Chapter 4 Economic modelling of a commercial *E. radiata* subsp. *radiata* oil production enterprise

4.1 Introduction

Growing trees for essential oil production may be an economically viable agricultural diversification option under certain conditions, and could be incorporated into an existing farm tree planting program. Only a relatively small area of land needs to be set aside for a plantation, and a positive financial return may be realised after just 4 to 6 years, compared with a minimum of approximately 15 to 20 years for a positive return from a commercial timber crop.

Davis (1995) determined that it is probably not feasible to set up a viable eucalyptus oil operation if land and all the required equipment have to be purchased. However, if land and some standard items of agricultural equipment are already owned, and the cost of establishment is covered by some other project such as planting for salinity amelioration, a profitable operation might be achieved. He concluded that market price is the key variable. Abbott (1989) earlier pointed out that small-scale farm production of eucalyptus oil has the potential to be an important rural industry.

It is difficult to predict the financial performance of a eucalyptus oil operation due to the many factors that influence production and marketing. The major determinants of profitability are the costs of production, markets and the selling price. Major costs lie in development (such as land clearing, road construction and ground preparation), plantation establishment and management, harvesting, distillation and marketing. The costs of production of a kg of eucalyptus oil can vary greatly (Abbott, 1989), depending on factors such as tree species, the age of the trees, leaf oil concentration, tree stocking rate, seasonal conditions, and harvesting and production methods. Abbott (1989) reported that accounts kept by Felton Grimwade and Bickford Pty Ltd reveal that commercial eucalyptus oil production from *E. polybractea* was, for them, only marginally profitable.

The aim of this component of the study is to determine the financial performance of a 'baseline' farm-scale *E. radiata* subsp. *radiata* oil production venture, and evaluate the impacts of gains in oil production achieved through selection and breeding, as well as incorporating different harvesting, processing and marketing regimes.

The objectives are:

(1) to develop a detailed spreadsheet-based economic model of a commercial farm-scale eucalyptus oil production venture, utilising realistic production and cost information;

(2) to determine the financial impact of production gains realised utilising selected stock, derived from information generated in Chapter 3;

(3) to determine the financial impact of incorporating improved efficiencies in production and marketing into the model; and

(4) to determine optimum production and price parameters required to achieve a realistic pre-determined rate of return from the venture.

4.2 Materials and methods

4.2.1 The 'baseline' scenario

This component of the study involves the development of a farm-scale *E. radiata* subsp. *radiata* plantation and oil production economic model using a Microsoft Excel 2000 spreadsheet. Initially, a 'baseline' scenario is modelled, primarily on the Brogo provenance/progeny trial and commercial plantation, and utilising the baseline production parameters presented in Table 4.1. Subsequent simulation of a number of production scenarios is carried out to investigate sensitivity to varying a number of key production variables. The model interface is included as Appendix C.

The baseline production parameters were determined from a number of sources. These included personal experience in plantation establishment and management, and extensive personal communication with J. Doran (1996-2002) who established, and has produced and sold oil from the *E. radiata* subsp. *radiata* provenance/progeny plantation trial at Brogo. Consultation with other growers and producers of various essential oil and mulch products including those from tea tree was also carried out. The justification for using the value presented in Table 4.1 is presented below.

To ease the initial cashflow situation, the plantation establishment program in the 'baseline' scenario is carried out in stages, with 5 ha being planted in each of years 0, 2 and 4. The still and some other basic equipment is either purchased or made up on-farm in year 2. A land opportunity cost of \$100 ha yr^{-1} is factored into the enterprise based on Zorzetto and Chudleigh (1999) and B. Gardiner (pers. comm., 2003). Estimated plantation establishment and maintenance costs of \$3,200 ha^{-1} for 2 years for a stocking rate of 2222 are based on personal experience in best practice establishment and early management techniques.

The oil yield figures are based on those achieved in Doran *et al.* (1998b) and from a recent commercial harvest of the Brogo trial (J. Doran, pers. comm., 2000). The harvesting and distillation costs are based on simple hand harvesting with chainsaw, cane knives and manual loading of the still, and are again based on the harvesting and distillation of the Brogo trial (J.

Doran, pers. comm., 2001). Graham Thompson of Reedy Creek Eucalyptus Oil Australia Pty Ltd (a producer of *E. radiata* subsp. *radiata* oil from native stands near Tilba in southern New South Wales) agrees with Doran's harvesting and distillation figures (J. Doran, pers. comm., 1998). The farm-gate bulk oil price used in the analysis (i.e. \$23 kg^{-1}) is that received for the oil produced from the Brogo trial sold into a niche-type market (J. Doran, pers. comm., 2001). The spent leaf mulch price used in the analysis accords with the farm-gate price that some tea tree producers in northern New South Wales are receiving for mulch from wholesalers (R. Dyason, pers. comm., 2001). Tree mortality following harvest of 5% of the total number of trees cut is estimated from the mortality following commercial harvesting of the Brogo trial (J. Doran, pers. comm., 2001).

When assessing an investment project such as this, the real discount rate should be used (R. Heane; F. Scott, pers. comm., 2002). This is determined as a function of the market interest rate and the inflation rate (Sinden and Thampapillai, 1995), and calculated using the following equation:

$$\mathbf{r = i - k} \qquad \text{... (Equation 4.1)}$$

where *r* represents the real discount rate; *i* represents the interest rate; and *k* represents the inflation rate. The Commonwealth government 10-year bond rate (8%) was used as the current market interest rate, while 3% inflation was used. The value of the real discount rate was therefore calculated at 5%. Annual cashflows were calculated on a non-discounted basis.

Table 4.1. Production parameters used for modelling a farm-scale baseline *E. radiata* subsp. *radiata* plantation and essential oil production operation

Parameter	Value	Units
Project timeframe	20	years
Area planted - year 0	5	ha
Area planted - year 2	5	ha
Area planted - year 4	5	ha
Tree spacing	3.0 x 1.5	m
Planting density	2222	trees ha^{-1}
Plantation establishment and early maintenance costs	3200 *	\$ ha^{-1}
Land opportunity cost	100	\$ ha^{-1}
Hand harvesting costs	14.00	\$ kg^{-1} oil
Distillation costs	3.50	\$ kg^{-1} oil
Leaf handling costs	1.20	\$ kg^{-1} oil
Oil marketing costs	1.30	\$ kg^{-1} oil
Farm still costs	6849	\$
Other equipment costs	2000	\$
First harvest	2	years
Subsequent harvests	2	years
First harvest oil yield	130	kg ha^{-1}
Subsequent harvest oil yield	340	kg ha^{-1}
First harvest mulch yield	0.98	t ha^{-1}
Subsequent harvest mulch yield	2.55	t ha^{-1}
Tree mortality rate after each harvest	5	%
Oil price	23.00	\$ kg^{-1}
Spent leaf mulch price	50.00	\$ t^{-1}
Discount rate (real)	5	%

* see Appendix D for details of establishment costs

4.2.2 Sensitivity analysis

A number of alternative production scenarios were modelled, each resulting in an annual cashflow, net present value (NPV) and internal rate of return (IRR) for the particular scenario, and allowing financial comparisons to be made with the baseline scenario. Parameters that were investigated included sensitivity to discount rate, the timing and area of plantation establishment, gains in production as a result of utilising selected stock (including the cost of improved seed), harvesting and distillation costs, and product sale price. The results were determined by making changes to key parameters in the baseline scenario and re-running the model. The implications of the Goods and Services Tax and other forms of taxation were not accounted for in these simulations.

To determine sensitivity of the baseline scenario to discount rate, the model was run using discount rates of 3%, 5% (baseline) and 7%. To determine sensitivity to timing and area of plantation established, the model was run varying the years in which the plantation was established and the area established each year. The total 15 ha area of the plantation was held constant. The three scenarios were: (1) establishing the whole 15 ha in year 0; (2) establishing 5 ha per year for each of the first 3 years; and (3) establishing 7.5 ha per year in each of the first 2 years.

To determine sensitivity to plantation oil yield as a result of selection and utilising improved planting stock, the model was run utilising various oil yields achieved through gains in leaf oil concentration as a result of selection and breeding (Chapter 3). The three oil yield scenarios were based on: (1) a plantation established from unselected *E. radiata* subsp. *radiata* seedstock from native stands in south-eastern New South Wales; (2) a plantation established from selected seedstock from native stands, resulting in a 20% relative gain in leaf oil concentration (i.e. the baseline scenario, being the Brogo trial); and (3) a plantation established from seedstock from selected superior trees in the Brogo provenance/progeny trial, resulting in an estimated further 11.7% relative gain in leaf oil concentration (Chapter 3). It was assumed that there was no genetic correlation between leaf biomass and oil concentration in *E. radiata* subsp. *radiata* (as reported for *E. polybractea* by Grant, 1997), and that leaf biomass production would therefore not change as a result of selection for high leaf oil concentration. The expected increase in total plantation oil yield would be achieved only via gains in leaf oil concentration on a weight of oil per weight of leaf basis (w/w%). The mass of spent leaf mulch product would not be expected to increase following selection, and was therefore held constant in modelling the different oil yield scenarios. This is likely to be conservative. When account is taken of Doran *et al.* (1998b)*'s* finding that tree basal area is strongly associated with leaf biomass in *E. radiata* subsp. *radiata* and the positive genetic correlation between basal area and oil concentration estimated in this study, it could be expected that selecting for high oil concentration may also result in increased leaf biomass production.

To determine sensitivity to production costs and product sale prices, the model was initially run assuming that no market was available for the spent leaf mulch. Subsequently the model was run varying the oil sale price. It was initially reduced to half of the baseline price of \$23.00 kg^{-1} and then increased to one and a half times the baseline price in increments of 12.5%. Runs were also performed holding all baseline parameters constant except for harvesting and distillation costs, which were reduced and increased in a similar manner as for oil sale price. Finally, concurrent changes in oil sale price and harvesting and distillation costs were investigated. Again, the two variables were increased and reduced in 12.5% increments from the baseline \$20.00 kg^{-1} oil harvesting and distillation costs and the \$23.00 kg^{-1} sale price of oil.

To investigate the requirement for an IRR of 15 percent, the model was run varying oil sale price and oil production costs systematically until the required IRR was achieved.

4.3 Results

Figure 4.1 illustrates the annual cashflow position generated throughout the 20-year time-frame of the 15-ha baseline plantation and oil production venture. The NPV of the baseline scenario was $68 and the IRR was 5.02 percent. The cashflow break-even point occurred in year 14.

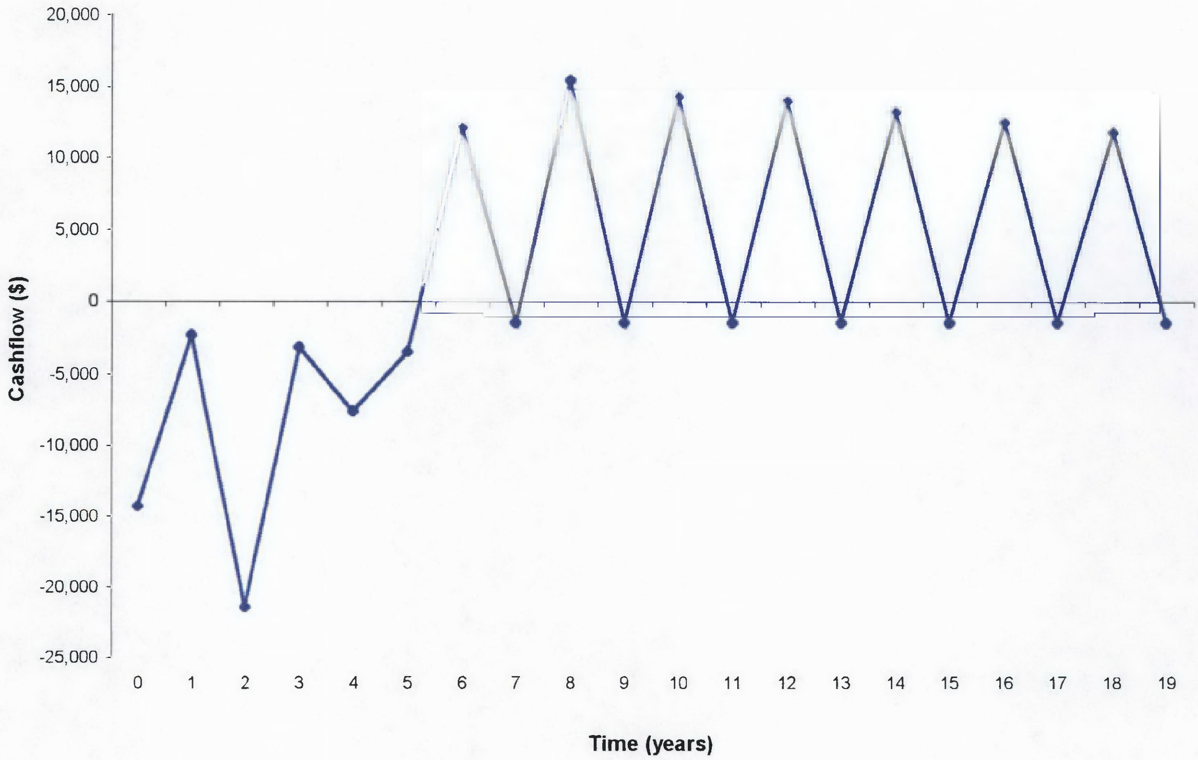

Figure 4.1 - Cashflow of the baseline *E. radiata* subsp. *radiata* oil production venture

Table 4.2 presents the results of the impact of discount rate on the NPV of the venture. A discount rate of 3% resulted in a NPV of $9,427, compared with the baseline scenario NPV of $68, using a discount rate of 5%. Using a discount rate of 7%, the NPV was -$6,684.

Table 4.2 – Sensitivity of the NPV of the venture to discount rate

Discount Rate (%)	Net Present Value ($)
3	9,427
5	68
7	-6,684

Figure 4.2 illustrates a comparison of the annual cashflow position of the venture over the 20-year time-frame under four different plantation establishment regimes: (1) the baseline scenario, (2) when all 15 ha were established in year 0; (3) when 5 ha were established in each of the first 3 years; and (4) when 7.5 ha were established in each of the first 2 years. When the total 15 ha were established in year 0, the NPV was $3,030 and the IRR = 5.68 percent. The cashflow break-even point occurred in year 10. When plantation blocks were established at 5 ha yr^{-1} in each of the first 3 years, the NPV was $1,188, while the IRR was 5.28 percent. The cashflow break-even point occurred in year 12. When plantation establishment was carried out at 7.5 ha yr^{-1} in each of the first 2 years, the NPV was $2,825 and the IRR was 5.64 percent. The cashflow break-even point occurred in year 12. A smoother cashflow pattern was derived, with a positive returns of similar magnitude generated each year (after year 3).

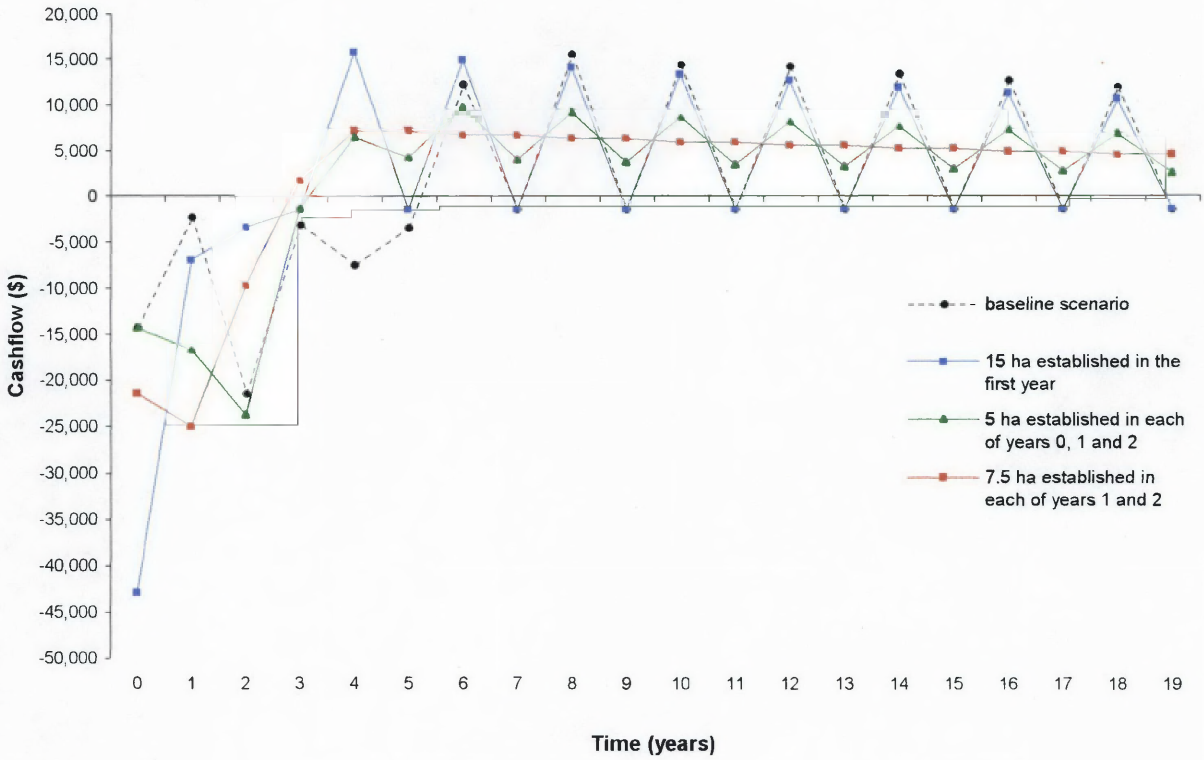

Figure 4.2 - Comparison of cashflow between the baseline venture and the same production scenario but with: all 15 ha of the plantation established in the first year; 5 ha established in each of the first three years; and 7.5 ha established in each of the first two years

Figure 4.3 illustrates the effect of utilising selected stock and the associated increase in leaf oil concentration and plantation oil yield. A venture based on a plantation established from unselected *E. radiata* subsp. *radiata* seedstock from native stands on the New South Wales south coast had an NPV of -$9,633 and an IRR of 2.39 percent. A venture based on a plantation established from seedstock selected from native stands, resulting in an estimated 20% gain in oil yield (i.e. the Brogo trial), had an NPV of $68 and an IRR of 5.02 percent. A venture based on a plantation established from seedstock selected for high leaf oil concentration from the Brogo trial (resulting in a further 11.7% gain in plantation oil yield) had an NPV of $6,861 and an IRR of 6.67 percent.

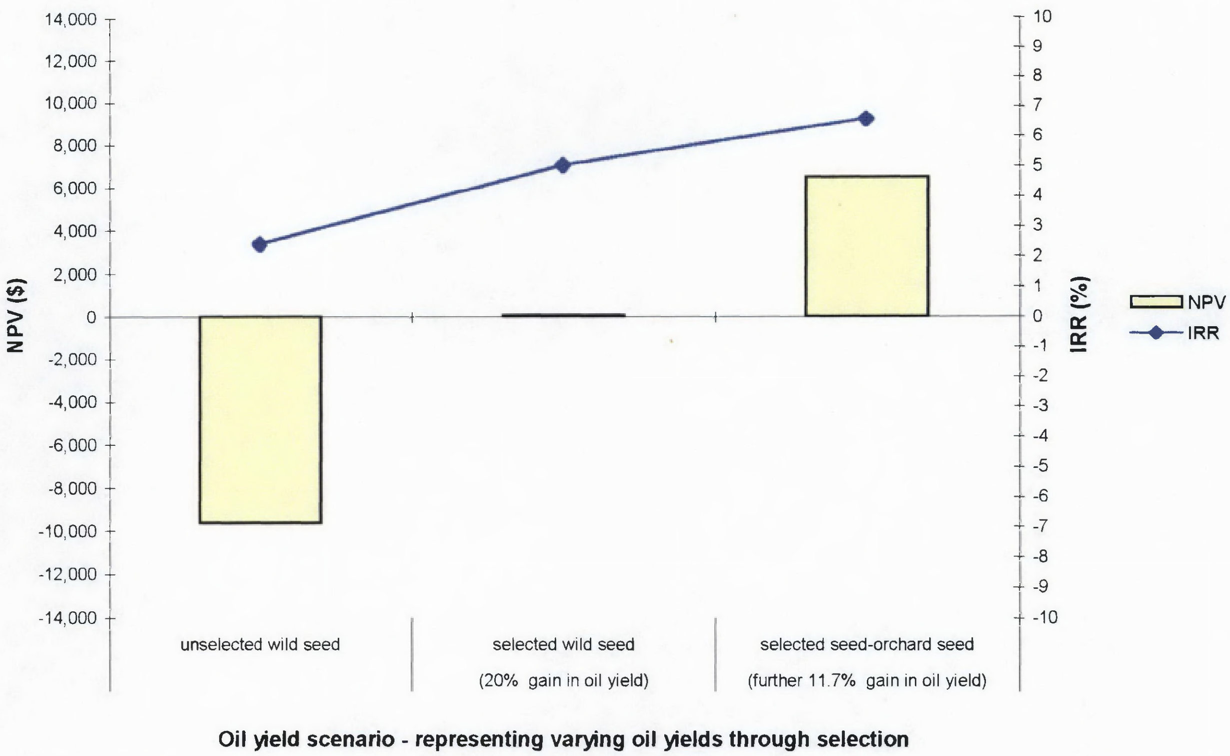

Figure 4.3 - NPV and IRR of the venture considering three oil yield scenarios as determined by the level of improvement of plantation seedstock for high leaf oil concentration

If sales of the spent leaf (as a garden mulch product) were not realised, and only the oil was sold, the NPV of the venture was -$7,160 and the IRR 3.10 percent. Figure 4.4 illustrates the result of varying the farm-gate sale price of oil from the baseline of $23.00 kg^{-1}. When production parameters were held constant, oil price increases ($25.88, $28.76, $31.64 and $34.50 kg^{-1}) resulted in NPVs and IRRs of $55,578 and 16.1 percent, $111,088 and 24.3 percent, $166,598 and 31.2 percent and $221,722 and 37.4 percent, respectively. When the oil price was reduced in 12.5% increments to half of the baseline price ($20.14, $17.26, $14.38 and $11.50), the NPVs were -$55,056, -$110,566, -$166,076 and -$221,585, respectively. Figure 4.5 illustrates the cashflow pattern of the venture when the farm-gate price received for oil was increased by half of the baseline scenario value to $34.50, and when it was halved, to

$11.50. The cashflow break-even point was achieved in year 6 when the price was increased by half.

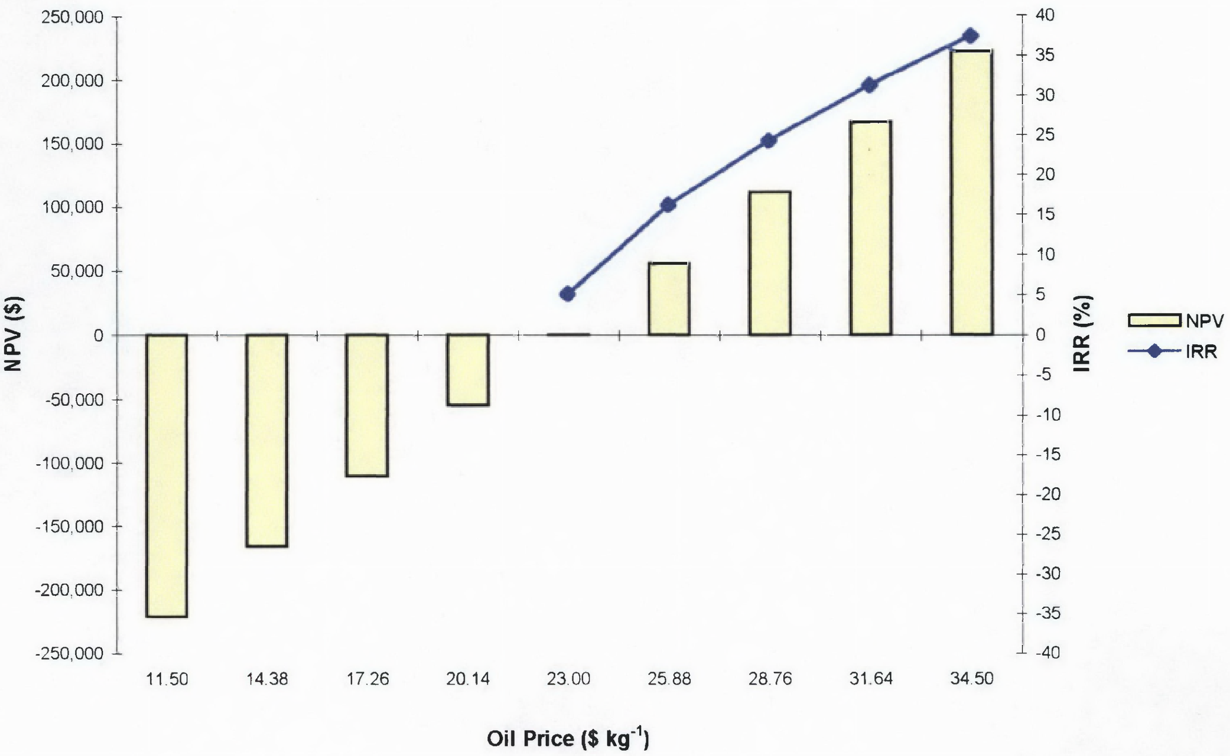

Figure 4.4 - The effect on the net NPV of the venture by varying the farm-gate oil sale price while all other parameters of the baseline scenario are held constant

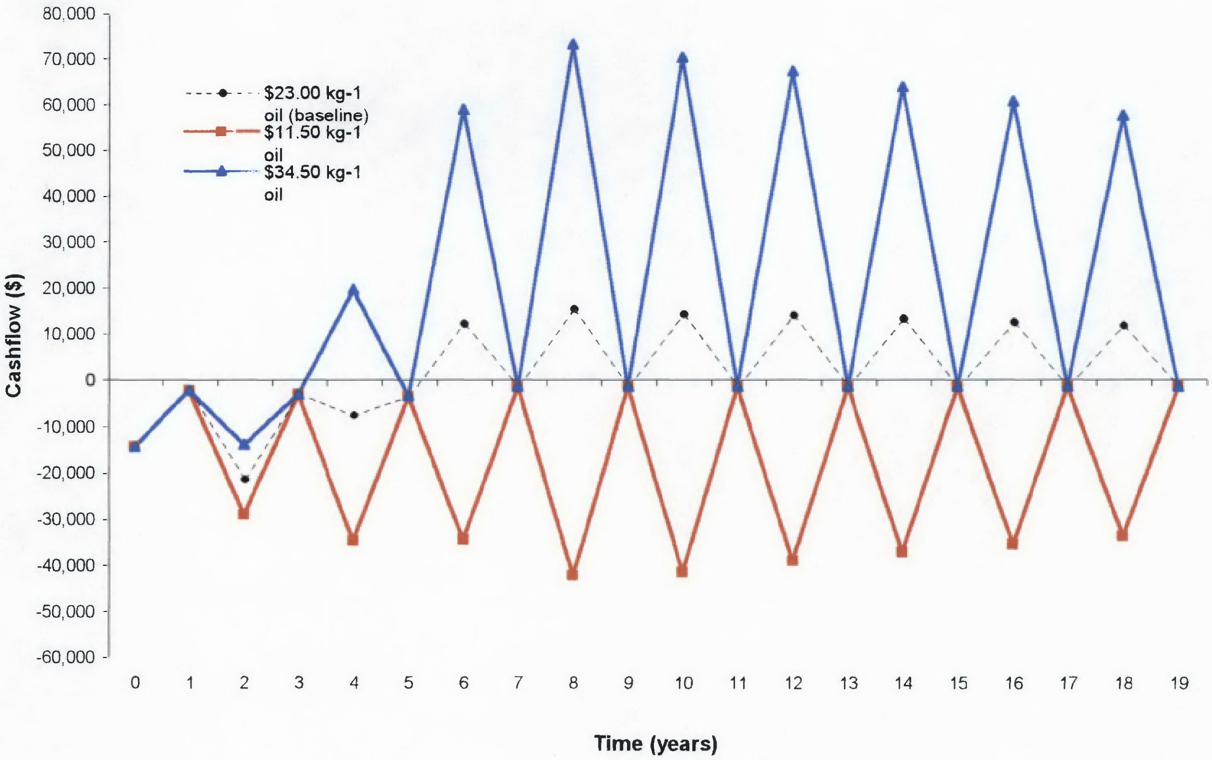

Figure 4.5 – Comparison of cashflow of the venture if farm-gate price received for oil was increased by 50% (i.e. $34.50 kg^{-1}), and reduced by 50% (i.e. $11.50), while all other parameters of the baseline scenario are held constant

Figure 4.6 illustrates the sensitivity of the operation to harvesting and distillation costs. When parameters in the baseline scenario were held constant, but the harvesting and distillation costs were increased by 12.5% from the baseline cost to $22.50 kg^{-1} of oil produced, the NPV fell from $68 to -$48,117. If the harvesting and distillation costs were increased to one and a half times the baseline costs, the NPV of the venture was reduced to -$192,674. When harvesting and distillation costs were reduced by 12.5% from baseline costs to $17.50 kg^{-1}, the NPV of the venture was $48,254 and the IRR 14.8 percent. Production costs were further reduced to half of the costs in the baseline scenario, and the NPV of the venture improved to $192,881 and the IRR to 34.2 percent.

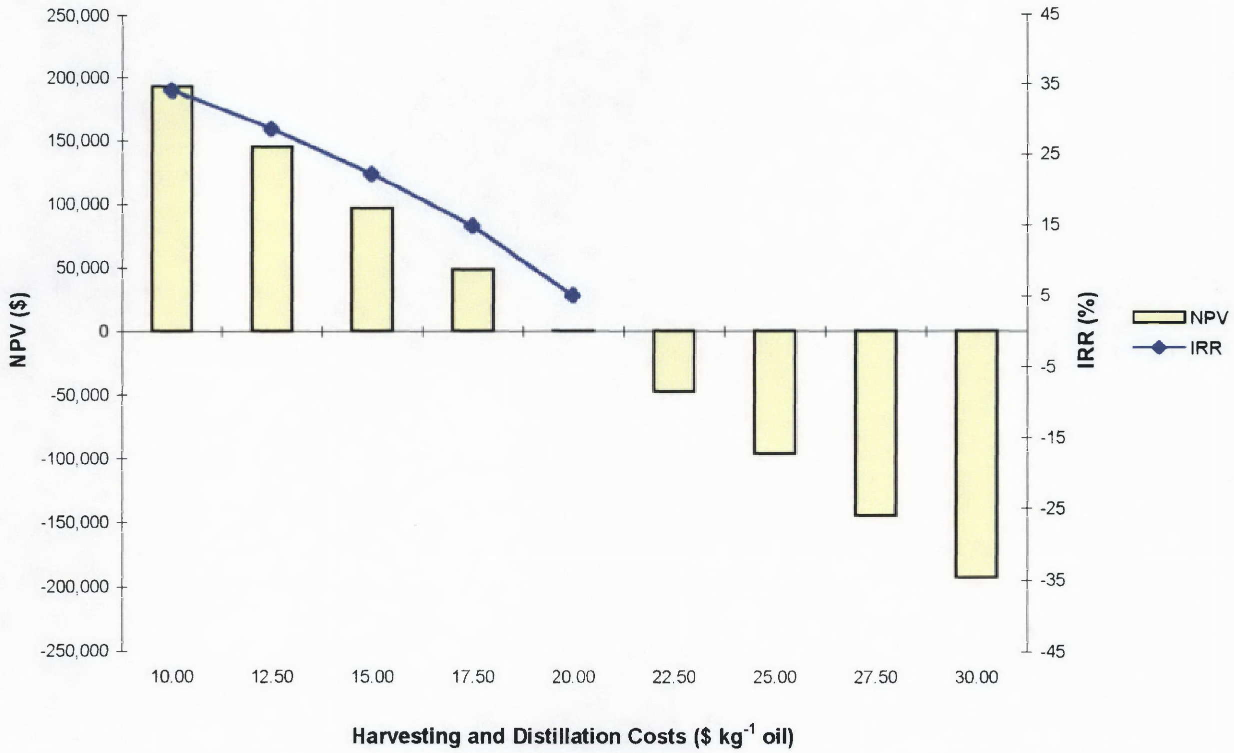

Figure 4.6 - The effect on the NPV of the venture by varying the harvesting and distillation costs while all other parameters of the baseline scenario are held constant

To this point, the cost of mechanical harvesting had not been factored into the simulations. If such equipment was purchased at the time of the first harvest for $50,000 the resultant NPV was $151,346 and the IRR was 20.5 percent, assuming harvesting, distillation and handling costs had been effectively reduced by 50% as a result of mechanisation. Figure 4.7 illustrates the cashflow pattern of the venture achieved as a result of increasing production costs by half over the baseline costs, as well as that brought about by reducing the production costs by half (but including the additional costs of mechanised harvesting equipment).

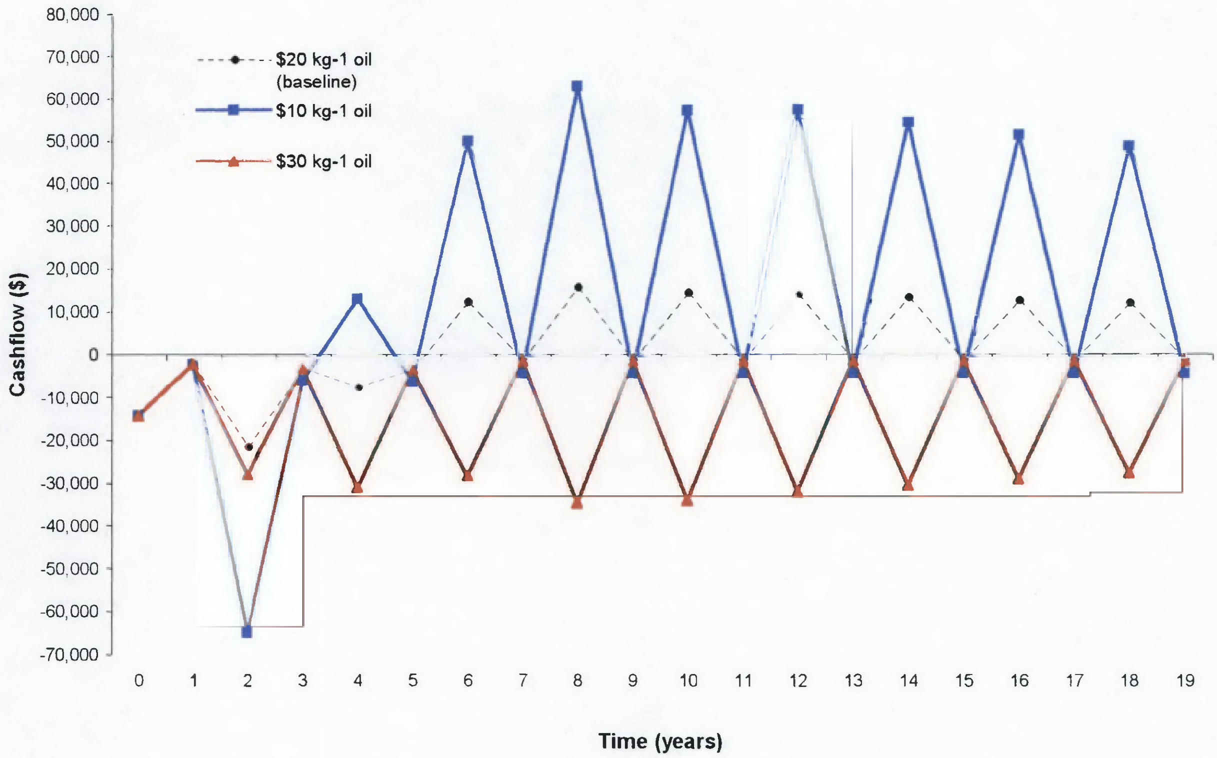

Figure 4.7 - Comparison of cashflow of the venture if harvesting and distillation costs were increased by 50%, and if harvesting and distillation costs were reduced by 50% (and costs of mechanical harvesting plant are added), while all other parameters of the baseline scenario are held constant

Figure 4.8 indicates the target farm-gate oil sale prices and production costs that a producer could aim to achieve in order to determine the NPV of their operation. For example, in order for the NPV of the operation to be positive while the market price for oil was approximately \$12.95 kg^{-1}, production costs could not exceed \$10 kg^{-1}.

Table 4.3 illustrates the oil sale price that must be achieved in conjunction with varying production costs and oil yield scenarios if the producer is to achieve an IRR of 15.0 percent on their business investment.

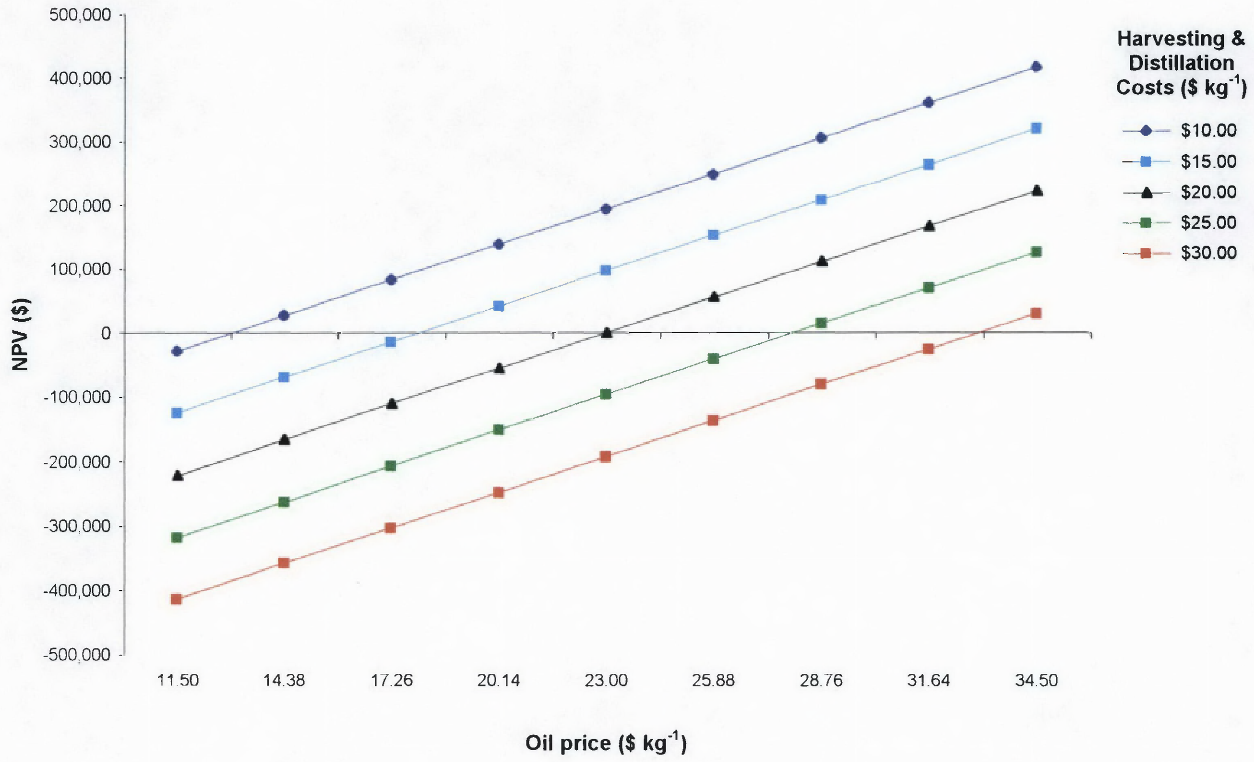

Figure 4.8 - The effect on the NPV of the venture by concurrently reducing or increasing the harvesting and distillation costs and the oil sale price while all other parameters of the baseline scenario are held constant

Table 4.3 – Relationship between oil production costs, plantation oil yield and oil sale price in achieving a 15 percent IRR

Harvesting & Distillation costs ($ kg^{-1})	Oil yield scenario*	Oil sale price required to achieve a 15% IRR ($ kg^{-1})
10.00	1	16.67
	2	15.55
	3	14.97
12.50	1	19.17
	2	18.05
	3	17.47
15.00	1	21.68
	2	20.56
	3	19.98
17.50	1	24.17
	2	23.05
	3	22.47
20.00	1	26.67
	2	25.55
	3	24.97
22.50	1	29.17
	2	28.05
	3	27.47
25.00	1	31.68
	2	30.56
	3	29.98
27.50	1	34.17
	2	33.05
	3	32.47
30.00	1	36.67
	2	35.55
	3	34.97

* plantation oil yield resulting from: 1 - unselected wild seed; 2 - selected wild seed (20% gain in oil yield); 3 - selected seed-orchard seed (further 12% gain in oil yield)

4.4 Discussion

The profitability of the baseline operation is marginal. The cashflow is 'lumpy' with a positive return occurring every second year (after year 5), alternating with a negative return every other year due to land opportunity cost and the depreciation of plant and equipment. In order for the venture to become financially viable, the grower must increase oil yield per hectare, increase production efficiency or realise a greater sale price for the oil. Through varying a number of key production parameters within realistic commercial bounds, the financial potential of a number of *E. radiata* subsp. *radiata* essential oil production scenarios may be more attractive than the baseline venture.

Establishing the whole 15 ha of plantation in the first year of operation incurs a greater initial cashflow burden than that encountered in the baseline scenario, being as much as -$42,975 in year 0. However, a positive cash return is realised earlier ($15,708 in year 4 cf. $12,164 in year 6 in the baseline scenario). Cashflow break-even point occurred 4 years earlier than in the case of the baseline scenario. The cashflow is still 'lumpy', due to land opportunity cost and the depreciation of plant and equipment and harvesting only occurring every second year. The overall net present value of the project is $2,962 greater than the baseline scenario.

In the case of a plantation established in 5 ha increments in each of the first 3 years, the initial cash burden is relieved somewhat from the scenario of establishing the entire plantation in the first year. However, a substantial deficit occurs in year 2 primarily due to the establishment of the final 5 ha and the purchase or construction of the still. A positive financial return is generated each year after year 3. The cashflow remains 'lumpy', however, as the 3 years of plantation establishment and subsequent growth coincide with the 2 year harvesting program, resulting in areas of 5 ha and 10 ha being harvested in alternate years. The NPV ($1,188) of the operation is $1,842 less that that of the '15 ha up-front' scenario, but is greater than that of the baseline scenario. The IRR (5.28 percent) is only slightly higher than that of the baseline scenario. The cashflow break-even point occurs 2 years earlier than in the baseline scenario.

When plantation establishment was carried out at 7.5 ha in each of the first 2 years, the cash burden is greater than that of the baseline venture, but not as significant as that of the '15 ha up front' scenario. The venture also provides a more regular cashflow compared to the previous scenarios as a result of harvesting the same area of plantation each year. The gradual declining trend in cashflow over the life of the project is due to the estimated 5% tree mortality following each harvesting operation.

A trade off exists between the initial establishment costs and the net present value of the project. Greater initial cash investment will result in a greater net present value of the project, a slightly higher internal rate of return and earlier achievement of the break-even point, than if the investment was staggered over a longer period. The most desirable establishment option will, however, vary among producers. Some growers might wish to see the physical results of growth and productivity of the first block before investing the second and third stages. Others may not be able to afford to establish the whole plantation 'up front', and will stagger their establishment program over 2-3 years. Some producers may be satisfied with a 'lumpy' cashflow, however, it is likely that most would prefer a steady income stream as evidenced in the case of establishing two equal areas of plantation in consecutive years (providing harvesting of each area was carried out biennially).

Wright and Eldridge (1985) evaluated the profitability of using selected seed in *Pinus radiata* plantations using discounted cashflow analysis to determine the financial impact of increased production of wood volume. Spending an additional \$10 ha^{-1} on improved Tallaganda seed orchard seed for plantation establishment on a similar moderate quality site in 1971, resulted in a projected yield improvement in log volume of 16% compared to a base (unimproved) plantation yield (taken from standard yield tables). NPV was $345/ha over a 36-year rotation using a 7% discount rate, and the IRR was 22.3 percent (Wright and Eldridge, 1985). Cameron and Cotterill (1988) estimated gains in volume over a routine unselected control from 16 *P. radiata* germplasm options (of seedlings and cuttings), and evaluated the net benefit of the gain in volume ($ ha^{-1}) against the initial plant costs per hectare for each option. Percentage gain in volume (from the unselected options) ranged from 3.9 to 56.8. The net benefit of gain in seedlings (with a one year production lead time) ranged from $142 to $1149 ha^{-1}. Total plant costs for those options ranged from $124 to $191 ha^{-1} for 'climbing selected' seedlings and 'tested second generation closed-pollinated full-sib family' seedlings, respectively. The difference in total plant costs per hectare is relatively small compared to the substantial differences in returns per hectare brought about by large gains in volume.

Cameron and Ginn (1983) studied stocking, harvesting and economic aspects of *E. regnans* seedling seed orchards. They reported that a gain in volume alone of only 2% would be sufficient to recover the higher cost of the seed. A gain in volume of about 13% and improvement in stem, branch and crown quality could be expected (Cameron and Ginn, 1983), thus concluding that the higher costs of seed orchard seed relative to routine seed is economically justifiable.

Incorporation of the gains in oil concentration achieved in Chapter 3 allowed the financial impacts of selection and tree breeding to be revealed. As expected, using unselected seed from parent trees in native stands resulted in an unprofitable plantation. As a result of sampling and selection of superior mother trees from native stands and an estimated 20% gain in leaf oil concentration, the financial performance of the baseline plantation (i.e. the Brogo trial) established from such stock appeared viable, albeit marginally. However, if subsequent selection of the trees with the highest leaf oil concentration from the Brogo trial occurred and seed orchard seed became available, the further 11.7% gain in oil concentration resulted in a more financially attractive venture. The small initial investment in selected seed (estimated at \$30 ha^{-1}) [2] was the difference between a marginal enterprise and a viable profitable operation (all other factors being equal). This simulation demonstrated the economic importance of using selected seed in eucalyptus oil plantation establishment, and suggests that a producer employing such a strategy is likely to have a market advantage over less efficient competitors.

The importance of selling spent leaf as a mulch product in conjunction with the sales of oil was highlighted, in that the operation is unviable if reliant on the sale of oil only. N. Reid (pers. comm., 2001) raised the issue that the export of leaf mulch off the site could have organic matter and nutrient mining effects that may have to be compensated for in increased fertiliser costs. The need for integrated production is supported in the large-scale example of the Western Australian Oil Mallee project, where a number of products are being considered, including eucalyptus oil and biomass for electricity production (Bartle, 2001).

This study shows that production efficiency and product sale price are critical to the financial performance of *E. radiata* subsp. *radiata* oil production ventures. Market forces, generally beyond the control of the small producer, can reduce the farm-gate oil price received by the producer. The results demonstrated that a small reduction could render a venture unviable. Conversely, an increased demand for the product, successful marketing or value-adding in a niche market (e.g community market sales of oil products) resulting in a higher sale price, could increase the profitability of the venture markedly over the baseline operation.

[2] Established from the premiums over routine seed applied by CSIRO Australian Tree Seed Centre in valuing eucalypt seedling seed orchard seed (J. Doran, pers. comm., 2002)

The modelling demonstrated that a small increase in production costs (harvesting, handling and distillation), for example through difficult harvesting conditions or inefficient leaf collection and distillation techniques, rendered the venture unviable. Improved production efficiencies, for example through the introduction of mechanised harvesting and improved distillation techniques, however, could reduce production costs and increase profitability and viability. Although 'upfront' and depreciation costs of mechanical harvesting equipment were incurred with increased production efficiencies, the model demonstrated that the additional investment in such equipment had a positive financial impact over the baseline scenario. R. Davis (pers. comm., 2002) pointed out that oil production costs incurred by G. R. Davis Pty Ltd for *E. polybractea*, including mechanical harvesting and distillation, were in the order of \$8.00 kg^{-1} of oil, indicating that the figures presented in this study could be achievable if such efficiencies were introduced.

It is impossible for a small producer to be able to set the market price received for bulk oils. It is, however, realistic to improve their production efficiency, and the results presented in Figure 4.8 may be useful in setting production cost goals and limits when faced with a particular market price in order to maintain a viable operation. If the oil price drops, efficiency must be improved in order to reduce production costs, or a lower return must be accepted. The model allows a producer to set maximum production cost benchmarks for a specific oil production and price regime when a nominated return on their investment is required (Table 4.3). For example, if a producer requires an IRR of 15 percent from their venture, the plantation was established from seed selected from native stands (baseline scenario), and the current farm-gate market price for oil is around \$23.00 kg^{-1}, they must aim for production efficiencies limiting costs to \$17.50 kg^{-1}. Vice versa, if harvesting and distillation costs \$22.50 kg^{-1}, the producer must achieve an oil sale price of approximately \$28 kg^{-1} in order to maintain that rate of return under that particular oil yield scenario.

Doran *et al.* (1998b) noted that if their yield estimates were used to determine the rates of return on an investment in oil plantations, care should be taken as growth in the provenance/progeny trial had been very vigorous (average tree height of 3.1 m at 2 years). Growth of routine plantings up-slope from the trial area had been significantly slower (mean of 2.5 m) with estimated first harvest yields of 71 kg ha^{-1} of oil, or approximately half those of the overall average for the trial (131 kg ha^{-1} of oil) (Doran *et al.*, 1998b). Yield estimates used in this study were taken from the results of Doran *et al.* (1998b), and it is therefore uncertain whether the absolute results of the modelling exercise presented here would apply to other sites.

The economic analysis developed in this chapter clearly highlights the sensitivity of the profitability of *E. radiata* subsp. *radiata* oil production to minor changes in oil yield, production costs and selling prices. The analysis demonstrates the importance of using improved seed in plantation establishment, minimising harvesting and distillation costs and achieving a high price for the oil.

Chapter 5 Developing a breeding strategy for *E. radiata* subsp. *radiata* oil production

5.1 Introduction

The *E. radiata* subsp. *radiata* oil production industry in Australia (with the exception of the Banalasta Oil Plantation) is comprised of a number of small-scale, generally undercapitalised producers. Although the current demand for seed is not great, there is developing interest from prospective growers in establishing small areas of oil plantation to diversify farm income (R. Dyason, pers. comm., 2001; pers. obs.). In order to be economically viable, it is necessary for growers to establish new plantations from improved seed (Chapter 4). The development of a simple, low cost tree breeding strategy to capture potential gain in *E. radiata* subsp. *radiata* oil production traits would be beneficial to the future of the industry.

The aim of this component of the study is to formulate a breeding strategy to produce improved stock for use in southern NSW.

The objectives are:

(1) to briefly review the biological characteristics of *E. radiata* subsp. *radiata* that will influence a breeding plan;

(2) to incorporate the genetic parameters as determined in Chapter 3 into the planning process; and

(3) to determine appropriate actions and time-frames to include in a breeding strategy.

5.2 Factors influencing breeding strategy development

Tree improvement programs aim to develop new plantations superior to their predecessors in one or more key economic traits, by accumulating benefits over successive generations through a cycle of testing, selection and mating. In this case, the major breeding objective for *E. radiata* subsp. *radiata* is to increase the yield of oil per unit planting area by improving leaf oil concentration. Key biological factors influencing a breeding strategy include the breeding system, potential for asexual reproduction, extent of variation in traits of economic importance, and genetic parameters.

Eucalyptus flowers are morphologically bisexual and insects, birds and mammals are the main pollinators. Outcrossing appears to be predominant but there is opportunity for selfing within the crown. Methods of controlled pollination for eucalypts are described by Moncur (1995), but they may not be practical for producing *E. radiata* subsp. *radiata* seeds for mass propagation, as the techniques are costly and require accurate timing, suitable equipment and technical expertise (Doran *et al.,* 1998b). Open pollination is probably the most suitable mating method to employ in this case. *E. radiata* subsp. *radiata* can set their first major flush of flower buds at approximately 7-8 years from planting. Flowers are present from October to January, and mature seeds can generally be collected in December to February. There is an average of 2100 viable seeds per 10 g of seed and chaff mixture.

Opportunities to capture rapid gains in oil yield through vegetative propagation of selected trees appear to be limited in *E. radiata* subsp. *radiata* (Doran *et al.,* 1998b). Donald and Newton (1991) reported that the rooting of cuttings taken from juvenile coppice shoots was difficult, and found that only 5 out of 80 selected ortets rooted. Chang *et al.* (1992) found that rooting of *E. radiata* subsp. *radiata* coppice shoot cultures could be achieved with reasonable success. Donald and Newton (1991) advocated the use of micropropagation as the preferred method to produce clonal plantations of high oil-yielding potential. However, the benefits must be weighed up against the high costs of this process. It would seem that the desired gain in leaf oil concentration is best achieved through the development of seed orchards of trees selected for superior oil traits.

Eldridge *et al.* (1994) defined an appropriate breeding strategy as recurrent selection for general combining ability with open pollination in a single breeding population, keeping family identity. According to Eldridge *et al.* (1994), this involves a number of steps, as described in the following idealised example: a) collect open-pollinated seed from about 300 trees; b) establish a well replicated progeny trial of about 30-50 seedlings per family and 1 to 5 trees per plot; c) measure and cull the first generation progeny as early as possible; d) collect open-pollinated seed from the best trees in all but the worst families to establish the second generation; e) cull the first generation heavily for future seed production by removing families identified as having low general combining ability at the first measurement of the second generation; and f) each new generation is composed of the best trees of the previous generation, plus a small infusion of new material from any other promising source. Harwood (1996) indicated that breeding strategies employing this basic approach have been developed for *Acacia*, *Melaleuca*, and *Grevillia* species in many countries over the last decade, and that useful gains have been achieved. This method is engaged in the development of a proposed breeding strategy in this study.

As Matheson (1990) highlighted careful consideration of the methods engaged in selecting superior material must be made. This includes the progeny tests in which selection is carried out, measurement techniques and selection technology (e.g. selection indices). Of the 3 fundamental methods of selection (Section 3.4.3), index selection is generally more efficient than independent culling, which in turn, is more efficient than tandem selection (Cotterill and Dean, 1990). Index selection utilises genetic, economic and pedigree information to maximise the probability of selecting trees with the best genes (Eldridge *et al.*, 1994). By reducing the measured values for several traits to one index value, the selection becomes equivalent to selecting on one trait. Selection in the breeding strategy proposed in this study could be based on a simple selection index combining tree basal area, leaf oil concentration and 1,8-cineole content.

5.3 Proposed breeding strategy

The results presented in Chapter 3 of this study determined that there was significant variation in most tree growth and essential oil traits both within and between provenances of *E. radiata* subsp. *radiata*. The key oil trait of interest (leaf oil concentration) was found to be highly heritable and selection for this trait at the rate of 1 tree in 10 could provide a gain in plantation oil yield (all other factors being equal) of approximately 11.7% over the mean oil concentration of the trial.

Due to the fact that the industry is comprised of small-scale growers, most of whom do not have the technical and financial resources to design and implement an elaborate breeding strategy, a simple, relatively low cost strategy and plan such as described by Eldridge *et al.* (1994) is proposed. Such a strategy might be adopted and implemented by a cooperative-style group of growers.

Figure 5.1 illustrates the process involved in the proposed breeding strategy for *E. radiata* subsp. *radiata* in southern New South Wales based on the results of this study. In an effort to maintain a broad genetic base throughout, inclusion of three previously untested north-eastern

Victorian provenances into the breeding program will be adopted. The three best overall performing provenances in the Brogo provenance/progeny trial were Big Belimbla, Gulph Creek and Reedy Creek. Yowrie can be eliminated from further investigations. Trees in native stands at Big Belimbla, Gulph Creek, Reedy Creek and 3 north-eastern Victorian provenances will be intensively sampled for an indication of high oil concentration. Six hundred trees will be screened for oil concentration through leaf sampling and oil analysis. As Big Belimbla was the best overall performing provenance in the Brogo provenance trial, an attempt could be made to screen approximately 120 seed bearing trees from that provenance and 90 from each of Gulph Creek and Reedy Creek provenances. One hundred trees from each of the untested Victorian provenances will be screened. At a cost of approximately $20 per tree for laboratory oil extraction and GC analysis alone, this will cost in excess of $12,000. Seedlots from the 60 best individuals preferably from all 6 provenances (i.e. 1 in 10) for oil concentration will be used as the genetic resources to establish a seedling seed orchard. The remainder will be disregarded. Progeny of the 60 selected families will then be established in a combined breeding population/progeny trial/seedling seed orchard. A design incorporating 5 tree single-row plots in 8 replications, at a spacing of 4 x 2 m (to give a final average spacing of approximately 4 m x 8 m after thinning), would be suitable. At Year 3, growth measurements will be carried out and the progeny test will be thinned out to the best 3 trees per plot. The 10 poorest performing families will be removed. At Year 5, trees in the progeny test will be assessed for oil characteristics (a further $10,000) and thinned to the best single tree per plot for the commercial production of improved seed. This process continues on in a recurrent manner, with each subsequent generation expected to produce a gain.

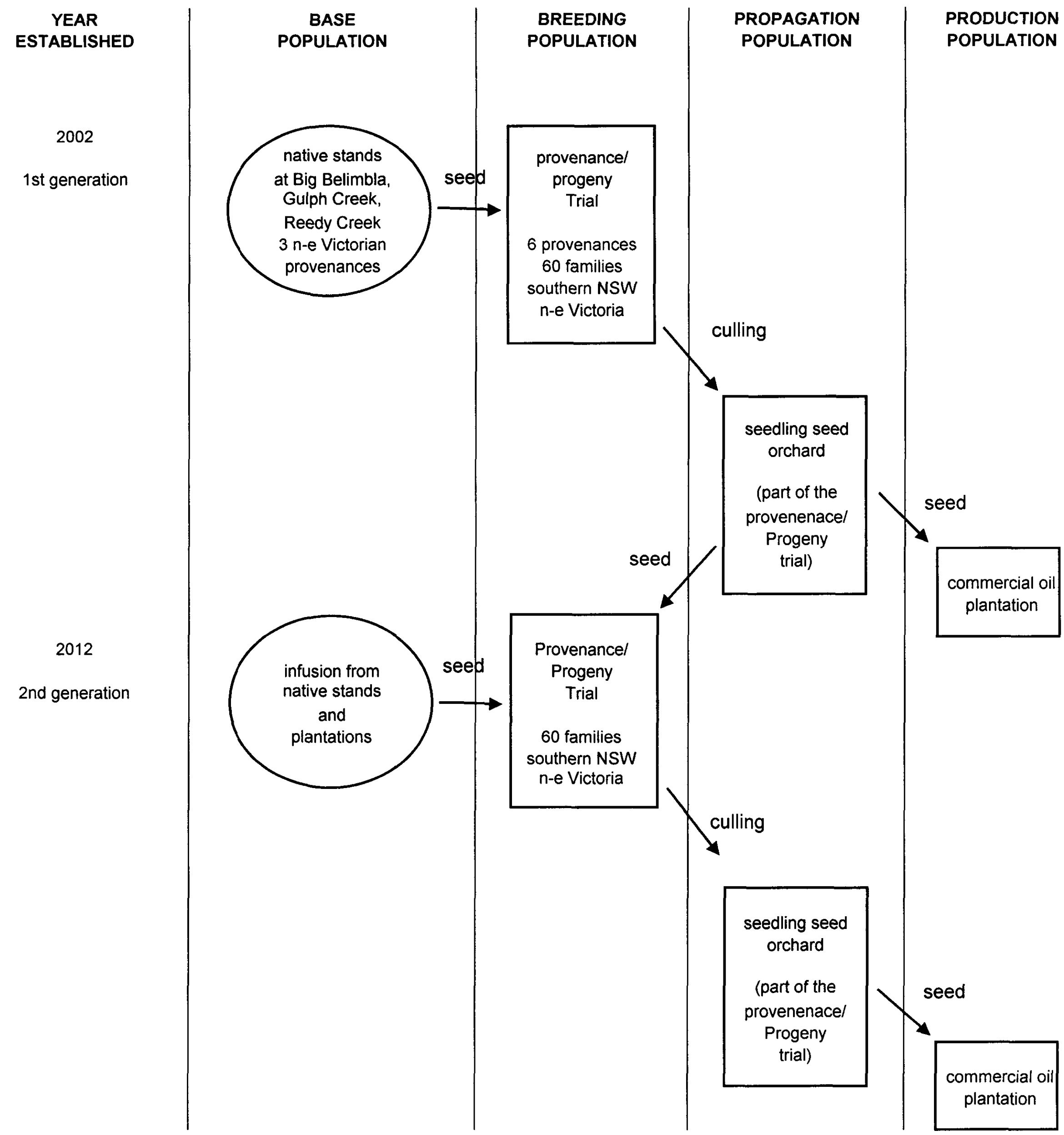

Figure 5.1 – Breeding strategy for *E. radiata* subsp. *radiata* in southern New South Wales

5.4 Discussion

The determination of genetic parameters in conjunction with the economic modelling carried out in this study indicate that investment in a breeding program to improve leaf oil concentration in *E. radiata* subsp. *radiata* would lead to a greater productivity and financial return in commercial oil production ventures. If implemented successfully, the breeding program has the potential to increase leaf oil concentration of the provenance/progeny trial mean from 8.3% to 9.3% in the first generation of selection and breeding, and generate an accompanying increase in the net present value of a venture based on the improved stock of over \$425 ha^{-1}.

Donald and Newton (1991) recommended the use of micropropagation as the preferred method to produce clonal plantations of high oil-yielding potential. However, the current farm-gate price for oil (\$23 kg^{-1}) and the high cost of developing a practical tissue culture method for mass producing tissue-cultured plantlets, would be hard to justify in economic terms. Doran *et al.* (1998b) commented that oil prices would need to improve dramatically to make a tissue culture strategy feasible. The most technically and economically viable option in this case is likely to be to produce improved seedstock.

The breeding strategy proposed here allows the continued production of highly improved seed for production plantations whilst continuing with recurrent selection and mating for longer term genetic improvement for future industry needs. Despite the strategy being quite simple in nature, its development and implementation may require significant funds (a minimum of \$22,000 for oil extraction and GC analysis, as well as field measurement and sampling costs) and some input from a professional tree breeder (incurring additional cost). The formation of a grower cooperative-type arrangement (assuming there is a sufficient number of interested parties; perhaps a minimum of 5) could be one solution. The cooperative would facilitate the sharing of information, raising adequate funds for the development and implementation of such a breeding strategy, and ultimately, collectively benefiting from access to improved planting stock within the group. Agencies such as RIRDC could be approached to assist with funding for the development of the strategy as it is in accord with their Research and Development Plan for Essential Oils and Plant Extracts for 2002-2006 (Section 2.1).

Eldridge *et al.* (1994) stated that the justification for breeding eucalypts is the genetic gain actually realised in improved plantations and the financial return on the investment in breeding. Yield trials of *E. radiata* subsp. *radiata* incorporating seed orchard seedlots in comparison with routine commercial seedlots used previously by the industry (southern NSW, central western NSW and Victoria) should be established at the earliest opportunity to determine the real genetic gain in trees growth and oil yield, and the economic effectiveness of the breeding program.