6. Conclusions

The 150-year history of the *Eucalyptus* oil industry in Australia has seen both booms and down turns. Where Australia was once the world leader in eucalyptus oil production, the introduction of eucalypt species to a number of developing countries in conjunction with cheap labour, has resulted in a significantly diminished domestic industry often operating at marginally viable levels. Testament to this is the fact that Australia has been a net importer of eucalyptus oil for over 30 years, primarily due to the availability of cheap oil produced overseas.

In order to maintain a profitable enterprise, Australia's current and prospective producers need to increase efficiency throughout the entire production process by including utilising improved planting stock, mechanical harvesting, modern distillation techniques, and value-adding and marketing. This can be achieved by adopting a combination of key efficiency strategies including increasing oil yield from the same unit area of land, reducing harvesting and distillation costs and realising a greater price for the product. Plantation establishment utilising germplasm selected for superior leaf oil concentration or chemical characteristics will increase total oil yield per hectare or oil quality respectively, over unselected seedstock. The introduction of mechanised harvesting and more efficient leaf handling and distillation techniques could reduce production costs, while a market campaign or product value-adding could increase the sale price achieved for the product.

This study has demonstrated that there is considerable variation in tree growth and essential oil traits in *E. radiata* subsp. *radiata* in the provenance/progeny trial at Brogo at age 38 months. The large variation allows selection of trees with superior desirable characteristics and breeding from these to create progeny with improved oil production potential.

Variations in survival rate, leaf oil concentration, and 1,8-cineole content were significant between families within the four provenances. Variations in individual tree basal area, the number of stems per tree, and 1,8-cineole content were substantial between and within provenances. It was interesting to note that there was no significant difference in leaf oil concentration between provenances, but this comparison may have been confounded by the use of progeny from mother trees already selected for their higher than average oil yields. Also, the limited number of families in some provenances, and the widespread variation between families within provenances could result in indeterminate real differences between provenances. High genetic correlations were found between tree basal area and leaf oil concentration, tree basal area and 1,8-cineole content, and leaf oil concentration and 1,8-cineole content. Leaf oil concentration and 1,8-cineole content were found to be highly heritable traits.

The Big Belimbla provenance appeared to be the best 'all-round' performer in the Brogo trial, demonstrating the best survival rate, the greatest tree basal area, the highest leaf oil concentration and the highest 1,8-cineole content. J. Doran (pers. comm., 2002), however, indicated that the population at Big Belimbla Creek is limited in the number, and that it may not be possible to source sufficient parent trees for the establishment of the initial seedling seed orchard in the breeding strategy from this provenance alone. With this in mind, and the similarity in leaf oil concentration between the provenances, selection of families for this trait from within the three better overall performing provenances (Big Belimbla, Gulph Creek and Reedy Creek) could form the starting point for an *E. radiata* subsp. *radiata* breeding program relevant to south-eastern New South Wales.

The patterns of variation, heritability, phenotypic and genetic correlation and potential gains reported in this study are specific to the provenance/progeny trial at Brogo, and it would be

useful to compare these patterns to similar *E. radiata* subsp. *radiata* provenance/progeny trials using the same genetic material that are currently underway at the Banalasta Oil Plantation on the Northern Tablelands of New South Wales (A. Kar, *pers. comm.*, 2000). The two localities are geographically and climatically quite different, and if a substantial genotype-environment interaction was found to occur in the species, a separate breeding program would be required for the Northern Tablelands.

All production parameters being equal, a farm-scale *Eucalyptus radiata* subsp. *radiata* oil venture based on seedstock selected for superior essential oil production traits would provide a greater financial return than the same venture established using unselected seedstock. Further selection and breeding would likely result in subsequent productivity increases and higher financial returns. The slightly higher plantation establishment costs involved in using selected seedstock (over unselected seed) is negligible. The benefits of selected seedstock were highlighted in the economic simulations in the difference between a financial loss and a profitable return.

Production efficiency and the sale price received for the distilled oil are the two other key parameters in determining profitability. Under the current practice of hand harvesting and basic distillation techniques employed by many small-scale operators, and the relatively low farm-gate price received for bulk oil, the economic viability of such a venture is marginal. Introducing greater efficiency in leaf harvesting and distillation, thereby decreasing production costs by as little as \$1-2 kg^{-1} of oil can turn a marginal enterprise into an attractive investment. Likewise, achieving a marginally higher selling price for the oil through market development or value-adding, can increase the viability of the operation. A combination of reduced production costs and increased sales revenue serves to improve the marginal financial

performance of a venture based on unselected seedstock, or, more importantly, increase the profit likely to be generated in an operation based on selected stock.

In order to ensure a profitable venture with an internal rate of return on investment of at least 25%, the farm-scale producer of *E. radiata* subsp. *radiata* oil must plan and implement their venture with attention to detail. Plantations must be established for a maximum cost of $\$3{,}200\ ha^{-1}$ from selected seedstock at a planting density capable of yielding at least $130\ kg\ ha^{-1}$ of oil at the first harvest and at least $340\ kg\ ha^{-1}$ of oil in subsequent (biennial) harvests. Best practice plantation establishment and management techniques including initial weed control, deep ripping, mounding (if required), second cultivation, fertilising and follow-up weed control must be carried out to ensure seedling survival and growth. The operation should incorporate the sale of eucalyptus oil as well as the spent leaf as a mulch-type product. If production costs including harvesting, distillation, leaf handling and marketing are kept below $\$15\ kg^{-1}$ of oil produced, the farm gate price received for bulk oil must be greater than $\$24\ kg^{-1}$ and the farm gate price for the spent leaf mulch must be $\$75\ tonne^{-1}$ or more.

This study has brought together a combination of forest science, statistics, economic analysis and practical experience in order to assess the commercial viability of *E. radiata* subsp. *radiata* essential oil production. In its crude form (i.e. the 'baseline' enterprise), *E. radiata* subsp. *radiata* oil production is only a marginal business. Profitability is highly sensitive to small changes in all the production parameters. The importance of selected seedstock in plantation establishment, efficiencies to minimise production costs, and a premium oil sale price in order to generate an acceptable financial return have been confirmed.

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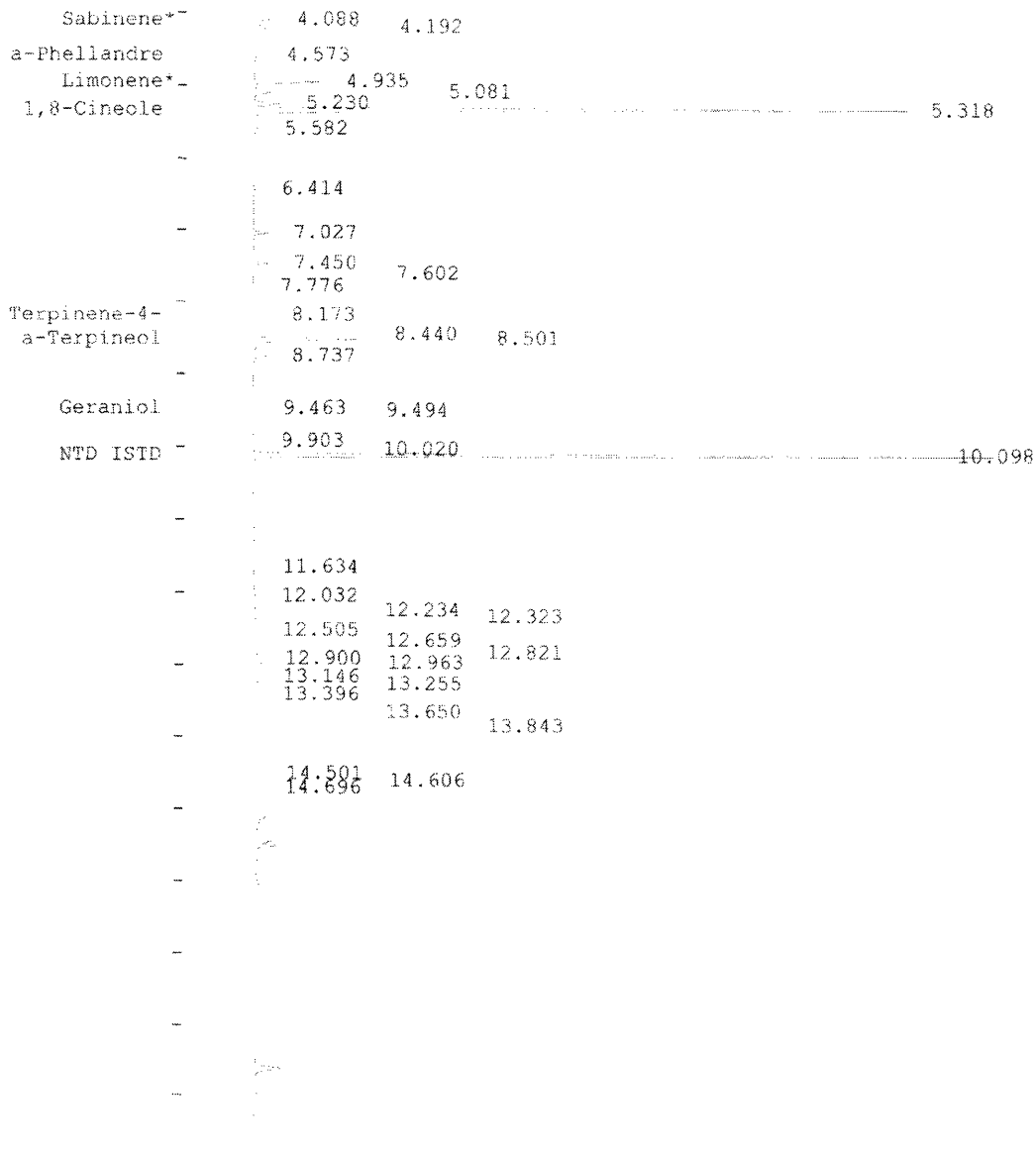
Appendix A

Typical chromatogram output from the gas chromatography analysis



Appendix B

	Survival (%)		No. of stems per tree		Tree basal area (cm2)		1,8-cineole (%)*		Leaf oil concentration (w/w% DW)*	
	Doran *et al.* (1998b)	This study	Doran *et al.* (1998b)	This study	Doran *et al.* (1998b)	This study	Doran *et al.* (1998b)	This study	Doran *et al.* (1998b)	This study
Tree age	(23 months)	(38 months)	(23 months)	(38 months)	(23 months)	(38 months)	(23 months)	(38 months)	(23 months)	(38 months)
FAMILY	RANKING	RANKING	RANKING	RANKING	RANKING	RANKING	RANKING	RANKING	RANKING	RANKING
1	15	6	25	17	2	4	3	19	28	17
2	26	27	9	3	17	18	16	13	31	23
3	27	28	26	15	27	24	26	28	10	30
4	28	25	28	13	24	28	32	32	23	31
5	18	16	10	19	12	26	10	26	5	12
6	7	2	19	22	13	21	31	29	22	5
7	23	23	4	2	21	13	29	31	14	32
8	24	24	5	21	9	8	22	30	7	22
9	19	20	20	20	25	26	27	2	32	25
10	16	13	6	7	3	5	17	25	19	20
11	21	17	11	24	7	19	18	21	15	16
12	2	3	31	32	10	22	11	20	18	15
13	11	9	32	23	30	30	12	8	20	27
14	30	30	29	29	31	31	13	24	21	19
15	25	18	30	25	20	16	30	9	27	4
16	31	31	3	12	23	25	4	14	8	10
17	20	21	21	26	26	29	19	6	11	8
18	9	10	12	27	4	10	20	11	3	2
19	10	12	7	8	1	1	14	16	12	9
20	3	4	13	14	8	15	21	18	25	14
21	32	32	8	31	32	16	1	7	30	28
22	4	5	1	4	11	20	5	4	4	7
23	17	19	14	18	22	9	23	22	5	13
24	12	26	27	28	29	23	6	3	16	24
25	22	22	22	16	15	7	7	17	24	18
26	29	29	15	5	28	27	28	23	26	29
27	5	7	23	11	6	2	8	1	17	26
28	13	14	24	9	19	12	15	5	1	6
29	8	8	16	6	18	3	2	10	9	3
30	1	1	17	10	5	6	24	12	2	1
31	6	11	18	30	14	11	25	27	29	11
32	14	15	2	1	16	14	9	15	13	21

Ranked comparison of tree growth and essential oil traits between Doran *et al.* (1998b) (trees aged 23 months) and this study (trees aged 38 months) of the *E. radiata* subsp. *radiata* trial at Brogo, New South Wales.

*1,8-cineole (%) and leaf oil concentration (w/w% DW) for Doran *et al.* (1998b) were determined on a bulk sample from Replicate 1 only.

APPENDIX C

ECONOMIC MODEL INTERFACE

oil plantation modelling exercise

	variables	year 0	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19
area established (ha)		5		5		5															
establishment cost ($ / ha)		2800		2800		2800															
maintenance costs ($ / ha)			400		400		400														
total establishment costs ($)		14000	2000	14000	2000	14000	2000														
oil yield (kg / ha)				130	0	340	0	340	0	323	0	307	0	292	0	277	0	263	0	250	0
farm gate value of oil ($ / kg)	23.00			23.00	0.00	23.00	0.00	23.00	0.00	23.00	0.00	23.00	0.00	23.00	0.00	23.00	0.00	23.00	0.00	23.00	0.00
mulch (dry t / ha)				0.98	0	2.55	0	2.55	0	2.42	0	2.30	0	2.19	0	2.08	0	1.97	0	1.87	0
mulch value ($ / tonne)	50			50.00	0	50.00	0	50.00	0	50.00	0	50.00	0	50.00	0	50.00	0	50.00	0	50.00	0
total area / harvest (ha)				5	5	10	10	15	15	15	15	15	15	15	15	15	15	15	15	15	
total oil yield / harvest (kg)		0	0	650	0	2350	0	4050	0	5015	0	4849	0	4607	0	4376	0	4158	0	3950	0
total oil value / harvest				14950	0	54050	0	93150	0	115345	0	111533	0	105956	0	100658	0	95625	0	90844	0
total mulch yield / harvest (t)				4.9	0	17.6	0	30.4	0	37.6	0	36.4	0	34.6	0	32.8	0	31.2	0	29.6	0
total mulch value / harvest				243.75	0	881.25	0	1518.75	0	1880.625	1	1818.48875	1	1727.54531	1	1641.16805	2	1559.10964	2	1481.15416	2
total oil + mulch value ($)		0	0	15193.75	0	54931.25	0	94868.75	0	117225.63	0	113351.22	0	107683.86	0	102299.47	0	97184.50	0	92325.2761	0
hand harvest ($ / kg oil)	14.00			14	0	14	0	14	0	14	0	14	0	14	0	14	0	14	0	14	0
distillation ($ / kg oil)	3.50			3.50	0	3.50	0	3.50	0	3.50	0	3.50	0	3.50	0	3.50	0	3.50	0	3.50	0
unloading still ($ / kg oil)	1.20			1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0	1.20	0
marketing ($ / kg oil)	1.30			1.30	0	1.30	0	1.30	0	1.30	0	1.30	0	1.30	0	1.30	0	1.30	0	1.30	0
land opp cost ($/ha/ann)	100	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
land locked up (ha)		5.00	5.00	10.00	10.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
total land opp cost ($/kg oil)		500	500	1.54	1000	0.64	1500	0.37	1500	0.30	1500	0.31	1500	0.33	1500	0.34	1500	0.36	1500	0.38	1500
production costs / kg oil				21.54		20.64		20.37		20.30		20.31		20.33		20.34		20.36		20.38	
still ($)				6849																	
general equipment				2000																	
depreciation																					
total production costs / harvest		14500	2500	36849	3000.00	62500	3500	82500	1500.00	101800	1500.00	98485	1500.00	93636	1500.00	89029	1500.00	84653	1500.00	80495	1500.00
Annual cash flow		-14500	-2500	-21655	-3000	-7569	-3500	12169	-1500	15426	-1500	14866	-1500	14048	-1500	13271	-1500	12532	-1500	11830	-1500
tree mortality rate after each harvest (from yr 6)	5%																				
			-17000	-38655	-41655	-49224	-52724	-40555	-42055	-26830	-28130	-13283	-14763	-715	-2215	11055	9555	22087	20587	32417	30917
oil																					
unselected wild seed (inc. harvest mortality)				108		283		283		269		255		243		231		219		208	
selected wild (inc. harvest mort.)	y			130		340		340		323		307		292		277		263		250	
selected seed-orchard seed (inc. harvest mort.)				145		380		380		361		343		326		310		294		279	
mulch (wt % of leaf fresh wt)	0.75																				
unselected wild seed (5% mortality each harvest)				0.98		2.55		2.55		2.42		2.30		2.19		2.08		1.97		1.87	
selected wild seed (5% mortality)	y			0.98		2.55		2.55		2.42		2.30		2.19		2.08		1.97		1.87	
selected seed-orchard seed (5% mortality)				0.98		2.55		2.55		2.42		2.30		2.19		2.08		1.97		1.87	
Discount rate	5%																				
NPV	$88																				
IRR	5.02%																				

APPENDIX D

SCHEDULE OF PLANTATION ESTABLISHMENT COSTS

SPACING	*3m x 1.5m*
STOCKING RATE	*2222/ha*

OPERATION	METHOD	PRODUCT COSTS per ha	OPERATING COSTS per ha	TOTAL per ha
planning			300	**300**
clearing etc	*small dozer / farm tractor*		100	**100**
pre-cultivation herbicide	*broadcast spray*	45.00	75	**120**
rip / mound	*small dozer / farm tractor*		120	**120**
cultivate rows	*farm tractor*		100	**100**
pre-plant herbicide	*along rows*	46.00	90	**136**
seedlings	*hikos*	1125.00		**1125**
planting	*hand planting*		300	**300**
survival monitoring			150	**150**
first season fertilising	*50g / tree*	56.00	170	**226**
over-spray post-plant herbicide	*boom spray over seedlings*	113.00	90	**203**
post-plant herbicide	*tractor / handspray*	45.00	115	**160**
post-plant herbicide / slashing	*hand / tractor spray and slash*	45.80	115	**161**
TOTAL		1476	1725	**3201**