An assessment of timber values from alternative silvicultural systems tested in wet *Eucalyptus obliqua* forest in Tasmania

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Abstract

The Warra silvicultural systems trial in southern Tasmania is being established in wet Eucalyptus obliqua *forest to compare feasible alternatives to the routine clearfell, burn and sow system. Six silvicultural systems have been implemented in the trial: (i) clearfell, burn and sow (CBS), (ii) CBS with 5% retained understorey islands, (iii) stripfell, (iv) 10% dispersed retention, (v) 30% aggregated retention, and (vi) single tree/small group selection (SGS). Two variants of each of the latter three systems are tested here in economic models.*

This paper uses the expectation value concept to compare the economic feasibility of the different silvicultural treatments. This is the notional income that an investor would expect from one hectare of an existing forest stand under the assumption that a defined silvicultural system is implemented for a designated rotation length over infinite rotations. The analysis focusses solely on timber values and does not include non-timber values.

Growth and growth suppression were modelled and costs estimated from data gathered at the Warra silvicultural systems trial. Expectation values were calculated using discount rates of 2% (which assigns a high value to future forest assets) and 10% (which reflects expectations of commercially driven forestry). The analysis was conducted for rotation lengths of 90 and 180 years for most treatments. An 18-year cutting cycle was used for the SGS treatment.

In terms of timber values, CBS ranks as economically superior to all other systems at the trial. The SGS treatment had the lowest economic rank. The economic analysis was dominated by the high value of the existing crop.

Introduction

The dominant commercial native forest vegetation type in Tasmania is wet eucalypt forest (Resource Planning and Development Commission 2002). The eucalypts in wet forests normally require fire for their regeneration (Gilbert 1959; Florence 1996) and have adaptations that promote fire and ensure their own succession (Mount 1964).

The routine silvicultural practice in wet eucalypt forest is clearfelling of all the trees, followed by a hot regeneration burn and sowing of seed from aircraft (Hickey and Wilkinson 1999). This system is referred to as clearfell, burn and sow (CBS). Clearfelling is defined as felling of all, or nearly all, the trees on an area in one operation, where the minimum size of the area has a diameter of four to six times the average tree height (Forest Practices Board 2000). The CBS system is considered to partially mimic the process of wildfire

(Florence 1996), although there are some key differences between wildfire and clearfelling disturbances (Lindenmayer and McCarthy 2002).

A negative perception of clearfelling in Tasmania (Hocking 2004), especially by environmentalists, may be influenced by attitudes in Central Europe (e.g. Strie *et al.* 1994). In the Central European region, where the principles of silviculture first emerged, temperate broadleaved forest of shade-tolerant species is the dominant ecotype. The silvicultural system that evolved in Europe in the 19th century was a result of observations by local foresters of natural regeneration from small-scale disturbances (e.g. Gayer 1886, cited in Schabel and Palmer 1999). These natural disturbances are predominantly caused by windthrow and the collapse of ageing single trees. By matching the scale of these disturbances in the ecosystem at suitable intervals, it became possible to continuously harvest forest products by adopting continuous cover, or 'near natural', forestry (Schabel and Palmer 1999).

In Tasmania, the Regional Forest Agreement (Commonwealth of Australia and State of Tasmania 1997) noted a priority for research on the 'commercial viability of new and alternative techniques especially for harvesting and regenerating wet eucalypt forests and maximising special species timbers[1] production and rainforest regeneration where appropriate'. This resulted in the establishment of a major silvicultural systems trial (SST) at the Warra Long-Term Ecological Research (LTER) Site in southern Tasmania (Hickey *et al.* 2001) to test alternative treatments that might be more acceptable to the general community, improve the retention of biodiversity, still meet biological requirements for eucalypt regeneration and productivity, and deliver a commercial return to the forest owner. The Warra site is representative of wet eucalypt forest in Tasmania (Neyland *et al.* 2000) and therefore the observations and results from the trial are applicable to a broad range of areas with wet eucalypt forests.

The Warra SST comprises six silvicultural systems, of which five are alternatives to the standard CBS system (Table 1). The trial was established mainly between 1998 and 2004, although a second, modified single tree/small group selection (SGS) treatment is planned for harvesting in 2005. Photo 1 shows aerial views of the treatments at establishment.

Two variations of the dispersed retention (DRN), aggregated retention (ARN) and single tree/small group selection (SGS) treatments were included in the economic analysis. Variant A of the treatments is as they were applied at the Warra trial. Variant B of the DRN and ARN treatments assumes that an excavator is used to heap the slash prior to burning and that eucalypt seed is subsequently aerially sown on the coupes. Variant B of the SGS treatment assumes that an excavator is used to remove the slash from the site at a cost of $40/t. It is estimated that one tonne of slash must be disposed of for every tonne of timber removed. The implications for regeneration of these variations is unknown, so for this study it was assumed that similar regeneration would be achieved under either variant.

The treatments at the Warra trial will be evaluated over time for their ecological, social and economic performance. This paper provides the first economic comparison of the silvicultural treatments.

[1] 'Special species timbers' refers to timber from non-eucalypt tree species, with the most common being blackwood (*Acacia melanoxylon* R.Br.), myrtle (*Nothofagus cunninghamii* (Hook.) Oersted), leatherwood (*Eucryphia lucida* (Labill.) Baill.), celery-top pine (*Phyllocladus aspleniifolius* (Labill.) Rich. ex Hook.f.) and sassafras (*Atherosperma moschatum* Labill.).

Table 1. Treatments at the Warra silvicultural systems trial (Forestry Tasmania 2004a). Treatment variants labelled B were not implemented at the trial but have been modelled subsequently.

Code	Treatment	Objective	Year established
CBS	**Clearfell, burn and sow**	Efficient eucalypt harvest with maximum growth of eucalypt regeneration.	2000, 2001
CBS+UI	**CBS with understorey islands** Up to 5% of the coupe retained as dispersed, machinery-free areas, 40 m by 20 m. Overstorey eucalypts can be felled from the islands if required.	Efficient eucalypt harvest, with retention of small machinery-free zones to increase local survival of understorey flora.	2000, 2001
Strips	**Stripfell** 250 m by 80 m strips; low intensity burn, natural seedfall.	Eucalypt harvest, with strips of undisturbed forest retained for half the rotation for habitat and seed supply (all species).	2000 (2 coupes)
DRN	**Dispersed retention**	Eucalypt harvest, with individual eucalypt trees retained for a full rotation for fauna habitat and seed supply.	1998
A	A. 10% basal area retention, low intensity burn, natural seedfall.		2000
B	B. As above plus slash heaping and supplementary sowing.		
ARN	**Aggregated retention**	Eucalypt harvest, with patches of undisturbed forest retained for a full rotation for habitat, seed supply (all species) and aesthetics.	2004 (2 coupes)
A	A. 30% area retention, log one tree length either side of snig tracks, retain aggregates of 0.5–1.0 ha, low intensity burn, natural seedfall.		
B	B. As above plus slash heaping and supplementary sowing.		
SGS	**Single tree/ small group selection**	Harvest of mature trees, while encouraging special species regeneration and maintaining a continuous tall forest cover.	2001 (second coupe to be established in 2005)
A	A. Retain > 75% forest cover, permanent snig tracks, harvest 40 m^3/ha every 18 years, mechanical disturbance, no burning, natural seedfall.		
B	B. As above plus mechanical removal of slash and off-site disposal.		

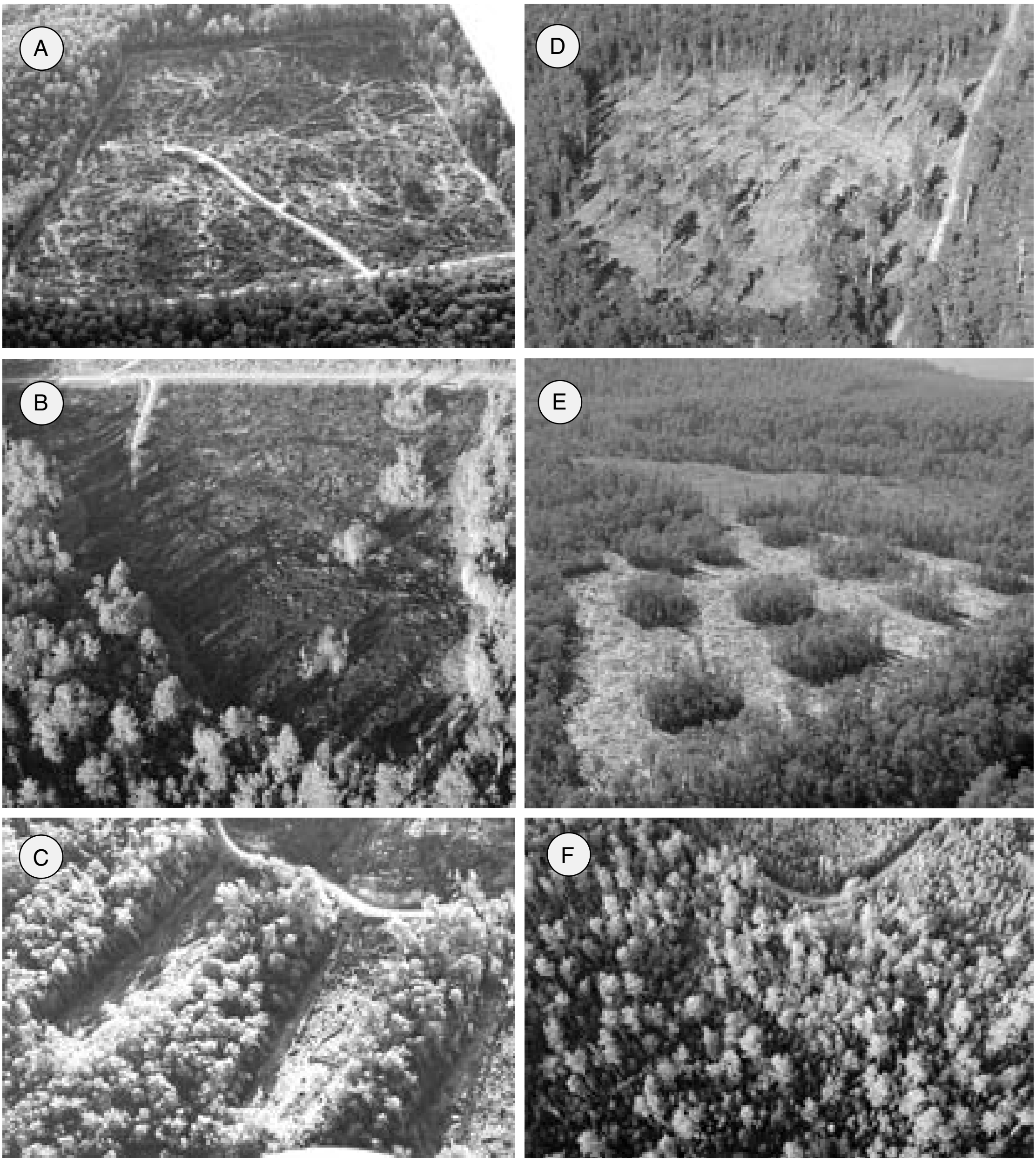

Photo 1. Aerial view of the silvicultural treatments, soon after establishment, at the Warra silvicultural systems trial (from Forestry Tasmania 2004a). A, Clearfell, burn and sow (CBS), 26 ha; B, CBS with understorey islands, 18 ha; C, stripfells, 250 m x 80 m; D, 10% dispersed retention prior to regeneration burning, 16 ha; E, aggregated retention prior to regeneration burning, 26 ha; F, single tree/small group selection, 9 ha. (Areas are coupe sizes.)

Economic terminology and theory

Some commonly used economic terms and theories are briefly introduced to explain the method used for this assessment of timber values.

Opportunity cost

'Opportunity cost' is an estimate of the benefits foregone as a result of possible actions (Adamowicz *et al.* 1996). The process of making an economic decision often involves choosing between two or more alternative options; that is, one input often excludes the use of others. An opportunity-cost approach to investment decisions compares the actual economic feasibility of an option against the best alternative. Fundamentally, the decision process involves the undertaking of any production with an opportunity cost less than zero. This implies that the output must be accounted for in monetary terms. If the output contains non-monetary values, for example aesthetics and biodiversity, the opportunity cost must be converted to some relative measure, monetary or not, by which the relative feasibility of different silvicultural systems can be compared.

Part of the opportunity cost of intensively managed timber production could be that certain recreational benefits are foregone and *vice versa*. Part of the opportunity cost of a wilderness area is the potential net income from marketed products foregone. Assessing the opportunity cost of undertaking a new silvicultural practice is one economic method of obtaining information about the value of the pool of non-timber assets that a forest provides. For example, if an owner were to adopt a silvicultural system that was financially less attractive than clearfelling, in order to provide additional non-timber benefits, then the difference in value between the two systems is a potential measure of the non-timber benefits. If the new system is implemented, it is because the value of the pool of non-timber benefits is at least as great as the opportunity cost of foregoing the financially optimum system.

In this analysis, opportunity cost is calculated as the expectation value of the best economic option for a particular discount rate, less the expectation value of a particular alternative at that discount rate.

Discount rate

The discount rate is the interest rate used when discounting future cash flows to the present. The discount rate reflects the preference and value assigned to the present as compared to the future. This preference varies with individuals, fashion, trends, risk, technological research, development, and availability of resources. A relatively high discount rate indicates a preference for present utility over future utility. Utility in this context is perceived from a social stance and means human satisfaction or well-being. A relatively low discount rate reflects higher importance for the utility of future generations. The level at which the discount rate is set is an important factor when calculating net present value.

Net present value and the value of capital

The net present value (NPV) of an investment is the present value of future revenues minus the present value of future costs. It is calculated using Equation 1. The NPV may be interpreted as the value of an investment at time $t = 0$. The decision to undertake the investment or not is based on the future expected return of the investment. The investment is profitable if the NPV is positive, which implies that the investment as a minimum returns the discount (interest) rate.

The NPV defines an investor's willingness to pay for an asset based on estimated benefits, costs, and the desired rate of return. Thus, NPV is a powerful tool for valuing forest properties and a crucial element of the assessment of timber values (Klemperer 1997).

Equation 1

$$NPV = \sum_{t=0}^{n} \frac{TR_t - TC_t}{(1+r)^t}$$

where

TR_t = total revenue at time t
TC_t = total cost at time t
n = total length of the investment
$(1 + r)^t$ = the discount factor
where r represents the discount rate

Net disposal value (R)

The net disposal, or liquidation, value (*R*) of a stand of timber is the net revenue obtained from selling the stand as stumpage (i.e. the price of the merchantable volume of wood in the standing trees).

Soil expectation value (L)

The soil expectation value (also denoted the value of bare land, the willingness to pay for bare land or the land expectation value) is determined by the land's long-term productive capacity, which is calculated as the NPV of a given use, here forestry, over endless successive rotations at a given discount rate, commencing with bare land. The productive capacity of bare land is related to the use of the land, assuming that the objective is profit maximisation under a given set of circumstances. The land use yielding the highest NPV is assumed to be optimal (risk is not taken into consideration here, other than that associated with reduced growth). The most important factors in a forestry context are growth rates and rotation length, due to the discount rate, and the choice of tree species and silvicultural system.

The NPV of one rotation of one crop is given by Equation 2. The soil expectation value (L) at time $t = 0$ incorporates these parameters and expresses the value of bare land just before sowing/planting the optimal crop over endless successive rotations (Klemperer 1997). The soil expectation value is given by Equation 3, which is equivalent to:

$e \times$ NPV,

where

$$e = \left[\frac{(1+r)^T}{(1+r)^T - 1} \right],$$

the factor implying a perpetual series of rotations (Openshaw 1980).

Expectation value (EV)

The expectation value (EV) concept takes the value of the standing timber into account. It is defined as the present value of all future cash flows of a stand and the successive stands at any point in time given a defined silvicultural system. For this analysis, it is assumed that a natural mature forest initially occupies the land. The calculation determines the EV just before the event of harvesting and regeneration, which reflects the objective of this paper—to estimate the most economically viable system for a given stand. The expectation value is given by Equation 4. This formula enables the estimation of the value of any stand at any point in time (*t*). The first four terms in the formula are related to the disposal value of the stand and the last term reflects the soil expectation value of the land, as described earlier.

Methods

The economic model developed required the following components: a model of forest growth over time, defined rotation lengths, estimated revenues from harvesting, and estimated costs of harvesting and regeneration.

Growth model

Modelling stand productivity for the various treatments is complex, especially because little research on the growth of multi-aged stands has been carried out in wet eucalypt forest. An unpublished eucalypt growth model (Goodwin 2000), an integral part of the economic model, was provided by Forestry Tasmania. The growth model uses site index and age to predict eucalypt sawlog, pulpwood and entire stem volume over time for even-aged regrowth. The site index (defined as the height in metres of the tallest dominant trees at age 50) for the forest at the trial was estimated to be 36. The growth model tends to overestimate recovered sawlog volumes and, therefore, 50% recovery of predicted sawlog volume was used for this study, with the remainder being classed as pulpwood.

Equation 2*—NPV for one rotation of one crop*

$$NPV = R_T(1+r)^{-T} + \sum_{t=0}^{T} G_t(1+r)^{-t} - \sum_{t=0}^{T} Cv_t(1+r)^{-t} - \sum_{t=0}^{T} Cf_t(1+r)^{-t}$$

where

R_t = the revenue from the main cutting in year t
G_t = the revenue from thinning (if applied) in year t
Cv_t = the variable costs (silvicultural costs) in year t
CF_t = the fixed costs (overhead costs) in year t
T = rotation length
t = the number of years from establishment
f = discount rate

Equation 3*—Soil expectation value*

$$L = k \times \left[R_T(1+r)^{-T} - \sum_{t=0}^{T} G_t(1+r)^{-t} - \sum_{t=0}^{T} Cv_t(1+r)^{-t} - \sum_{t=0}^{T} Cf_t(1+r)^{-t} \right]$$

Equation 4*—Expectation value*

$$EV_t = R_T(1+r)^{-(T-t)} + \sum_{t=0}^{T} G_t(1+r)^{-(T-t)} - \sum_{t=0}^{T} Cv_t(1+r)^{-(T-t)} - \sum_{t=0}^{T} Cf_t(1+r)^{-(T-t)} + L^{-(T-t)}$$

The rate of growth of the uneven-aged stands established under non-clearfell systems will most likely differ from the growth predicted for even-aged regrowth established by CBS. Accordingly, simple measures were taken into account for decreased growth increment due to suppression from retained trees under alternative systems. The extent of the suppressive zone around a mature tree has been referred to as the zone of influence, a concept defined as an area over which the tree competes for site factors (Opie 1968). Trees growing outside the zone of suppression are assumed to follow the unrestricted regeneration growth curve. The ratio of the average diameter of the crown to the diameter at breast height (DBH) has traditionally been used as a measure of the growing space required by individual trees (Bi and Jurskis 1996). If the tree density exceeds the limits set by this ratio, the trees are considered suppressed in the context of this project. A number of trees were measured at Warra for DBH and crown radius and the resulting radius of suppression was calculated at 14.9 m. This suppression radius is within the range reported by Curtin (1964), Bi and Jurskis (1997) and Bassett and White (2001).

Reduced growth due to suppression from the surrounding edge and retained trees leads to deviation from the growth model. Growth was assumed to vary linearly from zero at the base of a retained tree or edge to full growth at 14.9 m from the base. The level of suppression by the edge effect was determined by the proportion of edge length to the total area of the coupe. The suppression varied from 5.0% in the CBS coupes to 23.4% in the stripfell coupe. The effect of suppression was considered to be a constant (K) for each treatment where:

$$K = (V_{\text{retained trees}} + V_{\text{edge}})/V_{\text{total}}$$

where

$V_{\text{retained trees}}$ = the predicted yield for trees suppressed by retained trees in the retention systems,

V_{edge} = the predicted yield of trees within 14.9 m radius of coupe edges,

V_{total} = the predicted yield of free-growing trees predicted by the growth model.

Therefore, a proportional relationship exists between the mean annual volume increment with suppression included and the mean annual volume increment determined from the generalised yield curve. This relationship was determined for each treatment and incorporated in the model. Nyvold (2001) gives a detailed account of the calculations used to calculate $V_{\text{retained trees}} + V_{\text{edge}}$.

The suppression effect has not been modelled for the SGS system, as the system is perceived to have fundamentally different growth characteristics. The mean annual increment under the SGS system was assumed to be about 2 m^3/ha/year, which is about 22% of that predicted for even-aged regrowth over a 90-year rotation on sites with the same site index.

The growth model was also adjusted to account for the loss of retained trees in the dispersed retention system. Some 10% of retained trees were assumed to be lost over a rotation, which is similar to the real losses reported over the first three years by Neyland (2004). No losses of retained trees were assumed for the stripfell and aggregated retention systems, as no data were available. However, some losses are expected.

Rotation length

The timber value assessment is based primarily on Forestry Tasmania's standard CBS planned rotation length of 90 years for most eucalypt forests (Whiteley 1999). However, this rotation length does not reflect the economically optimal rotation length, which would be significantly shorter, as discussed by Ferguson (1996). Shorter rotations would support mainly pulpwood production, whereas a 90-year rotation supports a higher degree of sawlog production, which is the forest product used to calculate Forestry Tasmania's sustained yield (Whiteley 1999). This sawlog-driven strategy is enshrined in the *Forestry Act 1920,* which requires Forestry Tasmania to make available at least 300 000 m^3/yr of high quality eucalypt sawlog/veneer log. The production of sawlogs is given priority because it is a high value-added product processed mainly within the State, creating more jobs and wealth per tonne than the production of pulpwood, which is largely exported. Consequently, the choice of a 90-year rotation was a social compromise that recognised sawlog production as the main objective. A 180-year rotation was selected for comparison to allow greater development of late-successional (oldgrowth) species and to accommodate a perceived future need for large diameter eucalypt logs along with logs from understorey species such as myrtle (*Nothofagus cunninghamii*). It is important to acknowledge that the prescribed rotation lengths are not economically optimal.

The SGS system has polycyclic harvests but the notional rotation, or stump return time, was still considered to be 90 years. This was modelled to be achieved through five cutting cycles at 18-year intervals.

Revenues

The initial revenues used in the economic model are based on actual recovered volume from the harvest of the existing stands using 2003 stumpages for veneer log, sawlog, peeler log and pulpwood. For successive rotations, revenue has been modelled using 2003 stumpage prices (this assumes no real price increases) multiplied by the yield predicted by the growth model (Table 2). The stumpages used are all within the range of stumpages published by Private Forests Tasmania (2003).

Costs

Actual cost statistics for the different treatments at Warra have been collected by Forestry Tasmania. However, these costs are derived from initial trials and there would be potential cost reductions if the systems were to be implemented at an operational scale. Accordingly, the costs applied in the assessment of timber values at Warra are based on best estimates for future operational level costs (Table 2) rather than actual costs of the first operational trials. For example, a harvest subsidy of \$11/t was required for harvesting the first aggregated retention coupe, but future costs are anticipated to be about \$1/t above the clearfell rate for the same forest (Forestry Tasmania 2004a).

There is little experience with selectively logging tall wet eucalypt forest under modern standards for worker safety (Forestry Tasmania 2004b). Where SGS trials have been done, the actual cost of felling, snigging and loading logs has been more than double that required when clearfelling. In this analysis, an optimistic 80% increase in harvest cost for SGS, over clearfelling, has been used under the assumption that harvest costs for selective logging would be reduced as efficiencies were developed with operational experience. A harvest subsidy of \$15/t above the clearfell rate was used as the predicted harvesting cost for the SGS treatment, although the real cost at the trial was about \$30/t above the clearfell rate.

An overhead cost of \$21/ha/year was applied to all systems to reflect the cost of managing lands for wood production and fire protection. It was nominally based on the fixed cost of maintaining a Forest District.

Discount rates

The discount rates used for revenues and costs in this analysis are 2% and 10%. These values were chosen to simulate two different approaches to calculating NPV. The first, at 2%, reflects a 'social opportunity cost' approach, which assigns high value to future forest assets. The second, at 10%, reflects a proxy for the expectations in commercially driven forestry. The two rates are chosen to reflect widely different expectations and ignore the complexities of taxation and possible declining marginal social rates of time preference as discussed by Ferguson (1996). All calculations are performed at fixed 2003 prices under the assumption that all future cash flows follow the inflation rate. This assumption implies no change in relative costs and prices—a widely accepted assumption for this kind of analysis.

The economic model

The economic model produces expectation values that are directly comparable. For the CBS system and the CBS with understorey islands, expectation value is represented by the soil expectation value plus the liquidation value of the mature forest because the rotation length is fixed and the stand is clearfelled, leaving bare soil. Expectation value calculations for clearfell systems are relatively simple compared to partial felling systems, where the value and growth of the retained overstorey has to be taken into account.

There are usually two options for partial felling systems:

- Continue the cyclic treatment, or
- Halt the cycle and clearfell the residual stand.

By choosing to continue the cyclic system, the value of the current stand (R in Equations 2 and 3) is automatically

Table 2. Summary of cost and benefits ($/ha) for all systems over the first cutting cycle. Age is the number of years from establishment when cost or benefit is incurred.

	Age (yr)	CBS	CBS +UI	Strips	DRN A	DRN B	ARN A	ARN B	SGS A	SGS B
Costs										
Retained tree marking	0	0	30	0	80	80	150	150	30	30
Felling unsafe trees with explosives	0	35	35	20	190	190	25	25	240	240
Contractor subsidy	0	0	0	0	660	660	260	260	1 100	1 100
Seed-crop assessment	1	1	1	1	1	1	1	1	1	1
Fire-line construction	1	150	150	580	100	0	100	0	0	0
Slash treatment	1	0	15	50	60	360	60	360	0	2 944
Burning	1	30	30	230	100	100	100	100	0	0
Seed and sowing by aircraft	1	220	220	$0	0	220	0	220	0	0
Annual overhead cost	all	21	21	21	21	21	21	21	21	21
Benefits (harvest of standing timber)										
	0	7 627	7 412	3 813	6 864	6 864	5 339	5 339	1 525	1 525
	18								1 525	1 525
	36								1 525	1 525
	45			3 813						
	54								1 525	1 525
	72								1 525	1 525
	90	20 149	19 581	7 123	17 484	17 484	14 104	14 104	1 525	1 525

re-invested in economic terms. The NPV of this investment is then calculated using a simple NPV formula (Holten-Andersen 1987, 1988).

Results

Results are presented for a discount rate of 2% and then for a discount rate of 10%.

2% discount rate

The results of the analysis, using a 2% discount rate, are shown in Figure 1. The CBS system has the highest economic viability of the tested systems at Warra, and the SGS-B system the lowest. Expectation value (EV) was positive for all treatments analysed, except SGS-B. The analysis was dominated by the high value of the existing crop, which has a liquidation value (*R*) of $7627/ha, if sold at 2003 stumpage prices. Not surprisingly, the results show that optimal EV is closely related to silvicultural systems with high immediate revenue and low re-establishment costs. This is a natural consequence of the EV calculations when a discount rate is applied.

The effect of growth suppression on EV was tested by running the model with and without suppression included. The greatest effect was for the stripfell treatment, where the model predicted that suppression by retained edges reduced the merchantable volume from a 90-year rotation by 21%. However, after discounting, this resulted in only an 8% reduction in EV. The reduction in EV by growth suppression in dispersed and aggregated retention treatments was about 3%.

10% discount rate

The results of the analysis, using a 10% discount rate, are shown in Figure 2. Again, the CBS system has the highest economic

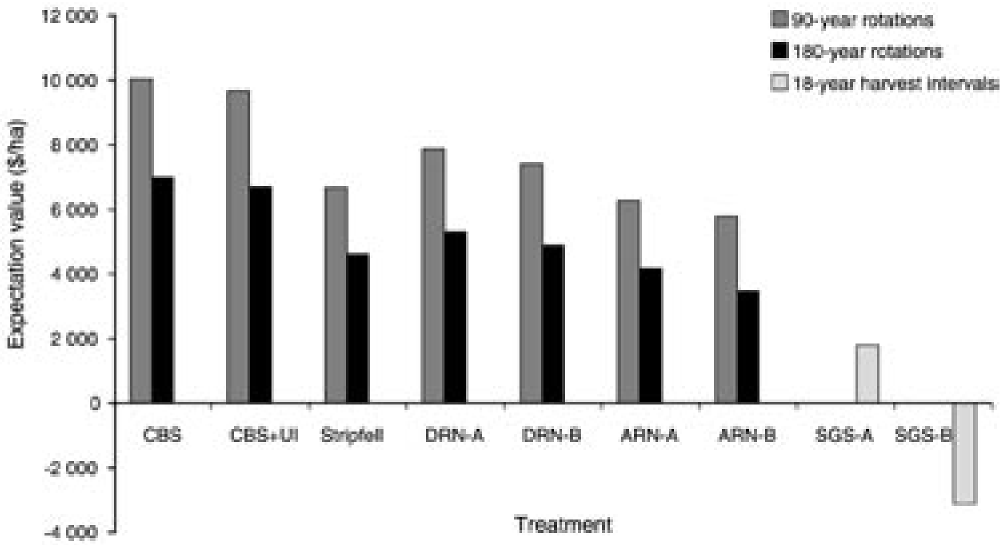

Figure 1. Expectation value of the various silvicultural systems when applying a 2% discount rate.

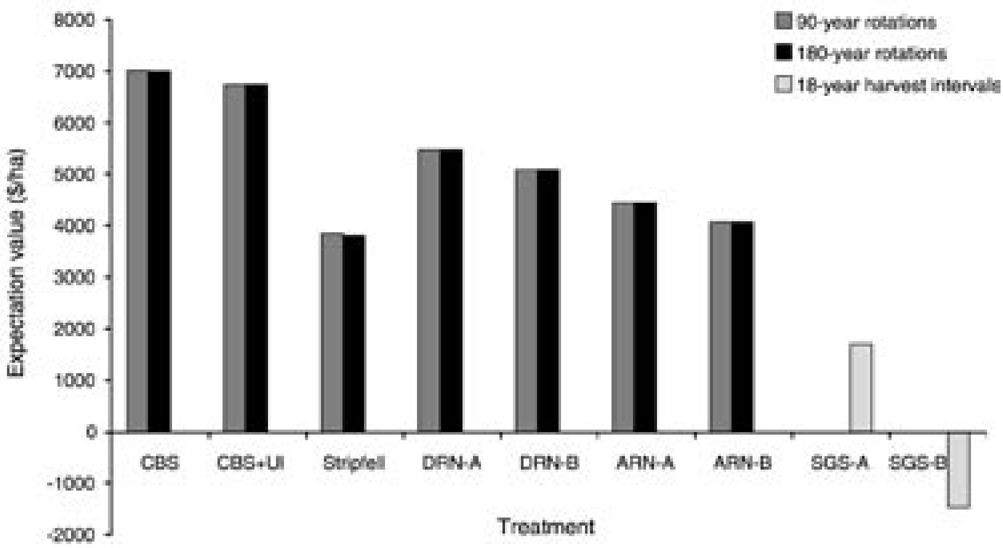

Figure 2. Expectation value of the various silvicultural systems when applying a 10% discount rate.

viability of the systems tested at Warra, and the SGS-B system has the lowest economic viability. However, the stripfell and aggregated retention systems have changed their ranking between discount rates of 2% and 10% (Figures 1 and 2).

Expectation value was positive for all treatments analysed, except SGS-B. Again, the analysis was dominated by the high value of the existing crop and shows that optimal EV is closely related to silvicultural systems with high immediate revenue and low regeneration costs, particularly when the higher discount rate is applied. This is reflected in Figure 2 by the insignificant differences in EV for each treatment between 90- and 180-year rotations with 10% discount rate, compared to the obvious differences in Figure 1 where a 2% discount rate is applied.

The EV of $7016/ha for the highest ranked system, CBS over a 90-year rotation, was less than the liquidation value of $7627/ha. This indicates that an investment in regeneration cannot be recouped at a 10% discount rate.

The effect of growth suppression on EV was insignificant at a 10% discount rate. For example, the present value of the full harvest revenue from a clearfelling in 90 years time is only $4. Hence, suppression effects are irrelevant to the current economic decision even though they have a significant effect on future log supply.

Opportunity cost analysis

Calculation of opportunity costs allows the benefits foregone by not undertaking the optimal feasible economic solution to be compared. The economically optimal management decision under either discount rate is to undertake CBS on a 90-year rotation (Table 3). Other systems, therefore, are compared to this.

The opportunity cost analysis also indicates the value by which the grower must be compensated in order to be given an incentive to change silvicultural systems. For example, Table 3 indicates a grower would notionally require compensation of at least $3783/ha to change from a CBS system to an aggregated retention system (at a 2% discount rate and rotation length of 90 years).

Table 3. Opportunity cost of the silvicultural systems, calculated as expectation value of 'best option (CBS at 90 years)' less the expectation value of a particular alternative, for discount rates of 2% and 10%.

	Rotation length (yr)		
	18	90	180
Opportunity cost ($/ha) at 2% discount			
CBS	-	0	3 060
CBS+UI	-	373	3 346
DRN-A	-	2 172	4 749
DRN-B	-	2 653	5 172
Stripfell	-	3 373	5 437
ARN-A	-	3 783	5 879
ARN-B	-	4 265	6 303
SGS-A	8 263	-	-
SGS-B	13 170	-	-
Opportunity cost ($/ha) at 10% discount			
CBS	-	0	4
CBS+UI	-	259	262
DRN-A	-	1 531	1 534
DRN-B	-	1 913	1 916
Stripfell	-	3 157	3 203
ARN-A	-	2 562	2 564
ARN-B	-	2 944	2 946
SGS-A	5 310	-	-
SGS-B	8 468	-	-

Optimal economic rotation lengths

Although this research was aimed at examining the expectation value for given rotation lengths, it is possible to determine optimal economic rotation lengths from the model for regimes other than the SGS treatment. (The SGS treatment could not be usefully modelled due to lack of growth data). To do this, the model was run for rotations of five years, then for subsequent increments of five years (i.e. 5, 10, 15 etc.) for each regime and for both discount rates.

Using a discount rate of 2%, the optimal economic rotation ranged from 40 to 50 years (Table 4). At a 10% discount rate, the stripfell and dispersed retention regimes had a declining NPV from year zero onwards, indicating that they have no optimal economic rotation. For the CBS and aggregated retention treatments, the optimal economic rotation length was between 20 and 25 years.

Table 4. Optimal economic rotations, and expectation values (EV) at optimal economic rotations, for discount rates of 2% and 10% for the various silvicultural systems (insufficient growth data available to model SGS).

	Optimal economic rotation (yr)	EV ($/ha)
2% discount rate		
CBS	50	11 593
CBS+UI	50	11 162
DRN-A	45	9 718
DRN-B	45	9 137
Stripfell	40	8 865
ARN-A	50	7 302
ARN-B	50	6 737
10% discount rate		
CBS	20	7 363
CBS+UI	20	7 086
DRN-A	0	6 425
DRN-B	0	5 661
Stripfell	0	7 224
ARN-A	25	4 656
ARN-B	25	4 239

Discussion

The assessment of timber values in wet *Eucalyptus obliqua* forest is complex and involves many variables. Many of these factors, such as growth rates and potential cost reductions that can be achieved over time, are not known with certainty at this early stage of monitoring the silvicultural systems trial. This preliminary assessment of timber values required significant assumptions regarding factors such as growth, future stumpages, costs, and suppression levels, but these assumptions are consistently applied to the alternatives explored here.

The economic analysis is dominated by the high value of the standing crop. Due to the discounting of cost and revenue flows, future values quickly become less important. This makes most future timber price fluctuations relatively insignificant, especially at a discount rate of 10%. Hence, clearfell systems that initially recover the entire stand value are economically more favourable than stripfells and retention systems. SGS proved to be economically less attractive than all other systems trialled, partly due to high running costs, and partly due to the delay of harvest and thus the influence of discounting on revenue from future harvests. Another, but less important, factor is the suppression of the new stand, which means that the alternatives ultimately yield less timber than the CBS systems. While the effect of suppression is insignificant in this financial analysis, it may ultimately have a very significant effect on long-term timber supply, which would need to be reflected in present-day reductions in the sustainable yield supply for a region.

The relative rank of the silvicultural systems changes between the application of a 2% discount rate and a 10% discount rate, as aggregated retention becomes economically superior in terms of timber value compared to stripfelling when a higher discount rate is applied. This is a consequence of the relatively larger share of initial harvest in aggregated retention (70% of total) compared to stripfelling (50% of total). The second half of the stripfelled stand is harvested after half of the rotation length and the return has to be discounted to year zero. The present value of this future harvest is insignificant compared to the value of immediate felling of 20% more of the standing forest in year zero. With a 10% discount rate and a 90-year rotation, the mid-rotation harvest returns a present value of only $52 in year 45 compared to $3814 in year zero. The discounting makes up for the major difference in EV of the different systems. Further explanation may be found in the difference in operational costs between the systems.

The opportunity cost estimates the value foregone by not choosing the optimal economic silvicultural system under the given set of constraints during the management decision process, and can be taken as defining the size of a pool of non-timber values that justifies selection of an alternative system. Potentially, part of the opportunity cost may be compensated for by a ‘green premium’ gained from timber grown using more socially or ecologically desirable silvicultural systems. However, there is currently no evidence that such a premium would be reflected in the timber prices obtainable in the market. Market analysts suggest that prices will not be radically affected by ‘green premiums’ on certified timber. Instead, the certification of sustainable forest management practices will be a necessity for forest owners to stay competitive on the future market (Ozanne *et al.* 1999). The opportunity cost of the various systems is also subject to fluctuation, with improved efficiencies as new silvicultural systems are developed over time.

The results of this comparison are based solely on timber values and do not consider environmental and social values. The cost to the grower for not undertaking the optimal economic option (Table 3) may be compensated by increases through other values. These values must be acknowledged by the recipient in order to provide incentive for the grower to maintain or establish them. Such values are largely based on aesthetic or environmental benefits associated with particular silvicultural systems (Ford *et al.* 2005). Society may choose to reward the grower by subsidies or compensation payments to adopt economically sub-optimal systems that provide social or environmental benefits. Alternatively, it may use legislation or policy instruments to require owners to provide these benefits. This latter approach is more likely for forest on public land.

Non-timber value can be defined as a pool of values that are not directly linked to the value of the actual timber. The pool consists of many goods and services, and these are valued differently, depending on the person, society or part thereof that assesses them. It is obvious that members in society are bound to have preferences that rank non-timber values differently. The value assigned by a person fluctuates with time, trends and personal interests. This emphasises the need for a flexible management system that is adaptable to fluctuations in demand by society.

Conclusion

This preliminary economic assessment, based on timber values, of systems from the Warra silvicultural systems trial shows that none of the alternative systems at Warra are economically attractive at a discount rate normally used for investment purposes. Investment purposes in this context means a discount rate that a commercial forestry enterprise would apply to an investment decision, currently about 10%. At this discount rate, all operations following the liquidation of the existing stand have a negative influence on expectation value and are therefore not commercially attractive.

At the discount rate of 2%, there are three systems of 90-years rotation length that generate a profit greater than the liquidation value. These are CBS, CBS with understorey islands, and dispersed retention A. If clearfelling were not permitted, then the next most financially attractive system would be dispersed retention with a low intensity regeneration burn, followed in order by stripfell, aggregated retention and SGS. However, in practice, the selection of a particular alternative system would not be based on economics alone, but on a range of environmental and social factors as well as practical operational issues such as worker safety and operability.

This study has applied economic investment theory to understand and evaluate the economic differences of various silvicultural systems. Many forest management agencies do not use this approach directly because of the long time horizons, from an investment perspective, associated with native forest management. It is more commonly applied in plantation investment decisions, where time horizons are shorter, usually 15–30 years. A more common practice among agencies managing native forest is to apply the concept of profit maximisation to their business plan, by maximising revenues and minimising costs while operating within a sustainable forest management framework. This implies that an agency must produce an annual profit on an ongoing basis, which changes significantly the objective of an assessment of alternative silvicultural systems. Using this approach, all the systems at Warra are profitable, except for SGS-B, because they all generate higher revenues than the costs of planning, regeneration and management. The profit maximisation approach does not accommodate the long-term effects of a change in silvicultural system, as preferences for future utility must be assigned in order to make a rational decision. One system may generate profit on an annual basis in the near future but fail to do so in the distant future when the system has affected harvestable volumes of timber. Accordingly, economic investment theory is the best available method for economic evaluation of alternative silvicultural systems in native forest management.

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