and CPROD describes the change in coppice productivity relative to the original seedling crop. Loss of stumps is a common cause of reduced MAI in coppice crops (Matthews, 1992). However, there was insufficient information available on the effect of stump mortality on end of rotation yield to include it directly as a variable. The yield of coppice was considered only relative to the first rotation crop. The yield from a seedling crop in the second rotation (Y_s) was calculated as

$$Y_s = \mathrm{MAI}\left(1 + \frac{\mathrm{VGAIN}}{100}\right)(a_{R_s} - 1) \quad (9)$$

where a_{R_s} is the rotation length for a seedling crop, including the fallow period of 1 year between harvesting and replanting, and VGAIN the gain in volume production in second rotation seedlings. Genetic gain (GGAIN) in this case refers solely to increases in dry matter production directly attributable to provenance selection and breeding. GGAIN was made up of changes in volume production and gains in basic density (DGAIN) so that:

$$\mathrm{VGAIN} = X \times \mathrm{GGAIN} \quad (10)$$

and

$$\mathrm{DGAIN} = (1 - X)\mathrm{GGAIN} \quad (11)$$

where X is the proportion of genetic gain contributing to an increase in volume. The remainder of genetic gain contributes to increasing basic density.

All abbreviations used above are listed and described in Table 3.

2.2. Sensitivity analysis

The sensitivity of the model to variation in input variables was examined using Crystal Ball® 2000.2 (Decisioneering Inc., 2002) to fit probability distributions to variables and run Monte Carlo simulations. The base values in the model (Table 4) reflect realistic estimates derived from the literature and discussions with *E. globulus* plantation growers in Australia.

Sensitivity analyses looked at the impact changes in model variables had on the NPV of first and second rotation crops, and the incremental NPV of coppice and seedling crops in the second rotation. Sensitivity to changes in a particular variable was calculated as a rank correlation over 10,000 iterations. All variables, with the exception of the cost penalty at harvest (f) associated with a coppice crop and the proportion of

Table 3
A list of abbreviations used to describe of the model, and their meanings

Abbreviation	Description
NPV	Net present value
I_{PV}	Present value of incomes
C_{PV}	Present value of costs
P	Present value
V	Any cost or income
d	Discount rate
a	Time in years (a_V the time a cost or income occurs, a_0 the time of plantation establishment, a_R the rotation length, a_{R_s} the rotation length for seedlings, and a_{R_c} the rotation length for coppice)
G	Income per green metric tonne delivered (G_1 1R, G_{2_s} 2R seedling, G_{2_c} 2R coppice)
O	Income per oven dried metric tonne delivered
D	Basic density (metric tonnes per cubic metre)
DGAIN	Percentage genetic gain affecting basic density
r	Percentage reduction in basic density in coppice relative to maiden crop
S	Green specific gravity
I	Stumpage per green tonne
h	Harvest and transport cost per green tonne
f	A percentage of the harvest and transport cost, a penalty incurred when harvesting coppice
Y	Yield (green t ha^{-1}) (Y_c yield from coppice, and Y_s the yield from seedlings)
MAI	Mean annual increment (green t ha^{-1} per year)
CPROD	The percentage change in productivity of coppice in relation to first rotation yield
GGAIN	The percentage genetic gain in seedlings over the previous crop
VGAIN	The genetic gain in volume production
X	The proportion of genetic gain contributing to increased volume production

Table 4
Base values for model parameters, used in all cases where alternative values are not specifically stated

Assumption	Base value	Range	Reference
Discount rate, *d* (%)	7.0	5.6–8.4	Selkirk and Spencer (1999)
Basic density, *D* (t m^{-3})	0.53	0.42–0.64	
Reduction in basic density, *r* (%)	0	0–20	Ferrari (1993)
Harvest costs, *h* (AU\$ t^{-1})	17	13.6–20.4	Albertson et al. (2000)
Coppice harvest penalty *f* (%)	10	0–20	
MAI (m^3 ha^{-1} per year)	20	16–24	
CPROD (%)	100	80–120	
GGAIN (%)	20	0–40	
Density:volume, *X* (proportion)	0.2	0–1	
AU\$/oven dried tonne delivered, *O* (AU\$ OD t^{-1})	115	92–138	WRI-Ltd. (2000)

Coppice productivity (CPROD) is relative to first rotation productivity.

density increases in genetic gain, were allowed to vary according to a triangular distribution with maximum and minimum values ±20% of the base value. The coppice harvest and transport penalty was fitted with a triangular distribution ranging from 0 to 20% with the likeliest value 10%. The proportion of density gain to volume gain in genetic gain was allowed to vary from 0 (all gain is in volume) to 1 (all gain is in density) with a uniform distribution.

3. Results and discussion

If the productivity of a coppice crop were equivalent to the first rotation seedling crop, then genetic gain of between 20 and 25% (dry matter production) would be required for a seedling crop to have an NPV equivalent to a coppice crop (incremental NPV is zero) (Fig. 1). This is due to the reduced establishment and management costs for a coppice crop. Changes in the productivity of coppice have a large effect on the choice of crop system in the second rotation. A coppice crop producing 90% of the dry matter of the original seedling crop will be outperformed by a new seedling crop with genetic gain of 15% (Fig. 1). Such levels of genetic gain through provenance selection and breeding are probably achievable in *E. globulus* (Borralho et al., 1992), as many first rotation plantations were established with open pollinated native forest seed.

At a discount rate of 7%, varying coppice productivity from 70 to 130% relative to the original seedling crop resulted in a range of incremental NPV of approximately AU\$ 5000 ha^{-1} (Fig. 1). The range of incremental NPV resulting from variation in the productivity of coppice is more contracted at a discount rate of 12% (AU\$ ~3000 ha^{-1}, Fig. 2). The influence of changes in productivity due to the performance of coppice or genetic improvement are minimised at high discount rates (Fig. 2). Genetic gain of approximately 35% would be required before a seedling regime was favoured at a discount rate of 12%, when coppice productivity was equivalent to that of the first rotation crop (Fig. 2).

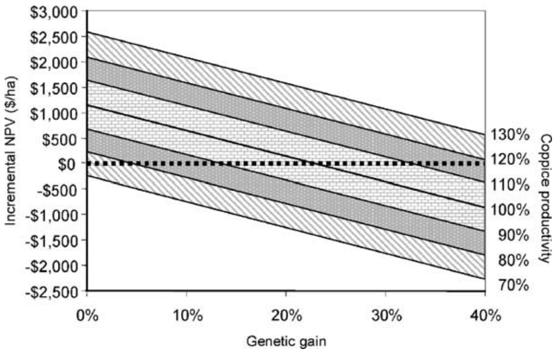

Fig. 1. Incremental NPV plotted against genetic gain (measured as percentage increase in dry matter production) showing the effect of increasing coppice productivity at the model base values. An incremental NPV of zero (broken line) indicates no difference in value between coppice and seedling crops in the second rotation. Incremental NPVs above zero indicate the value of coppice exceeding the value of seedlings, and incremental NPVs below zero indicate the value of seedlings exceeding the value of coppice. If the productivity of coppice crops is between 90 and 110% of the original seedling crop, then seedlings will start to become economically viable when genetic gain of 15–35% is available.

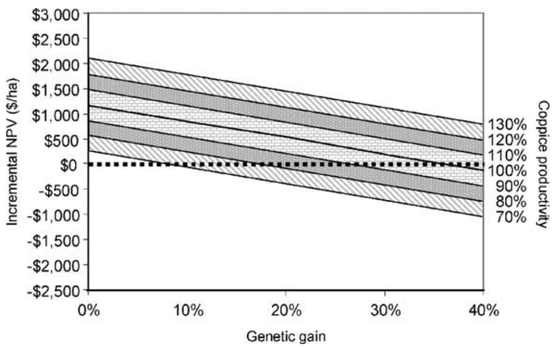

Fig. 2. Incremental NPV plotted against genetic gain (measured as percentage increase in dry matter production) showing the effect of increasing coppice productivity at high discount rates (12%). An incremental NPV of zero (broken line) indicates no difference in value between coppice and seedling crops in the second rotation. Incremental NPVs above zero indicate the value of coppice exceeding the value of seedlings, and incremental NPVs below zero indicate the value of seedlings exceeding the value of coppice. The reduction in cost of management combined with similar yields in a coppice crop when compared to a seedling crop mean that an increased discount rate drives the economics of plantation production towards using coppice in the second the second rotation.

Early growth of coppice is assisted by the established root system (Blake, 1983). The rapid growth of eucalypt coppice has led several authors (Jacobs, 1955; Carter, 1974; Matthews, 1992; Sims et al., 1999; Underdown and Bush, 2002) to suggest that coppice crops will produce up to 125% of the volume of the original seedling crop. Other authors (Skolmen, 1981; Prado et al., 1990; Alarcón, 1994; Whittock et al., 2003) have reported levels of stump mortality following harvest that would significantly reduce the productivity of a coppiced *E. globulus* plantation. Large differences in the ability of eucalypt species to regenerate through coppice (Blake, 1983; Sims et al., 1999; Little and Gardner, 2003) mean that yield information from other species may not apply in the case of *E. globulus*. In the absence of direct measurements, the broad range of coppice productivity covered in Figs. 1 and 2 realistically represents the possible range of *E. globulus* coppice productivity.

Sensitivity analysis showed that changes in basic density (*D*), MAI and the price paid for an oven dried tonne of chip (*O*) are the major factors affecting the NPV of first and second rotation crops (Table 5). Genetic gain and coppice productivity (CPROD) have rank correlations of a similar magnitude in second rotation seedling and coppice crops respectively (0.41 and 0.33) (Table 5), and a reduction in the basic density of a coppice crop (*r*) has a strong negative effect on its NPV (−0.48) (Table 5). The main variables driving changes in incremental NPV (the difference in value between coppice and seedling crops) are reduction in basic density (*r*), genetic gain and coppice productivity (−0.63, −0.52, and 0.44, respectively) (Table 5).

Table 5
Rank correlations for first rotation NPV (1R), second rotation seedling crop NPV (2R seedling), second rotation coppice crop NPV (2R coppice) and incremental NPV (iNPV)

Assumption	1R	2R seedling	2R coppice	iNPV
Basic density, *D*	0.58	0.52	0.46	−0.09
Reduction in basic density, *r*	–	–	−0.48	−0.63
Harvest costs, *h*	−0.16	−0.13	−0.15	−0.01
Coppice harvest penalty, *f*	–	–	−0.07	−0.10
MAI	0.42	0.39	0.32	−0.09
CPROD	–	–	0.33	0.44
GGAIN	–	0.41	–	−0.52
Density:volume, *X*	–	0.08	–	−0.12
AU$/oven dried tonne delivered, *O*	0.59	0.53	0.47	−0.09
Discount rate, *d*	−0.21	−0.21	−0.16	0.07

‘Basic density’ refers to the basic density of the first rotation crop, ‘reduction in basic density’ is the reduction in basic density of the wood in a coppice crop, ‘harvest costs’ include the cost of harvesting and transporting roundwood, ‘penalty’ is the cost penalty incurred when harvesting and processing a coppice crop, ‘MAI’ is the mean annual increment (m^3 ha^{-1} per year), ‘coppice productivity’ is the productivity of coppice relative to the first rotation seedling crop, ‘genetic gain’ refers to the increase in dry matter production from the first rotation crop to the second rotation seedling crop due to genetic improvement, ‘density:volume’ is the ratio of density gain to volume gain in genetic gain, ‘AU$/oven dried tonne delivered’ is the price paid for an oven dried metric tonne of wood delivered, and ‘discount rate’ is the discount applied.

This demonstrates that while the level of genetic improvement is an important consideration when choosing between coppice and seedlings in the second rotation, it will be very important to understand the factors affecting the productivity of a coppice crop.

The practice of varying underlying variables by ±20% for a sensitivity analysis does not take into account the likely variability of the underlying variables (Belli et al., 2001). The basic density of eucalypt coppice material has been found to be lower than that of the first rotation material (5%, Sesbou and Nepveu, 1991; 8%, Ferrari, 1993). However, the coppice material assessed was younger than the original stem material when tested (Sesbou and Nepveu, 1991), or as in the case of Ferrari (1993), the coppice growth had not been thinned. The sensitivity analysis conducted in this case may exaggerate the effect of a change in the basic density of coppice relative to the basic density of the initial seedling crop.

Coppice foliage in eucalypts typically shows higher stomatal conductance (Crombie, 1997; Reis and Reis, 1997), and higher stomatal number (Blake, 1980). *E. globulus* coppice foliage has a higher moisture content and increased carbon:nitrogen ratio when compared to seedling foliage (Steinbauer et al., 1998). Physiological changes in coppice foliage appear to leave it more susceptible to *Mycosphaerella* sp. (*E. marginata*, Abbott et al., 1993) and insect damage (*E. globulus*, Steinbauer et al., 1998) than seedling material. Replanting and turnover of genotypes may help to manage the risk of damage and loss due to pests and diseases. Coppice offers a plantation grower an opportunity to achieve a return for less investment. However, the risks associated with coppiced *E. globulus* plantations are likely to change over time. Where the NPV of coppice and seedling crops in the second rotation is equivalent, the grower should make their decision based on the crop that will incur less risk for the same NPV.

4. Concluding remarks

The use of a discounted cash flow model has identified situations where both seedling and coppice crops would be preferable in the second rotation. The current understanding of the productivity of coppice crops in *E. globulus* pulpwood plantations is inadequate to allow firm conclusions. However, the use of low quality genetic material to establish the first rotation will increase the relative level of genetic gain available in seedlings at the start of the second rotation, and make replanting more attractive. If it is assumed that a coppice crop will produce yields roughly equivalent to the first rotation crop, then a grower should start to consider replanting with genetically improved stock if the increase in dry matter yield would exceed 15% over the already established plantation.

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References

Abbott, I., van-Heurck, P., Burbidge, T., Williams, M., 1993. Damage caused by insects and fungi to *Eucalyptus* foliage: spatial and temporal patterns in Mediterranean forest of Western Australia. For. Ecol. Manage. 58, 85–110.

Agnihotri, Y., Arya, S.L., 1994. Economics of retaining optimum number of coppice shoots for getting the highest yield of *Eucalyptus*. Indian J. For. 17, 252–255.

Alarcón, C., 1994. Retoñación en cuatro especies del género *Eucalyptus* en Chile. In: Actas simposio Los Eucaliptos en el Desarrollo Forestal de Chile, Pucón, Chile, 24–26 November 1993, pp. 226–240.

Albertson, T., Eckersly, P., Blennerhassett, S., Moore, R., Hingston, R. 2000. Blue gum timberbelt design for alley farming. Joint Venture Agroforestry Program. Rural Industries Research and Development Corporation (RIRDC), Land and Water Resources Research and Development Corporation (LWRRDC), Forest and Wood Products Research and Development Corporation (FWPRDC). RIRDC Project No. DAW-70A, Report No. 00/154, Canberra.

Belli, P., Anderson, J., Barnum, H., Dixon, J., Tan, J.-P., 2001. Handbook on economic analysis of investment operations. Operational core services network and leadership center working paper. Report No. 20733. The World Bank Group.

Blake, T.J., 1980. Effects of coppicing on growth rates, stomatal characteristics and water relations in *Eucalyptus camaldulensis* Dehn. Aust. J. Plant Physiol. 7, 81–87.

Blake, T.J., 1983. Coppice systems for short rotation intensive forestry: the influence of cultural, seasonal and plant factors. Aust. For. Res. 13, 279–291.

Borralho, N.M.G., Cotterill, P.P., Kanowski, P.J., 1992. Genetic parameters and gains expected from selection for dry weight in *Eucalyptus globulus* ssp. *globulus* in Portugal. For. Sci. 38, 80–94.

Borralho, N.M.G., Cotterill, P.P., Kanowski, P.J., 1993. Breeding objectives for pulp production of *Eucalyptus globulus* under different industrial cost structures. Can. J. For. Res. 23, 648–656.

Borralho, N.M.G., Dutkowski, G.W., 1998. Comparison of rolling front and discrete generation breeding strategies for trees. Can. J. For. Res. 28, 987–993.

Brigham, E.F., Houston, J.F., 2002. Fundamentals of Financial Management, Concise 3rd ed. Appendix 12D: Comparing Projects with Unequal Lives. Thomson International New York, pp. 12D1–12D3.

Carter, W.G., 1974. Growing and harvesting eucalypts on short rotations for pulping. Aust. For. 36, 214–225.

Crombie, D.S., 1997. Water relations of jarrah (*Eucalyptus marginata*) regeneration from the seedling to the mature tree and of stump coppice. For. Ecol. Manage. 97, 293–303.

Dasgupta, A.K., Pearce, D.W., 1972. Cost–Benefit Analysis: Theory and Practice. MacMillan, London.

Dutkowski, G.W., Potts, B.M., 1999. Geographic patterns of genetic variation in *Eucalyptus globulus* ssp *globulus* and a revised racial classification. Aust. J. Bot. 47, 237–263.

Ferrari, G., 1993. La qualità del legno in cedui di eucalitto. Cellulosa-e-Carta 44, 17–21.

Greaves, B.L., Borralho, N.M.G., Raymond, C.A., 1997. Breeding objective for plantation eucalypts grown for production of kraft pulp. For. Sci. 43, 465–472.

Greaves, B.L., Borralho, N.M.G., Raymond, C.A., 1997. Assumptions underlying the use of economic weights—are they valid in breeding for eucalypt kraft pulp? For. Genet. 4, 35–42.

Harbard, J.L., Griffin, A.R., Espejo, J., 1999. Mass controlled pollination of *Eucalyptus globulus*: a practical reality. Can. J. For. 29.

Irvin, G., 1978. Modern Cost–Benefit Methods: An Introduction to Financial, Economic and Social Appraisal of Development Projects. Barnes and Noble, New York.

Jacobs, M.R., 1955. Eucalypts for planting. Series title: FAO Forestry and Forest Products Studies, Number 11. FAO, Rome.

Kerr, R.J., McRae, T.A., Dutkowski, G.W., Apiolaza, L.A., Tier, B., 2001. TREEPLAN®—a genetic evaluation system for forest tree improvement. In: Proceedings of the IUFRO Symposium on Developing the Eucalypt of the Future, Valdivia, Chile.

Little, K.M., Gardner, R.A.W., 2003. Coppicing ability of 20 *Eucalyptus* species grown at two high-altitude sites in South Africa. Can. J. For. Res. 33, 181–189.

Macfarlane, C., Adams, M.A., 1998. Delta13C of wood in growth rings indicates cambial activity of drought stressed trees of *Eucalyptus globulus*. Funct. Ecol. 12, 655–664.

Matthews, J.D., 1992. The coppice system. In: Silvicultural Systems. Clarendon Press, Oxford, UK, pp. 190–224.

Miranda, I., Almeida, M.H., Pereira, H., 2001. Provenance and site variation of wood density in *Eucalyptus globulus* Labill. at harvest age and its relation to non-destructive early assessment. For. Ecol. Manage. 149, 235–240.

Nobre, S.R., Rodriguez, L.C.E., 2001. A method for the creation and economic evaluation of coppice regimes. Scientia Forestalis (60).

Opie, J.E., Curtin, R.A., Incoll, W.D., 1984. Stand management. In: Hillis, W.E., Brown, A.G. (Eds.), Eucalypts for Wood Production. CSIRO Australia/Academic Press, Sydney, pp. 179–200.

Platais, G.H., Betters, D.R., 1989. A computer model for economic evaluation and sensitivity analysis of short rotation coppice plantations—application to *Eucalyptus*. Revista Árvore 13, 210–215.

Prado, J.A., Bañados, J.C., Bello, A., 1990. Antecedentes sobre la capacidad de retoñación de algunas especies del género *Eucalyptus* en Chile. Ciencia e Investigación Forestal 4, 183–190.

Reis, G.G., Reis, M.G.F., 1997. Fisiologia da brotação de eucalipto com ênfase nas suas relações hidricas. Série Técnica IPEF 11, 9–22.

Schimleck, L.R., Michell, A.J., Raymond, C.A., Muneri, A., 1999. Estimation of basic density of *Eucalyptus globulus* using near-infrared spectroscopy. Can. J. For. Res. 29, 194–201.

Selkirk, S.W., Spencer, R.D., 1999. Economics of fibre production from industrial hemp and blue gum plantations. Aust. For. 62, 193–201.

Sesbou, P.A., Nepveu, G., 1991. Viabilité infraspécifique et effet du recépage sur la densité du bois, le rendement papetier et la longueur des fibres chez *Eucalyptus camaldulensis* traité en taillis. Silvae Genet. 40, 173–179.

Sims, R.E.H., Senelwa, K., Maiava, T., Bullock, B.T., 1999. *Eucalyptus* species for biomass energy in New Zealand. Part II. Coppice performance. Biomass and Bioenergy 17, 333–343.

Skolmen, R.G., 1981. Growth of four unthinned *Eucalyptus globulus* coppice stands on the Island of Hawaii. In: Whitmore, J.L. (Ed.), Proceedings of the IUFRO/MAB/FS Symposium on Wood Production in the Neotropics via Plantations, Rio Piedras, Puerto Rico, 8–12 September 1980. International Union of Forestry Research Organizations, Washington, DC, pp. 87–95.

Steinbauer, M.J., Clarke, A.R., Paterson, S.C., 1998. Changes in eucalypt architecture and the foraging behaviour and development of *Amorbus obscuricornis* (Hemiptera: Coreidae). Bull. Entomol. Res.

Underdown, M., Bush, D., 2002. Coppicing eucalypt plantations—boon or bane? Aust. For. Grower, Winter, 18–19.

Volker, P.W., Orme, R.K., 1988. Provenance trials of *Eucalyptus globulus* and related species in Tasmania. Aust. For. 51, 257–265.

Volker, P.W., Dean, C.A., Tibbits, W.N., Ravenwood, I.C., 1990. Genetic parameters and gains expected from selection in *Eucalyptus globulus* in Tasmania. Silvae Genet. 39, 18–21.

Whittock, S.P., Apiolaza, L.A., Kelly, C.M., Potts, B.M., 2003. Genetic control of coppice and lignotuber development in *Eucalyptus globulus*. Aust. J. Bot. 51, 57–61.

WRI-Ltd., 2000. Global wood fibre market update. Wood Resource Quarterly. Second Quarter 2000, Wood Resources International Ltd. http://www.wri-ltd.com/PDFs/WRQJuly2000.pdf.

Zerbe Jr., R.O., Dively, D.D., 1994. In: Kaplan, B., Pisano, S. (Eds.), Benefit Cost Analysis in Theory and Practice. Harper Collins Publishers, New York.