FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

AN EVALUATION OF POPLAR ON NEW ZEALAND HILL COUNTRY

H McElwee & R. L. Knowles

Report No. 54 November 1998

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ABSTRACT

Data from previous inventories of New Zealand grown poplar (MacLean, 1997) was supplemented with data from additional inventories in poplar stands in the Bay of Plenty and East Coast regions. Existing height and volume functions were subsequently re-estimated from the supplemented data set. Functions were also developed to estimate log grade allocation by volume and value. These functions can be used to generate yield tables illustrating the effect of site, age and silviculture on recoverable log grade volumes.

In addition, digital images of stand canopies in the Bay of Plenty and East Coast were captured to develop a model to estimate the effects of stand development on canopy closure in poplar stands. This model can be used to estimate understorey livestock carrying capacity. Canopy closure can also be used as a surrogate for water use, and in conjunction with estimates of root biomass development as an indicator of soil protection on erosion prone land.

In the final phase of research, the costs of growing poplars were summarised, and the physical and financial impacts of planting poplars on East Coast farmland were evaluated using AEM (Agroforestry Estate Model). The results indicated that the profitability of poplar agroforestry on East Coast hill country farms appeared to be potentially greater than that of pastoral farming, but lower than that of *Pinus radiata* agroforestry. The difference between poplar and *Pinus radiata* was predominantly due to higher yields and higher log prices for *Pinus radiata*, which more than offset the higher silvicultural costs and greater livestock displacement. Estimates of root biomass indicated that the erosion control benefits of poplars are as least as great as for *Pinus radiata* for the first 15 years of growth, and also for a period of several years after the harvesting of *Pinus radiata*. Sensitivity analysis indicated that significant improvements in the profitability of poplars are possible if higher prices could be realised through the development of domestic and export markets for poplar wood products. At the current time, an absence of markets for New Zealand grown poplar adds considerable risk to the decision to grow poplars for timber production.

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INTRODUCTION

The objective of this research is to evaluate the integration of poplar agroforestry into farming practice. In order to do this, yield tables and understorey pasture relationships are required in order to model both the timber resource and livestock carrying capacity over time. Although yield equations have been estimated for poplar clones grown in other countries (Birler, 1994), these relationships have not been previously established for New Zealand grown poplar plantations.

MacLean (1997) collected data from a sample of poplar stands throughout New Zealand, and used this data to develop preliminary height and volume functions for New Zealand grown poplar. This data was supplemented with additional inventories from poplar stands in the Bay of Plenty and East Coast regions, and the height and volume functions were subsequently re-estimated to include the new data. In addition, functions were developed to estimate log grade allocation by volume and value.

Digital images of stand canopies in the Bay of Plenty and East Coast were also taken in order to develop a model for canopy closure in poplar stands. This model will be useful in estimating understorey livestock carrying capacity in poplar stands on farmland. Canopy closure can also be used in conjunction with estimates of root biomass development as an indicator of soil protection on erosion prone land.

In the final phase of research, the costs of growing poplars were summarised, and the physical and financial impacts of planting poplars on East Coast farmland were evaluated using AEM (Agroforestry Estate Model). The two farm types used were Gisborne-Wairoa small farms and Gisborne-Wairoa large stations. Typical farm accounts for each of these generalised farm-types have been published by the Ministry of Agriculture (1997). The estimated yield functions were used to produce yield tables as inputs for AEM, while the canopy closure model and other previous pasture growth research was used to estimate the rate of pasture suppression, and hence the impacts on livestock displacement.

PART 1: DEVELOPMENT OF YIELD TABLES FOR NEW ZEALAND GROWN POPLAR

1.1 Development of height and volume functions

1.1.1 Introduction

Stand yields may be predicted using one of three model formulations (Vanclay 1994):

1. Yield form:

$$Y = f(T, E)$$

where:

Y = response (yield) variable
T = age
E = set of explanatory variables

2. Difference form:

$$Y2 = f(Y_1, T_1, T_2, E)$$

3. Growth form:

$$\Delta Y / \Delta G = f(T_1, \Delta T, E)$$

The yield form is usually estimated from single assessments of mature and semi-mature stands, while difference and growth functions usually require time series data in order to explicitly model changes in yields. A limitation of yield equations is that they assume a prescribed management regime throughout the period of projection. Growth equations have an advantage that silvicultural treatment may be simulated at any time during the projection (Vanclay, 1994).

Only yield form equations were developed for New Zealand grown poplar in this study. Time constraints meant that only MARVL[1] inventory data was collected, that is, each stand was measured only once. The use of this method precludes the explicit modelling of responses to silviculture such as pruning and thinning. As such, pruning is assumed to have no effect on total yield, although this is unlikely to be the case in reality. Thinning of stands is modelled simply by changing the value of the stocking variable from the age at which thinning occurs, and assuming that future growth increments would be the same as those of a stand planted at the lower stocking from the outset.

[1] Method for Assessment of Recoverable Volume by Log type

1.1.2 Data collection

Following a nationwide survey of the extent of poplars in New Zealand undertaken in the winter of 1996, an in depth inventory assessment of 34 stands using MARVL was undertaken (MacLean, 1997). Objectives of the inventory were to assess the extent and quality of the mature and semi-mature poplar resource throughout the country. Stands were divided into four general land classes, broadly representing the range of reasons behind the historical planting of poplar:

a. riverberm, including free draining agricultural land
b. swamp
c. hill
d. erosion control plantings

This data was supplemented with data from additional inventories of five poplar stands on the East Coast, giving a total of 39 MARVL assessments.

A number of different poplar clones and species were included in the data set although black poplars, particularly Italian hybrids, made up the bulk of the sample. It should be noted at this point that yield tables would usually be estimated for a single species or clone, not for an entire genus. Much of the variability in height and volume between stands was undoubtably due to inherent differences between poplar species and clones. However, due to the small size of the poplar resource in New Zealand, and the wide variety of species and clones planted, it was difficult to obtain a large data set for any one species or clone. In addition, the younger stands tended to contain different species/clones to the older stands. The Italian hybrids which were commonly planted in the 1960's and early 1970's have now been replaced by new possum and rust resistant clones. Given that the existing resource of New Zealand-grown poplar is quite small in size and narrow in genetic base, it is entirely possible that provenances and clones which have not yet been trialed in New Zealand may prove to be more productive in New Zealand's maritime climate than those trialed to date. The only way to objectively estimate yield tables for New Zealand-grown poplar at this point in time however, is to use the limited data available on clones currently grown in New Zealand. The number of stands assessed by region and by clone are displayed in Table 1. 1.and Table 1. 2.

Table 1. 1. Poplar MARVL inventory assessments by region

Region	**No. of stands assessed**
Bay of Plenty	10
East Coast	11
Rangatikei	1
Wairarapa	2
Wanganui	1
Canterbury	8
Marlborough	1
Otago	2
Southland	3
Total	**39**

Table 1. 2. Poplar clones assessed in MARVL inventories

Poplar group	Clone	No. of stands assessed
Balsam	"Androscoggin"	4
	"Rochester"	1
Black	*P. deltoides* x	4
	P. eugenei	1
	"I-30"	2
	"I-78"	9
	"I-214"	7
	"I-488"	1
	"Robusta"	5
	mixed *P. euramericana* clones	1
White	"Yeogi 1"	2
Other	mixed clones	2
	Total	**39**

MARVL inventory assessments were undertaken in stands greater than 0.5 ha where at least 20 trees could be included in the plot without including edge trees. The majority of stands where MARVL assessments were taken were substantially larger than this minimum area. Other requirements included the potential for products other than pulp to be generated from the stands. In general circular plots were used although in three cases, to maintain a common species, line plots were used.

MARVL requires a description of qualities that define the external features of the tree. A descriptive code was developed for poplar (Table 1. 3) that was designed to include potential high value components such as short length internodes.

Also required by MARVL is a log cutting strategy (Table 1. 4). Emphasis in the development of a log cutting strategy for poplar was on maximising the volume recovery of high value log grades without creating large amounts of waste. Ideally separate cutting strategies for different stands would be more realistic, however the amout of data and generally small size of stands precluded this. It should be noted that the log prices are estimates only, and are somewhat artificial due to weak market information on the value of poplar.

Data was then analysed in the MicroMARVL software system to give per hectare results by assessment.

Table 1. 3. Poplar quality description

pruned	straight	peeler	A
		not peeler	B
	not straight	peeler	C
		not peeler	D
unpruned	straight	branches < 6cm	E
		branches 6-10 cm	T
		branches 10-14cm	G
		branches > 14cm	H
	swept sed/8 (3.7m)	branches < 6cm	I
		branches 6-10 cm	J
		branches 10-14cm	K
clear + branch	internode 0.5-2.0 m, branches < 6 cm		L
internodal	straight > 2 m		N
pulp	branches > 14 cm, severe sweep		P
pulp special	straight - dead branch on stem (< 6 cm)		V
reject			U

Table 1. 4. Poplar log cutting strategy

Log type/lengths	**Min sed[2] (cm)**	**Max sed (cm)**	**Max led[3] (cm)**	**Log price ($\$/m^3$)**	**Qualities**
Pruned sawlog (P) 2.4-5.5m	30	150	150	100	ABCD
Internodal > 2m (I) 2.4-4.9m	20	150	150	70	ABCDN
Sawlog Br < 6cm, straight (S), 3.7-11m	20	150	150	70	ABCDELV
Sawlog, other (L) 3.5-11m	20	150	150	40	ABCDETGIJKLNV
Pulp 3.5-11m	10	150	150	35	ABCDETGHIJKLNPV

[2] Small end diameter
[3] Large end diameter

1.1.3 Height function estimation

MacLean (1997) regressed mean top height on stand age using a form of the Chapman-Richards model (Richards, 1959) where the "a" parameter which defines the asymptote of the curve, differs for each land class:

$$H = a*(1-\exp(-b*A))$$

where:

H	=	mean top height (m)
A	=	age (years)
a	=	41.9279 (riverberm)
	=	41.9897 (swamp)
	=	38.0948 (hill)
	=	40.0688 (erosion control)
b	=	0.06354

The similar values for the "a" parameters show that there appears to be little difference in height growth between land classes.

This model was re-estimated using MacLean's data, plus an additional 26 of the 40 stands used in the canopy closure model (section 2.1.2), giving a total of 60 data points. Data from 12 of the 40 stands was omitted as these stands were also used by MacLean, while a further 2 stands were omitted as their age was unknown. The fitted equation was a form of the Weibull function. When the data was treated as a single population (that is, ignoring differences in land class), the fitted function was:

$$H = a*(1-\exp(-b*A^c))$$

where:

H	=	mean top height (m)
A	=	age (years)
a	=	32.4841
b	=	0.02797
c	=	1.4874

The height function was also re-estimated using land class as a dummy variable; that is, the "a" parameter was allowed to vary for different land classes. Using an F-test, the hypothesis that there was only one population was rejected at the 5% level, but could not be rejected at the 2.5% level of significance. That is, the difference in height growth between land classes was not statistically significant to the 2.5% level. Therefore the sites were reclassified into "good", "medium" and "poor" sites, rather than "riverberm", "swamp", "hill", and "erosion control" land classes, and the model was again re-estimated using site quality as a dummy variable (Figure 1.1). Of the 60 stands, 27 were classified as good sites, 24 as medium sites, and 9 as poor sites. Poor sites were poorly represented in the sample as these sites were purposely excluded when the MARVL inventories were carried out, as many of these stands contained pulpwood only. Because of the small number of stands sampled of any single species or clone, and because of the difficulty in separating the effects of clonal and site differences, clonal variation was not used as an explanatory variable in the estimated function. Using the revised site classification, the difference between sites was statistically significant at the 1% level of significance. The parameter values of the fitted Weibull function were:

a = 36.8347 (good sites)
= 33.0338 (medium sites)
= 26.1662 (poor sites)
b = 0.04666
c = 1.2321

and an approximation of an r^2 for the model was 0.85.

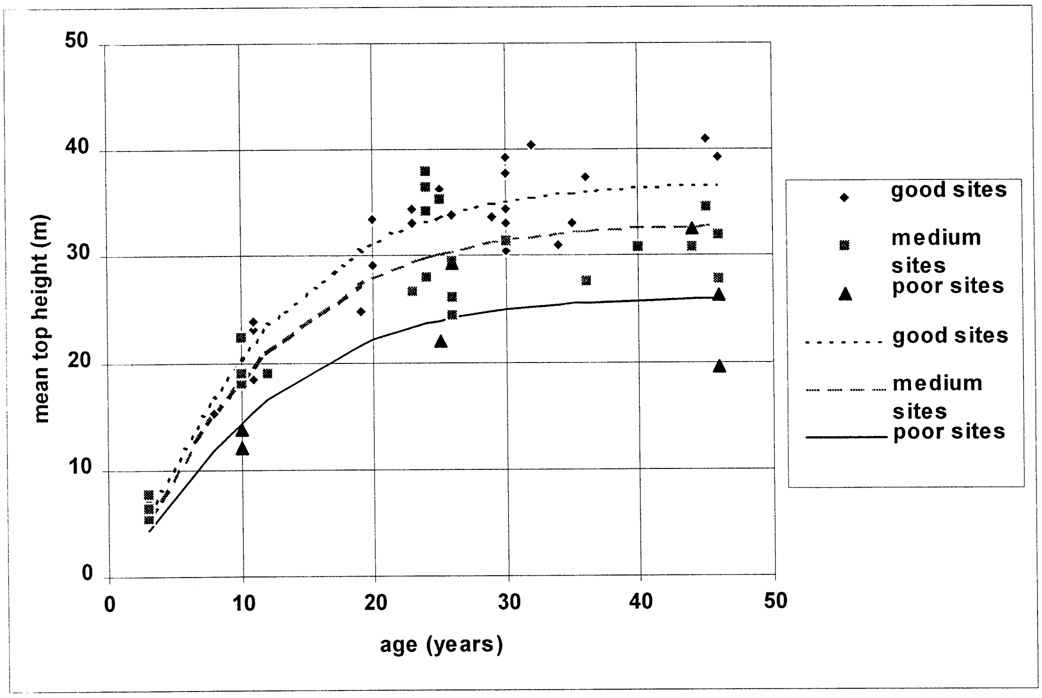

Figure 1. 1. Estimated height function for New Zealand grown poplar

1.1.4 Volume function estimation

MacLean (1997) also developed a function which uses mean top height and stocking to predict total stand volume in poplar stands. A power function was used where again the "a" parameter is a "dummy" variable to incorporate the effect of land class on volume growth.

$$V = a*H^b*N^c$$

where:

V = total volume (m^3/ha)
H = mean top height (m)
N = stocking (stems/ha)
b = 2.082277
c = 0.303817
a = 0.054906 (riverberm)
= 0.053877 (swamp)
= 0.016089 (hill)
= 0.049276 (erosion control)

Again, the similar values for the "a" parameters for the riverberm, swamp, and erosion control land classes indicate that there appears to be little difference in volume growth between these land classes. Volume growth appears to be considerably slower on the "hill" land class, however this is based on data from only four sites.

This model was also re-estimated in order to incorporate data collected from the additional five East Coast erosion control poplar stands. In addition, stand volume at each site was estimated for the revised model using new volume and taper functions developed for New Zealand grown poplar.

When the data was treated as a single population (Figure 1. 2) the estimated parameter values were:

a= 0.05559
b= 2.1398
c= 0.2697s

The volume function was again re-estimated using land class as a dummy variable, but the difference between land classes was not significant at the 5% level. However, using the revised site classification of "good", "medium" and "poor" sites, the difference between sites was significant at the 1% level. Of the 39 stands in which MARVL inventories were carried out, 20 were classified as good sites, 14 as medium sites, and 5 as poor sites. The estimated parameter values in this case were:

a = 0.07286 (good sites)
= 0.05414 (medium sites)
= 0.04516 (poor sites)
b = 1.9507
c = 0.3595

Figure 1. 2 and Figure 1. 3 illustrate the fitted function for good sites and poor sites.

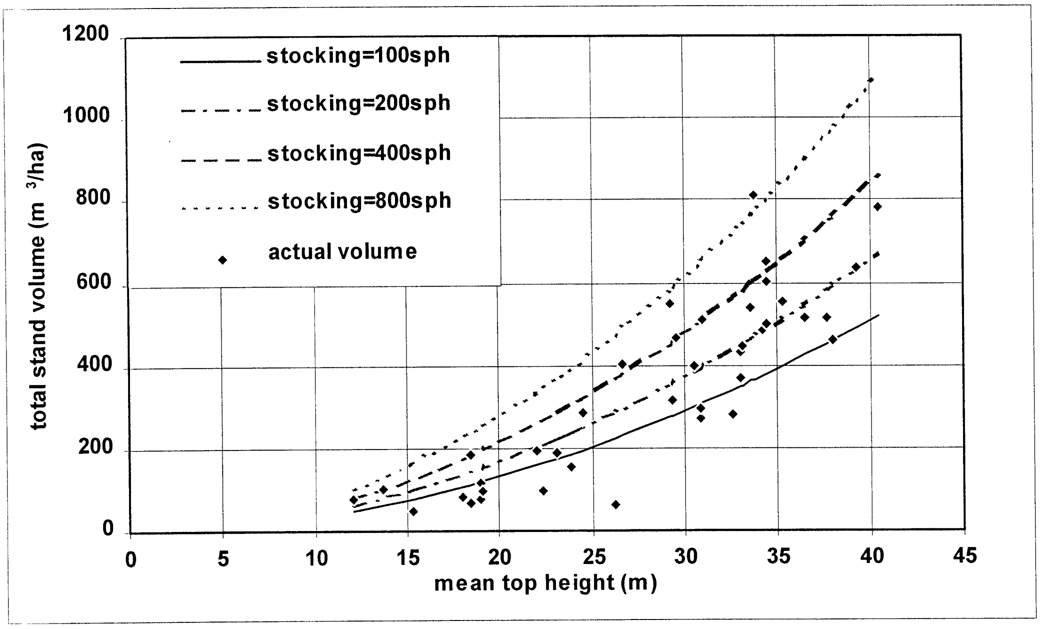

Figure 1. 2. Estimated volume function for New Zealand grown poplar on good sites

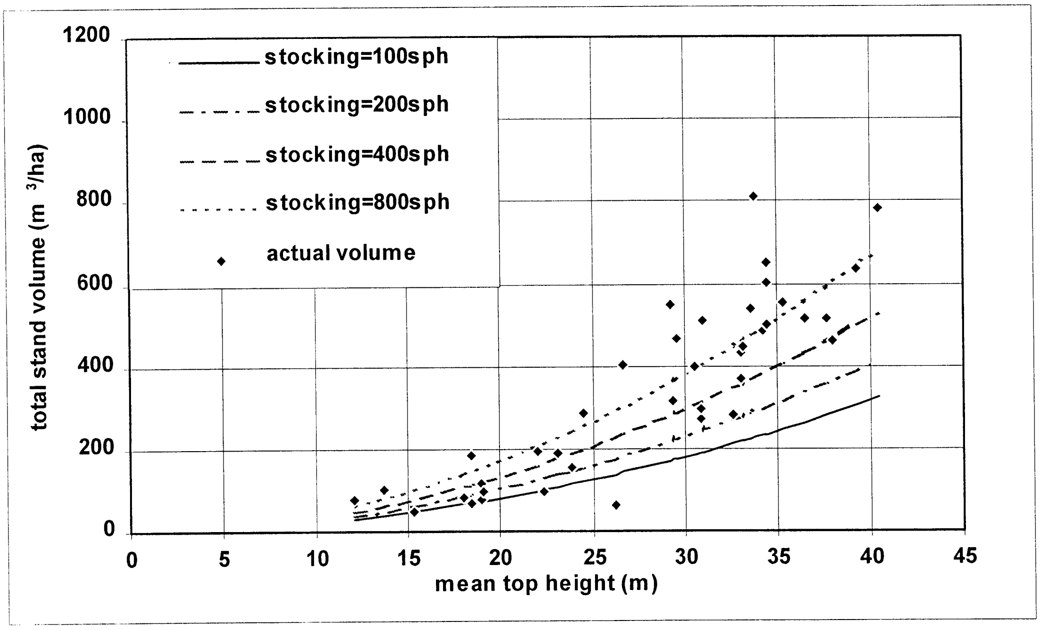

Figure 1. 3. Estimated volume function for New Zealand grown poplar on poor sites

1.2 Allocation of poplar volume to log grades and value

1.2.1 Introduction

In addition to estimating total stand volume, it is useful to be able to allocate that volume to various log grades, in order to estimate stand value. Therefore, equations to estimate volume by log grade were developed, using MacLean's MARVL data plus the further five MARVL assessments from the East Coast of the North Island.

1.2.2 Estimating total recoverable volume

A plot of total recoverable volume (trv) against total stand volume (tsv) indicated that the relationship between the two is approximately linear (Figure 1. 4). The difference between tsv and trv consists of waste (that is, breakage, stumps, unmerchantable stems and cutting waste).

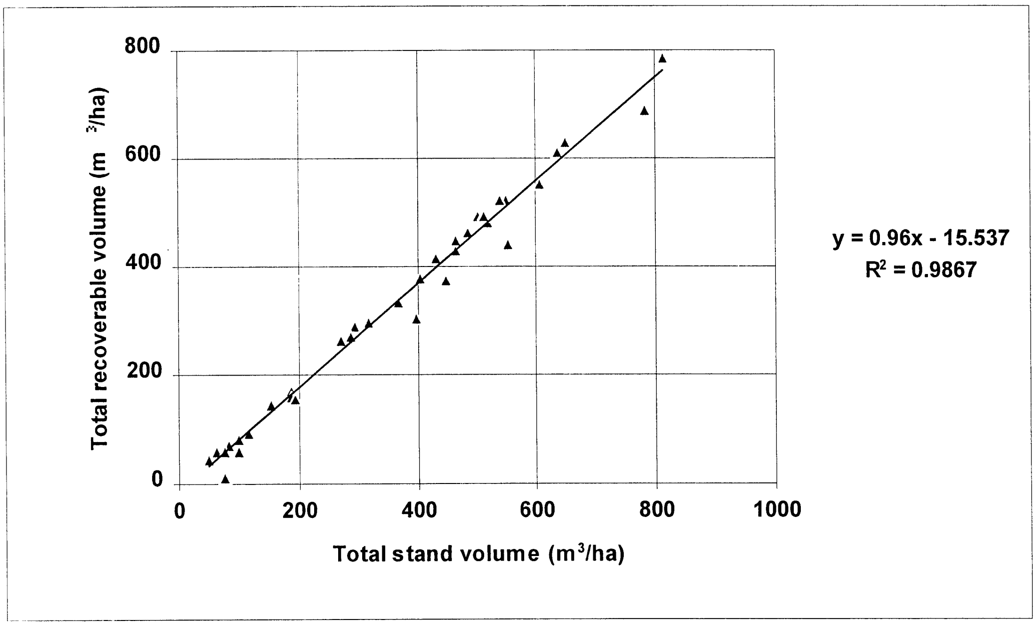

Figure 1. 4. Total recoverable volume versus total stand volume

1.2.3 Estimating pruned volume

The volume of pruned logs (P1) can be estimated directly from the integrated form of the taper equation used in the MARVL analysis. The standard functional form for taper equations used by MARVL software is:

$$D^2 = \frac{kV}{H} \left(b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4 + b_5 t^5 + b_6 t^{b7} + b_8 t^{b9}\right)$$

where:

D = dbh[4] outside bark in cm
k = a constant = $40000/\pi$
V = total tree volume in m^3
H = total tree height in m
t = relative distance from tip = distance from tip/H
b1 to b9 are estimated parameters

This can be integrated to give:

$$v = V\,(b_1t^2/2 + b_2t^3/3 + b_3t^4/4 + b_4t^5/5 + b_5t^6/6 + b_6t^{b7+1}/(b_7+1) + b_8t^{b9+1}/(b_9+1))$$

where:

v = volume between point t and the tip of the tree in m^3

Thus the pruned volume may be estimated as $v_2 - v_1$, where v_2 is the volume from the stump height to the tree tip, and v_1 is the volume from the pruned height to the tree tip.

This pruned volume estimate must be scaled down however, because some proportion of the trees will not meet the minimum small end diameter specification of 30 cm for pruned logs. This correction factor will also include downgrading of the pruned section due to sweep or other malformations. Because the required correction will be larger for stands of smaller diameter, pruned diameter can be used to predict the required correction factor (Figure 1. 5). Mean pruned height was also used as an explanatory variable in order to ensure that the function did not predict decreasing pruned volumes for increasing pruned heights. The estimated pruned volume from the integrated taper equation is multiplied by the correction factor to give the final estimated pruned volume. The fitted function for the correction factor in Figure 1. 5 is a logistic equation (Ratkowsky 1989) with asymptotes at 0 and 0.93.

$$C = a / (1+\exp(-b(Pd-(c+d*Pht))))$$

where:

C = correction factor to multiply estimated pruned volume by
Pd = diameter at pruned height (cm)
Pht = pruned height (m)
a = 0.9297
b = 0.3999
c = 32.1602
d = -0.7194

[4] Diameter at breast height (1.4m)

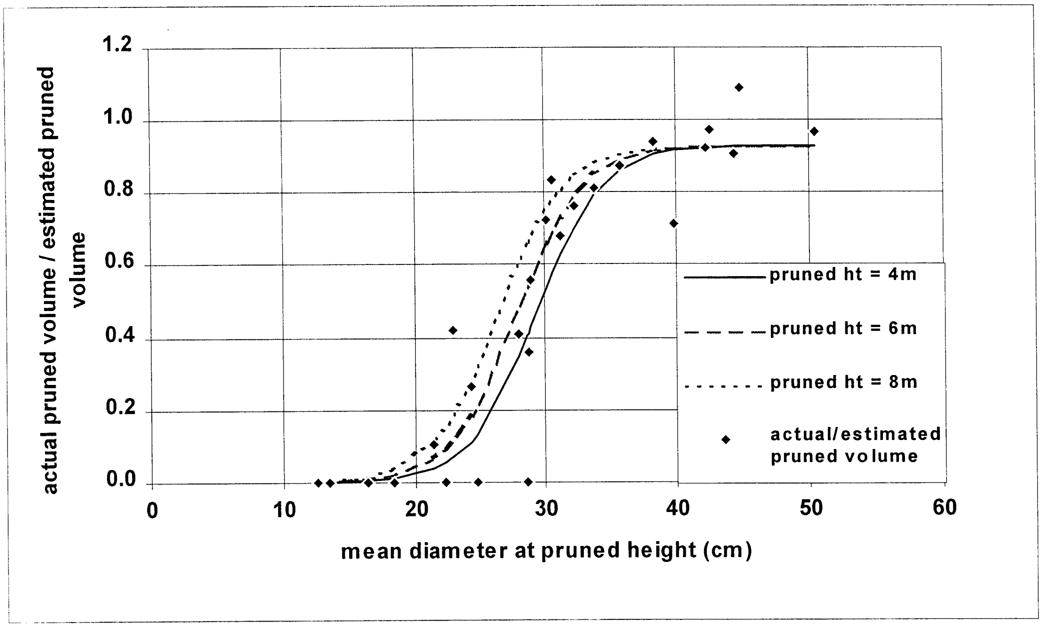

Figure 1. 5. Pruned volume correction factor versus diameter at pruned height

In order to be able to estimate the pruned volume correction factor for a minimum sed of other than 30 cm the “c” parameter in the regression equation can be approximated as the minimum sed multiplied by 1.072. This still gives a “c” parameter value of 32.16 for a minimum sed of 30 cm, but the fitted correction factor curve will move to the right or left if the minimum sed is higher or lower.

1.2.4 Estimating pulp volume

In order to predict the volume of pulp logs, pulp volume as a proportion of total recoverable volume was regressed on mean recoverable volume per tree (Figure 1. 6). The percentage of pulp clearly decreases as tree volume increases, with a lower bound at about 16% pulp. The fitted model was a form of the Chapman-Richards (Richards, 1959), with an approximation of an R^2 of 0.81:

$$Pulp = 1 - a*(1-\exp(-b*TRV))$$

where:

Pulp	= pulp volume as a proportion of TRV
TRV	= mean total recoverable volume per tree
a	= 0.8362
b	= 2.1283

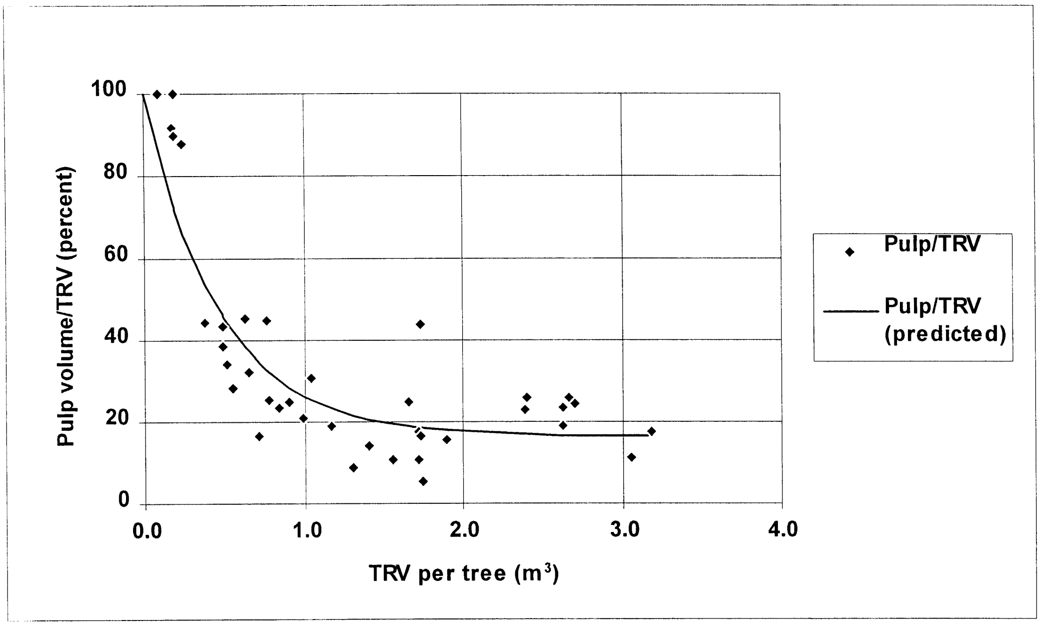

Figure 1. 6. Percentage pulp volume versus mean recoverable volume per tree for New Zealand grown poplar

1.2.5 Estimating unpruned sawlog volume

For the purpose of allocating the remaining recoverable volume, the "internodal" grade (I) was amalgamated with the "straight, small branched sawlog" grade (S), as they are likely to be of approximately equal value. The internodal grade volume was generally small and unpredictable between stands, hence it was convenient to include this volume with the small branched sawlog volume. Thus the residual volume (total recoverable volume minus pruned and pulp volume) was allocated between two grades only; the S+I and L log grades.

The proportion of volume allocated to the amalgamated S+I grade was expected to increase with increasing stocking and decrease with increasing age. That is, closely spaced trees are expected to be straighter, and have smaller branches, than wide spaced trees, while young trees are expected to have smaller branches than older trees. S+I log grade volume as a proportion of residual volume was regressed against stocking. Again, the fitted model was a form of the Chapman-Richards (Richards, 1959). The fit of the model was quite poor however, with an approximation of an R^2 of 0.43 (Figure 1. 7):

$$SI = 1*(1-\exp(-a*N))$$

where:

SI = volume of S+I grade as a proportion of S+I+L
N = stocking (stems/ha)
a = 0.009605

Although the fit of this model was not particularly good, a stand age variable was not added to the model because the residuals appeared to be uncorrelated with age. This was contrary to expectation, and indicates that either branch size does not increase significantly in poplars after 10 years of age (the youngest stand age of the MARVL assessments), or that there was insufficient data to pick up this effect.

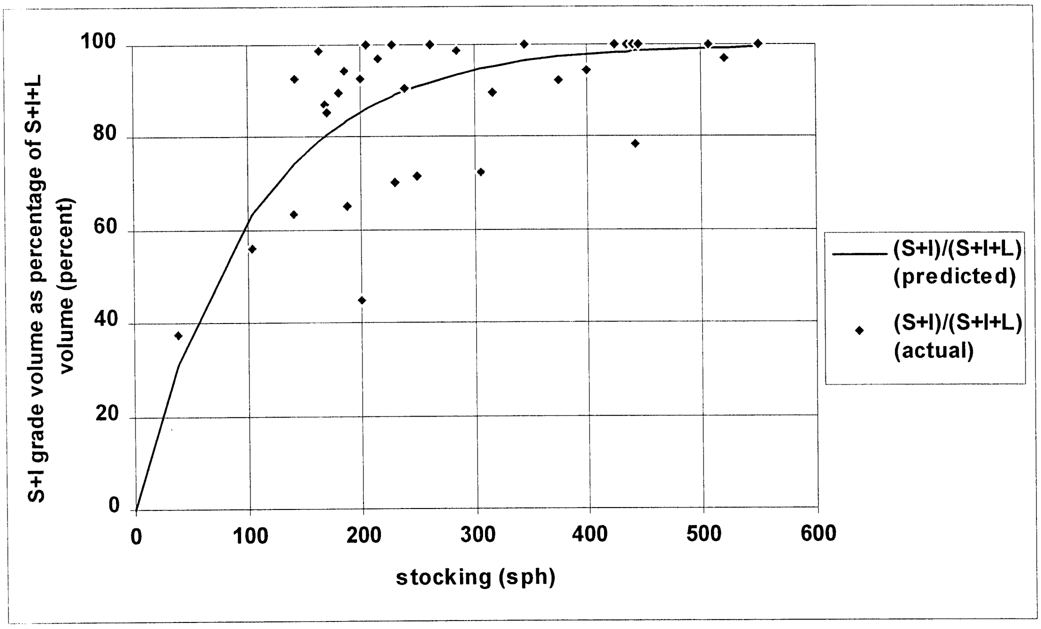

Figure 1. 7. S+I log grade volume versus S+I+L volume for New Zealand grown poplar

Once the pruned log, pulp log, and S+I log grade volumes have been estimated, the L grade log volume (swept or large branched sawlogs) can then be calculated by difference, eg. L vol = (S + I +L vol) - (S+I vol).

1.2.6 Estimation of stand value

The overall fit of the stand volume function and log grade allocation functions was tested by comparing the actual stand value computed by the MARVL software with the estimated stand value using these functions. The log price estimates used were $\$100/m^3$ for pruned logs, $\$70/m^3$ for small branched sawlogs and internodal lengths, $\$40/m^3$ for large branched sawlogs, and $\$35/m^3$ for pulp. It should be noted that these prices are estimates only, and are somewhat artificial due to weak market information on the value of poplar.

The mean actual stand value was $20,387/ha, while the mean estimated stand value was $19,200/ha, indicating that, on average, the estimated functions underestimated stand value at the time of the MARVL assessments by $1187, or 5.8%. A plot of the estimation errors against estimated value (Figure 1. 8) does not reveal any other clear pattern in the errors however; that is, the errors appear to be uncorrelated with the magnitude of the estimated stand value. It should be noted that this result will vary somewhat, depending on the relative prices assigned to different log grades.

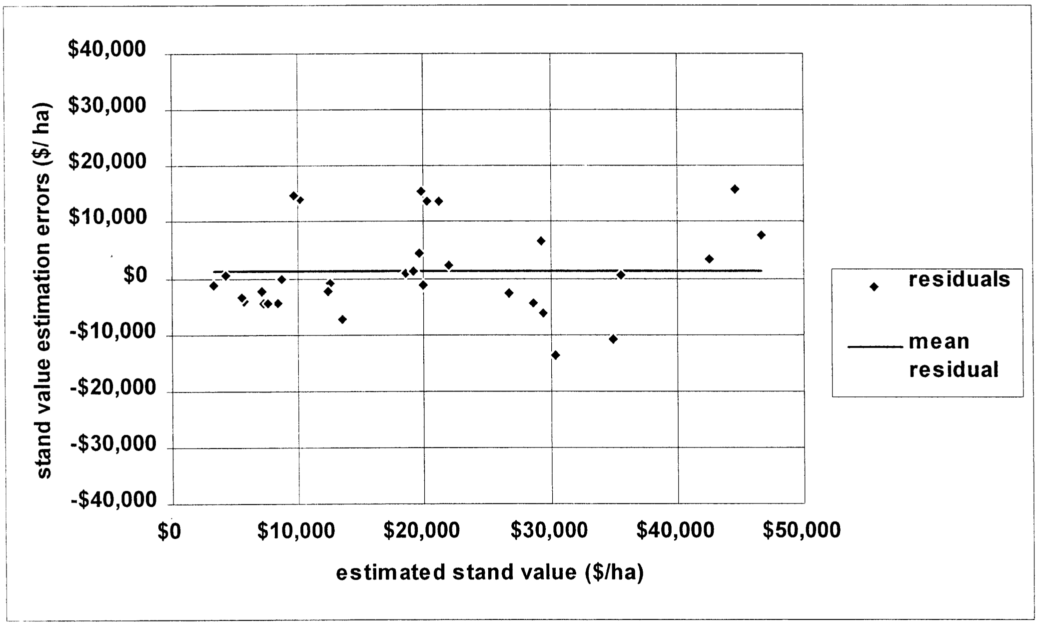

Figure 1. 8. Stand value estimation errors versus estimated stand value for poplar growth model

1.2.7 A user interface for predicting poplar stand volume, and volume and value by log grade

The estimated stand height and volume functions for poplar can be combined with the log allocation equations in order to predict stand volume and value by log grade. A spreadsheet can be used to automatically calculate these volumes and values (Table 1. 5 and Table 3), and display the results graphically (Figure 1. 9 and Figure 1. 10). The input variables are age, site quality, stocking, pruned height, proportion of trees pruned, thinning age, residual stocking after thinning, log prices, minimum pruned log small end diameter, and minimum pruned log length. Stand volume increments following thinning are assumed to be the same as the volume increments of a stand that was initially planted at the lower stocking. The log prices shown in Table 1. 5 and the values displayed in Table 3 correspond to the prices used in the stand value estimation analysis. The output variables are stand volume and mean top height, as well as values ($/ha) and volumes ($m^3$/ha) by log grade up to age 50 years.

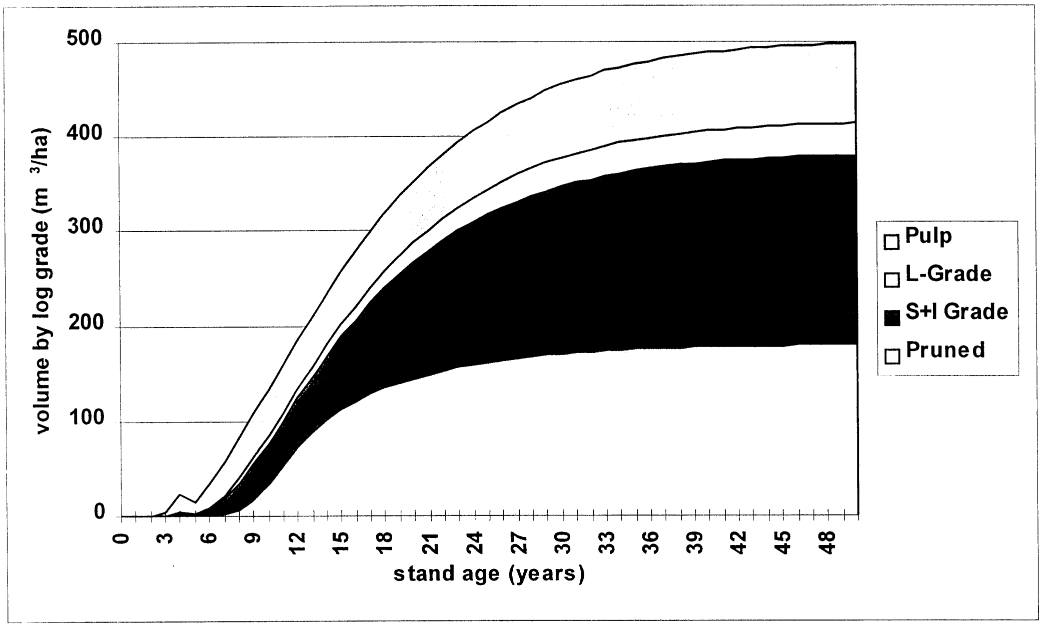

Figure 1. 9. Volume by log grade versus stand age

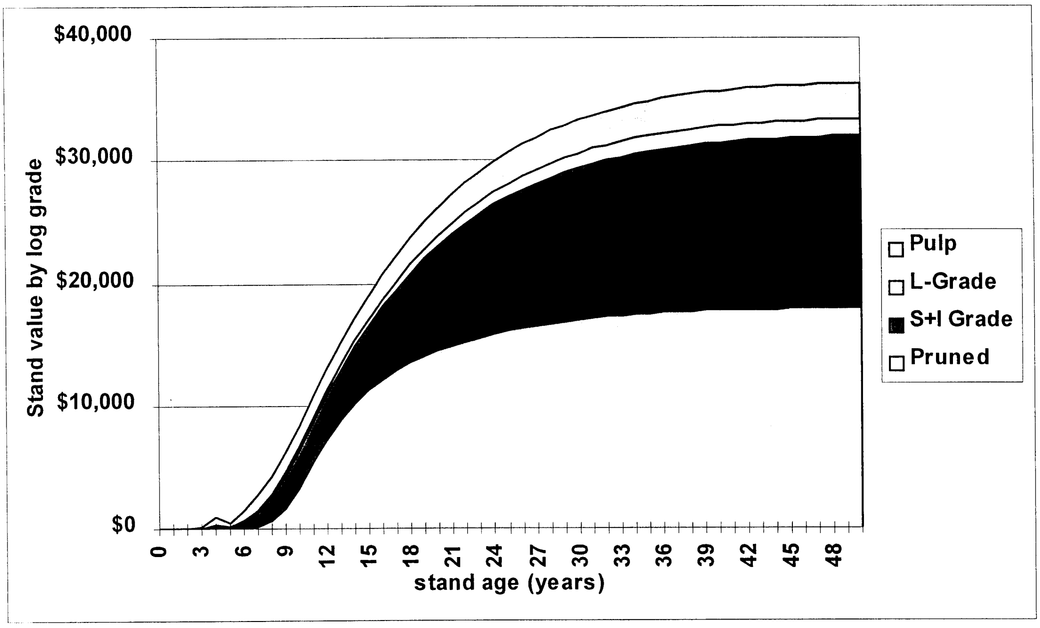

Figure 1. 10. Value by log grade versus stand age

Table 1. 5. Input variables for poplar yield estimation user interface

Stand variables

site quality	stocking (stems/ha)	pruned height (m)	percentage of trees pruned	thinning age (years)	residual stocking
good	400	6	100%	5	200

Log prices ($/m^3)

Pruned sawlog	S+I Grade (unpruned sawlog)	L-Grade (unpruned sawlog)	Pulp
100	70	40	35

Log grade variables

minimum pruned log length (m)	minimum s.e.d. for pruned logs (cm)
2.4	30

Table 1. 6. Output variables for poplar yield estimation user interface

		Height and Volume		Log Volumes (m3/ha)				
Stand Age (years)		Mean Top Height (m)	Total Stand Volume (m^3/ha)	Pruned	S+I Grade	L-Grade	Pulp	Total Recoverable Volume
0		0.0	0	0	0	0	0	0
1		1.7	2	0	0	0	0	0
2		3.8	9	0	0	0	0	0
3		6.1	21	0	0	0	5	5
4		8.4	40	0	3	1	18	22
5		10.6	31	0	1	0	13	15
6		12.7	53	0	7	1	26	35
7		14.8	76	2	17	3	36	58
8		16.7	102	6	29	5	42	82
9		18.5	128	16	38	7	46	107
10		20.2	155	33	44	8	49	133
11		21.8	182	53	47	8	51	159
12		23.2	209	72	52	9	52	185
13		24.6	235	89	58	10	53	210
14		25.8	260	102	66	11	55	234
15		26.9	284	112	76	13	56	257
16		27.9	307	121	85	15	58	279
17		28.9	328	128	95	16	59	299
18		29.7	348	135	105	18	61	319
19		30.5	366	140	114	20	63	336
20		31.2	384	145	122	21	65	353
21		31.8	399	149	130	22	66	368
22		32.3	414	153	138	24	68	382
23		32.8	427	156	144	25	70	394
24		33.3	439	159	150	26	71	406
25		33.7	450	161	156	27	72	416
26		34.1	460	163	161	28	74	426
27		34.4	468	165	166	28	75	434
28		34.7	476	167	170	29	76	442
29		34.9	483	169	173	30	77	449
30		35.1	490	170	177	30	77	455
31		35.3	495	171	180	31	78	460
32		35.5	501	172	182	31	79	465
33		35.7	505	173	185	32	80	469
34		35.8	509	174	187	32	80	473
35		35.9	513	175	189	32	81	477
36		36.1	516	176	190	33	81	480
37		36.2	519	176	192	33	81	482
38		36.2	521	177	193	33	82	485
39		36.3	523	177	194	33	82	487
40		36.4	525	178	195	33	82	489
41		36.4	527	178	196	34	83	490
42		36.5	528	178	197	34	83	492
43		36.5	530	178	198	34	83	493
44		36.6	531	179	198	34	83	494
45		36.6	532	179	199	34	83	495
46		36.6	533	179	199	34	83	496
47		36.7	533	179	200	34	83	496
48		36.7	534	179	200	34	84	497
49		36.7	535	180	200	34	84	498
50		36.7	535	180	200	34	84	498

Table 1. 6 (continued) Output variables for poplar yield estimation user interface

Log values ($/ha)				
Pruned	S+I Grade	L-Grade	Pulp	Total Value ($/ha)
$0	$0	$0	$0	$0
$0	$0	$0	$0	$0
$0	$0	$0	$0	$0
$0	$12	$1	$164	$201
$3	$236	$23	$645	$1,000
$4	$102	$10	$448	$628
$32	$522	$51	$904	$1,638
$168	$1,217	$119	$1,243	$2,925
$612	$2,016	$198	$1,473	$4,509
$1,634	$2,676	$262	$1,618	$6,422
$3,307	$3,072	$301	$1,709	$8,634
$5,318	$3,321	$326	$1,769	$10,987
$7,244	$3,622	$355	$1,817	$13,298
$8,871	$4,067	$399	$1,862	$15,465
$10,185	$4,641	$455	$1,910	$17,463
$11,246	$5,292	$519	$1,962	$19,299
$12,117	$5,977	$586	$2,019	$20,987
$12,847	$6,662	$653	$2,079	$22,538
$13,470	$7,328	$719	$2,141	$23,963
$14,008	$7,963	$781	$2,203	$25,269
$14,477	$8,559	$839	$2,264	$26,463
$14,889	$9,114	$894	$2,324	$27,553
$15,253	$9,626	$944	$2,381	$28,544
$15,575	$10,097	$990	$2,435	$29,444
$15,860	$10,527	$1,032	$2,485	$30,259
$16,113	$10,918	$1,071	$2,532	$30,994
$16,337	$11,272	$1,105	$2,575	$31,657
$16,536	$11,592	$1,137	$2,614	$32,253
$16,713	$11,881	$1,165	$2,650	$32,787
$16,869	$12,140	$1,190	$2,683	$33,265
$17,008	$12,372	$1,213	$2,712	$33,693
$17,131	$12,579	$1,233	$2,739	$34,074
$17,239	$12,765	$1,252	$2,763	$34,413
$17,335	$12,930	$1,268	$2,784	$34,715
$17,420	$13,076	$1,282	$2,803	$34,982
$17,495	$13,206	$1,295	$2,820	$35,220
$17,561	$13,322	$1,306	$2,835	$35,430
$17,620	$13,424	$1,316	$2,849	$35,615
$17,671	$13,514	$1,325	$2,861	$35,779
$17,716	$13,594	$1,333	$2,871	$35,924
$17,755	$13,664	$1,340	$2,880	$36,051
$17,790	$13,726	$1,346	$2,888	$36,163
$17,821	$13,780	$1,351	$2,896	$36,261
$17,847	$13,828	$1,356	$2,902	$36,347
$17,871	$13,869	$1,360	$2,907	$36,423
$17,891	$13,906	$1,364	$2,912	$36,489
$17,909	$13,938	$1,367	$2,917	$36,547
$17,925	$13,966	$1,369	$2,920	$36,598
$17,939	$13,991	$1,372	$2,924	$36,642
$17,951	$14,012	$1,374	$2,926	$36,681
$17,961	$14,031	$1,376	$2,929	$36,715

PART 2: ESTIMATING UNDERSTOREY PASTURE PRODUCTION IN NEW ZEALAND GROWN POPLAR PLANTATIONS

2.1 Developing a canopy closure model for New Zealand grown poplar

2.1.1 Introduction

Percentage canopy closure should be a useful as a surrogate for water use (Calder, 1996), and an indicator of the contribution of trees to soil stability, as it is correlated with interception losses, and to a lesser extent, transpiration losses. Other than direct physical reinforcement by tree roots, these are the two important mechanisms by which trees contribute to soil stability. Strictly speaking, transpiration should be more closely related to the Leaf Area Index (LAI) which is a measure of the ratio of leaf area to the ground area over which it lies. Percentage canopy closure is however a useful proxy and is far more easily measured.

Canopy closure is also directly related to understorey pasture production, and can therefore be used to predict changes in livestock carrying capacity of pastoral farmland planted into forestry.

Canopy closure, otherwise known as canopy density or crown closure, is defined as the ratio of horizontal area of projected tree canopy, relative to the total ground area covered (Knowles *et al.*, 1997). In effect it is an expression of the ground area shaded by overhead foliage (Daubenmire, 1959).

Knowles *et al.* (1996) showed that stand canopy closure for *Pinus radiata* can be correlated with basal area and mean height ratio. Basal area (BA) is defined as the sum of the cross sectional area of all tree stems at a height of 1.4m in one hectare,

$$BA = \frac{\Sigma\, \pi * (DBH/2)2}{A}$$

where:

DBH = diameter at breast height (m)
A = area (ha) of plot used for sample

Height ratio is defined as the height above ground to the base of green crown (crown height), divided by total tree height.

$$\text{Ht ratio} = \frac{\text{crown ht}}{\text{total ht}}$$

That is, a large height ratio indicates that the length of green crown is a relatively small percentage of total tree height, while a small height ratio indicates that the green crown length is a large percentage of total tree height.

2.1.2 Method

The data set was comprised of 40 poplar stands, of which 23 were in the Bay of Plenty and 17 on the East Coast. Of the 40 stands, 12 overlapped with the stands used by MacLean (1997) for MARVL inventory assessments. Many of the stands in which canopy closure was assessed would have been unsuitable for MARVL assessment, as they contained no mechantable volume other than pulpwood. A number of different poplar clones and species were included in the data set (Table 2. 1) although black poplars, particularly Italian hybrids, made up the bulk of the sample.

Table 2. 1. Species/clone of *Populus* spp. plots assessed for canopy closure

Group	Species/clone	No. of plots
Balsam poplars	"Androscoggin"	2
	"Oxford"	1
	yunnanensis	1
	"Geneva"	1
Black poplars	"I-30"	2
	"I-78"	5
	"I-214"	4
	"Robusta"	6
	"Veronese"	1
	"Flevo"	1
	P. deltoides x	3
	mixed *P. euramericana* clones	1
	mixed Italian hybrids	1
	unidentified Italian hybrids	6
Balsam/black poplar cross	"Kawa"	3
Other	mixed clones	2
	Total	40

The methodology for determining the degree of canopy closure was based on that previously developed at *Forest Research* for assessment of shelterbelt optical porosity (Horvath *et al.*, 1995), and assessment of radiata pine canopy closure (Knowles *et al.*, 1997). The procedure involved capturing a series of black and white images using a digital camera mounted on a tripod and set to view vertically into the forest canopy. Individual images were downloaded onto computer using the Photoimpact image assessment program. These images were then assessed for canopy closure using software developed at *Forest Research.* Pixels representing tree canopy show up as black, while those representing the sky background show up as white. The program counts the number of black and white pixels, thus giving a measure of percentage canopy closure.

Usually 17 images were taken in each stand in a star shaped pattern (Figure 2.1), although in some stands as few as 14 or as many as 25 images were taken. The spacing between images was chosen so as to ensure the images did not overlap at 30m stand height (ie., did not violate the assumption of independence). Where stands were very narrow such that a circular sampling pattern would not fit, the images were taken at intervals along a transect which was not parallel to the row direction. In each case the estimated canopy closure at each site was simply calculated as the mean of the percentage canopy closure evident in the individual images.

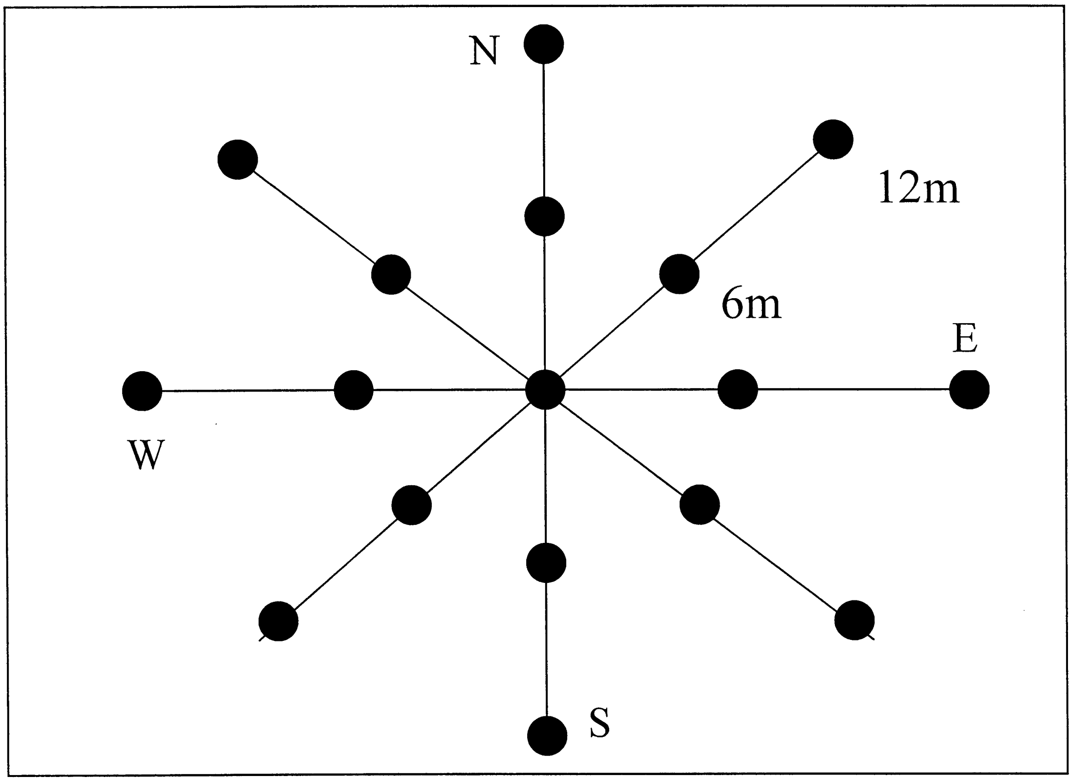

Figure 2. 1. Sampling design for acquiring video images of canopy closure in a sample plot

Based on the number of images taken, the sample size required in order to estimate canopy closure within plus or minus 5% was calculated for each stand. That is,

$$n = \frac{t^2 * \sigma^2}{w^2}$$

where:

n = required sample size
t = t statistic for 95% confidence level
σ = sample standard deviation
w = desired width of confidence interval

The results of this test indicated that a sufficiently large number of images were taken in only 18 out of 40 stands. However, the time involved in processing the images, the small size of most of the stands, and the need to space the images so they did not overlap, precluded the possibility of taking a larger number of images in most instances. The 95% confidence interval based on the actual number of images used, was less than plus or minus 10% canopy closure for 28 out of 40 stands. In addition, none of the points with wide confidence intervals appeared as outliers in a plot of canopy closure against basal area; therefore all data points were retained for the estimation of the model

Poplars are deciduous species, and so it is also necessary to model the seasonal changes in canopy closure that occur as the trees lose their leaves in winter. It is expected that due to reduced shading, relative pasture production beneath poplars during the winter months will be higher than during the summer months. Canopy closure during winter beneath a deciduous species is simply the ratio of horizontal area of projected tree branches, relative to the total ground area covered. Winter measurements of canopy closure were recorded for 11 of the 40 stands.
These included three stands of "Robusta", three of "I-78", two of "I-30", and one each of "Androscoggin", "Geneva" and "Oxford".

In addition to canopy closure, tree height, green crown height, dbh (diameter at breast height) and stocking were measured for a sample of trees in each stand, thus allowing basal area and mean height ratio to be calculated.

2.1.3 Results

Examination of the data indicated a strong correlation between canopy closure and basal area. A function was fitted of the form described by the Chapman Richard's model (Ratkowsky, 1989), which predicts canopy closure from stand basal area (BA) and height ratio (ht rat).

$$\text{Canopy Closure} = 92*(1-\exp(-a*BA*(1-b*(\text{ht rat}-0.4))))^{1/c}$$

where the coefficients for a, b and c were estimated from the data.

The values of the coefficients estimated for this data set were:

a = 0.0296
b = 0.3148
c = 1.8004

The model was also estimated using a green crown length variable instead of height ratio, but the effect of green crown length on canopy closure was less than that of height ratio.

The function is non-linear so a correlation coefficient cannot be calculated, but an approximation of an R^2 is 0.78.
Figure 2. 2 illustrates the form of the function for three height ratio classes of 0.25, 0.45 and 0.65. The actual and predicted values are shown in Figure 2. 3.

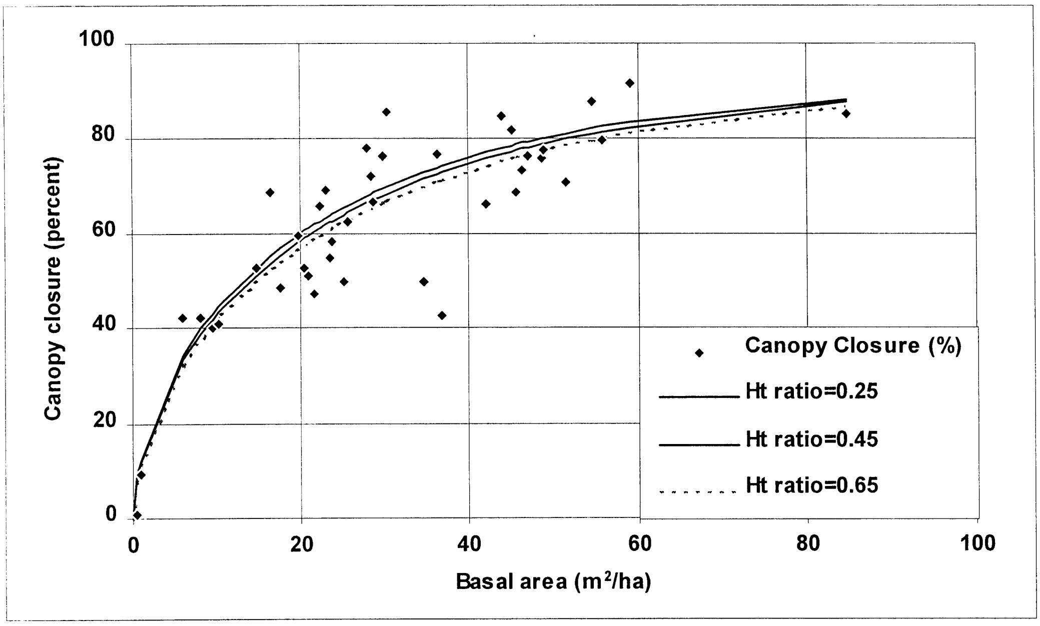

Figure 2. 2. Actual data and fitted function for predicting canopy closure in poplar stands

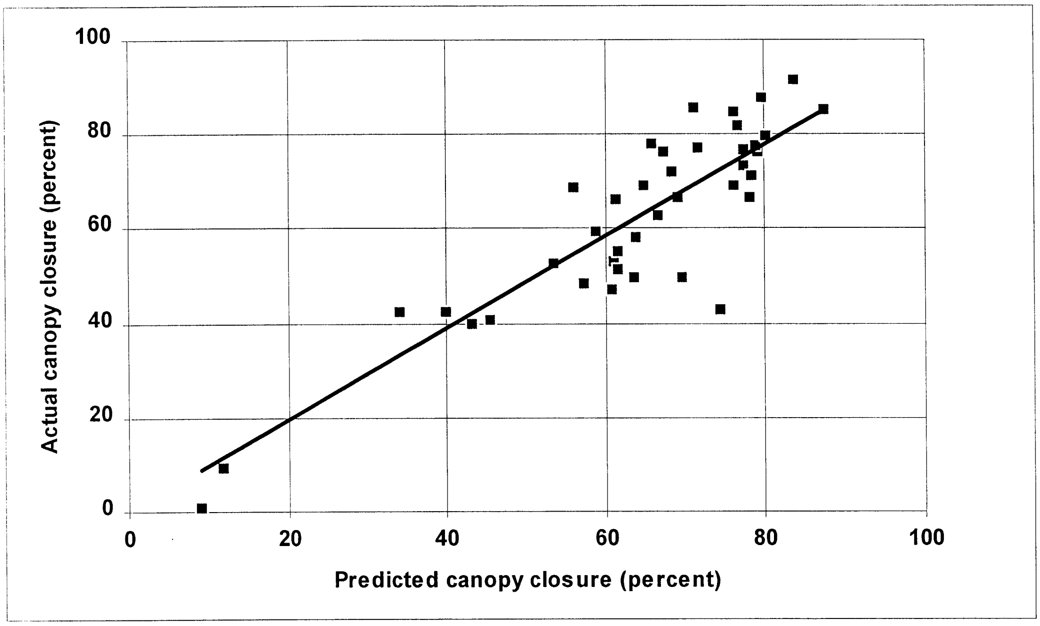

Figure 2. 3. Predicted canopy closure versus actual canopy closure for New Zealand grown poplar

Limitations on the quantity of data available for individual clones or species other than the Italian hybrids prevented the creation of individual functions. However, there did not appear to be any obvious differences between the two main groups of poplars planted for production forestry, the black poplars and the balsam poplars (Figure 2. 4).

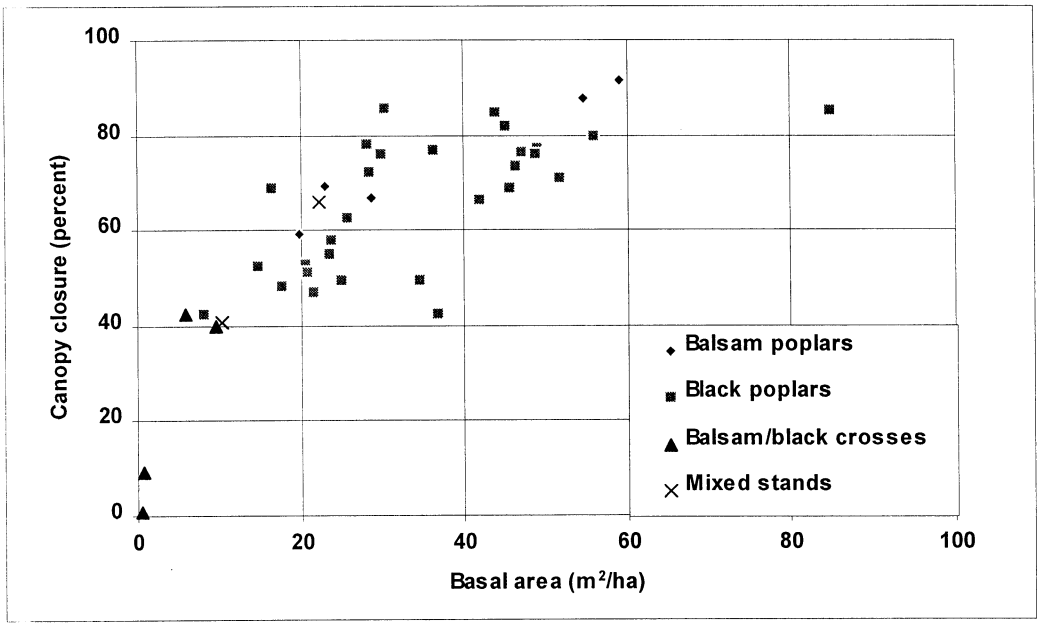

Figure 2. 4. Canopy closure versus basal area by poplar group

No obvious regional differences were evident between the East Coast and Bay of Plenty data sets. Data from all 40 stands was therefore combined for the estimation of the final model.

In the 11 stands used for winter assessments, winter canopy closure appeared to be approximately 31% of full summer canopy closure, as indicated by the straight line relationship in Figure 2. 5. That is, leaves were responsible for about two thirds of the shaded area during summer, with tree stems and branches responsible for the remaining third. There were no obvious differences in winter canopy closure between black poplars ("Robusta", "I-78" and "I-30") and balsam poplars ("Androscoggin", "Geneva" and "Oxford").

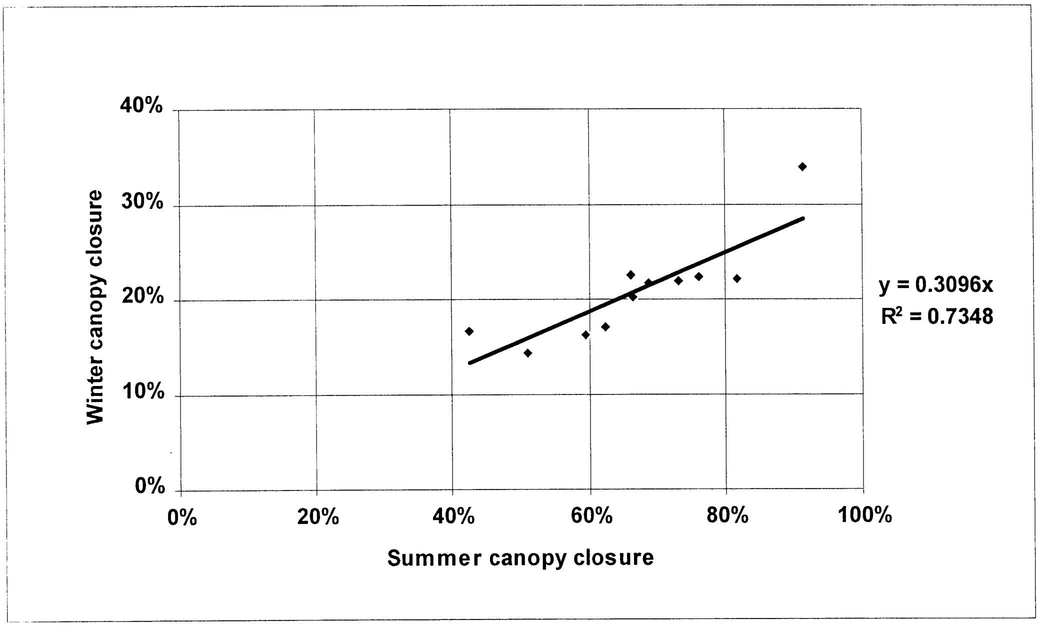

Figure 2. 5. Winter canopy closure versus summer canopy closure in New Zealand grown poplar stands

The reduction in canopy closure during winter was included in the canopy closure model by multiplying the estimated canopy closure by a factor of 0.31 for the months of May, June, July, August and September. The exact times of leaf fall in autumn and flushing in spring will vary between years, regions and clones. Observations made at Palmerston North over a number of years suggest that the time of flushing ranges from early September to late October for different clones, with late September or early October being about average (Van Krayenoord, unpubl.). Leaf fall usually occurs in about mid April, although this also varies by clone (Colin Stace, *pers. comm.*). Species which are prone to drought and rust may begin defoliate during February and March, especially during dry summers. The balsam poplars typically have later leaf fall and bud burst than black poplars.

2.2 Modelling understorey pasture production

Silvopastoral modelling systems require the prediction of understorey pasture production throughout the rotation (Knowles *et al.*, 1997). As the stand grows and the canopy expands, less light reaches the understorey leading to reduced pasture production. A relationship for predicting the pasture suppression can be combined with data on the seasonal distribution of pasture production (Radcliffe and Sinclair, 1975) to estimate the annual percentage reduction in pasture growth. This in turn can be used to estimate the rate of livestock displacement on land planted in poplars for erosion control.

To date however, little research has been conducted on the suppression of pasture growth under poplars; therefore it is difficult to accurately model the expected reduction in livestock numbers over time. Wilson (1973b) stated that a stocking rate of about 100 stems per hectare (sph) on flat land may reduce pasture production by around 7 percent after seven or eight years and 35 percent towards the end of a 16 year rotation, although these estimates were not based on numerical data.

Gilchrist *et al.* (1993) examined the pasture growth under single poplar, willow and eucalypt trees, concluding that pasture suppression (grass, clover and lotus) under conservation plantings during summer is likely to vary from 12.5 percent at 25 sph to 23 percent at 156 sph. They estimated a relationship between stocking and relative pasture production:

$$PP = 110*N^{-0.07154}$$

where:

PP = pasture production (kg dry matter/ha/yr) as a percentage of open pasture
N = stocking (stems/ha)

This relationship does not explicitly model the effect of stand age however, and must be assumed to apply only to trees of the same age used for the creation of the model (16 years). In addition, no suppression of pasture growth was found under deciduous trees during winter.

In a more recent study, Guevara-Escobar *et al.* (1997) found that pasture growth was suppressed by about 40% under a mature stand of *Populus deltoides* at a stocking of 37sph and mean dbh of 70.3cm. Based on stocking and mean dbh, basal area was approximately 14.4 m^2/ha, giving predicted canopy closure of 51.1%. Pasture under poplars was also found to be of slightly lower feed quality than that grown in the open.

Knowles *et al.* (1997) used a canopy closure model for *Pinus radiata* in conjunction with data on pasture and stand growth at the Tikitere agroforestry trial to estimate a relationship between pasture production (as a percentage of open pasture), and canopy closure. A linear relationship was found, with 100% pasture production at 0% canopy closure and 0% pasture production at 67% canopy closure (the extinction point). That is,

$$PP = -1.4822CC + 100$$

where:

PP = pasture production (kg dry matter/ha/yr) as a percentage of open pasture
CC = percentage canopy closure

If it is assumed that similar linear relationships also exist for other tree species, then only the extinction points need to be found in order to define these relationships. The other end of the straight line will still be at 100% pasture production and 0% canopy closure. Thus, compared to long term measurements of pasture production, canopy closure measurement offers a relatively simple technique whereby pasture production can be estimated directly from stand parameters (Knowles *et al.*, 1997).

Of the poplar stands used for canopy closure measurement in this study, only two were observed to be clearly past the extinction point (ie., no pasture production). These were also the two stands with the highest percentage canopy closure (91.6% and 87.7% respectively). All of the 11 stands with canopy closure between 75% and 85% appeared to still have some pasture production in the understorey. This indicates that the extinction point for poplar stands is likely to be about 85% canopy closure. Figure 2. 6 illustrates the relative pasture production model for *Pinus radiata* and a similar model for poplars, assuming a linear relationship and an extinction point at 85% canopy closure.

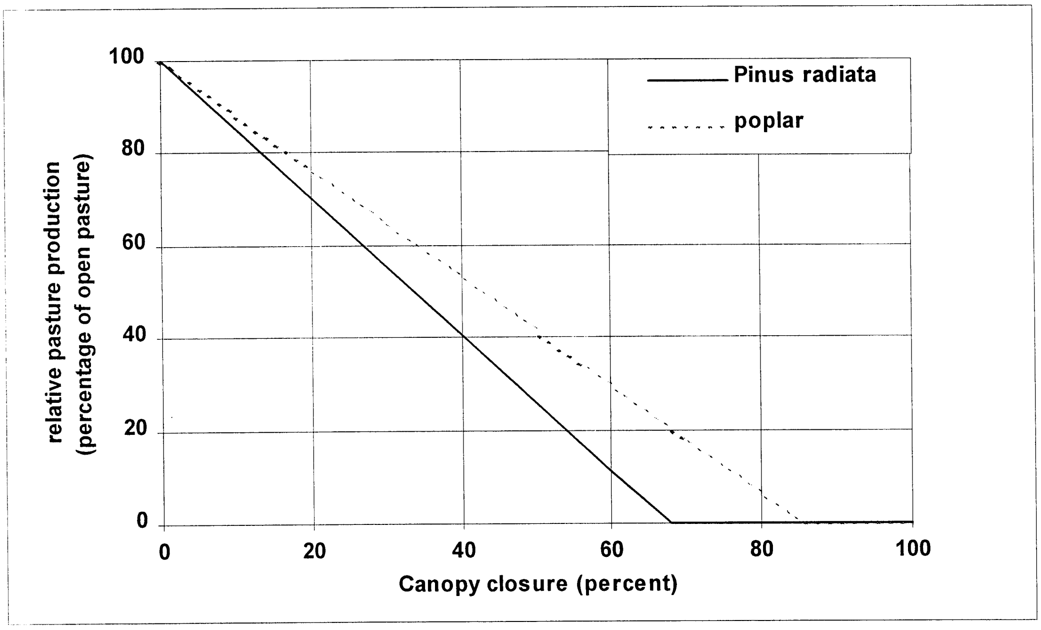

Figure 2. 6. Models for pasture suppression beneath *Pinus radiata* and poplar overstoreys

Although the model developed by Gilchrist *et al.* (1993) has stocking as the independent variable, stocking can be converted to canopy closure using the canopy closure model for 16 year old trees. If the linear relationship is then compared with estimates from the model developed by Gilchrist *et al.* (1993), it appears that the true relationship for poplars is likely to be non-linear (Figure 2. 7). The pasture suppression estimates made by Wilson (1973), and the case study by Guevara-Escobar *et al.* (1997) are also consistent with a non-linear relationship.

The non-linear curve in Figure 2. 7 was estimated to achieve 100% relative pasture production at 0% canopy closure, 0% pasture production at 85% canopy closure, and 60% pasture production at 51.3% canopy closure as recorded by Guevara-Escobar *et al.* (1997). The form of the function is:

$$PP = (100^a - b*CC^a)^{1/a}$$

where:

PP = relative pasture production (percent)
CC = percentage canopy closure
a = 1.3647
b = 1.2282

This curve indicates that Gilchrist's model may tend to overestimate pasture production. This is plausible, as the model was based on measurements around single trees only, and therefore includes the effects of incoming side-light, as well as that coming through the tree canopy.

Visual comparisons of pasture growth in the poplar stands relative to that of adjacent open pasture were also recorded (Figure 2. 7). These appear to be broadly consistent with a non linear function with an extinction point at 85% canopy closure. It should be noted however, that the small size of many of the poplar stands measured means that in many cases the understorey was receiving light from the side of the stand. In these cases the observed pasture growth is likely to be greater than could be expected in a larger stand of the same percentage canopy closure. Furthermore, the observation of a stand at a single point of time does not necessarily give a good indication of the production of pasture over time. Comparison with areas of pasture adjacent to the stand may also be misleading if the two areas have received different levels of fertiliser, or different grazing management.

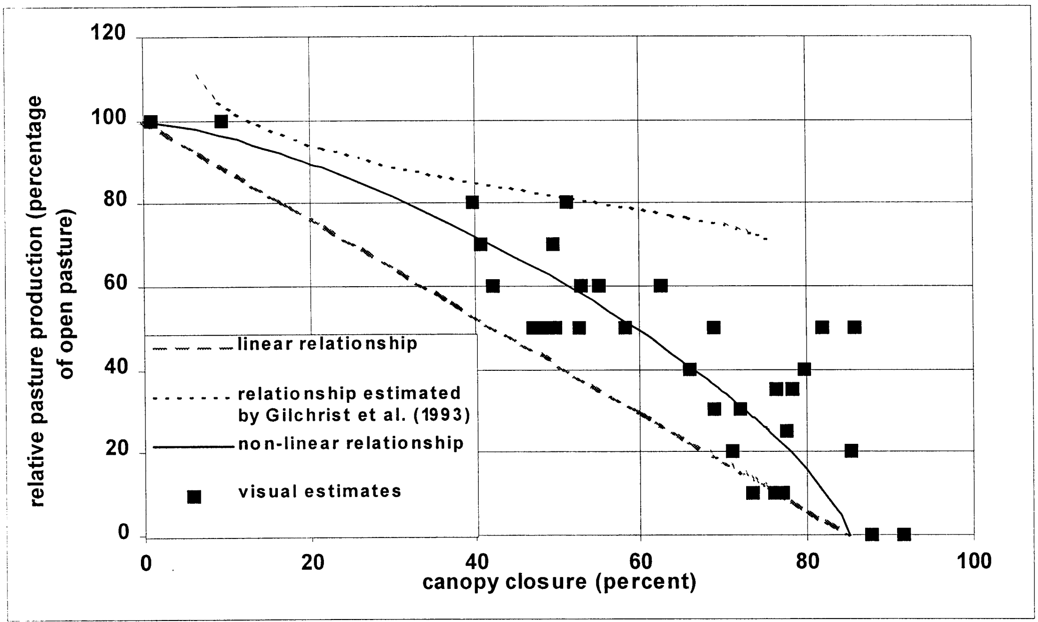

Figure 2. 7. Models of pasture suppression beneath poplar stands

A non-linear function might make sense theoretically if a poplar canopy tends to allow more light through than *P. radiata* for a given level of canopy closure, or if non-light related competition (for example, competition for water or nutrients) was greater beneath *P. radiata* than poplar. In the absence of further data however, no further conclusions can be drawn at this stage regarding pasture suppression beneath poplar stands.

Changes in pasture quality and species composition that occur as a stand develops are likely to further complicate the relationship between poplars and understorey pasture. In reality, the quality as well as the quantity of pasture will be changing over time (Guevara-Escobar *et al.*, 1997).

The non-linear pasture production function in Figure 2. 7 can be combined with the canopy closure model, including seasonal variations, to predict relative pasture production in a poplar stand over time. This is illustrated in Figure 2. 9 for stands planted on good sites at 100, 200 and 400 stems per hectare.

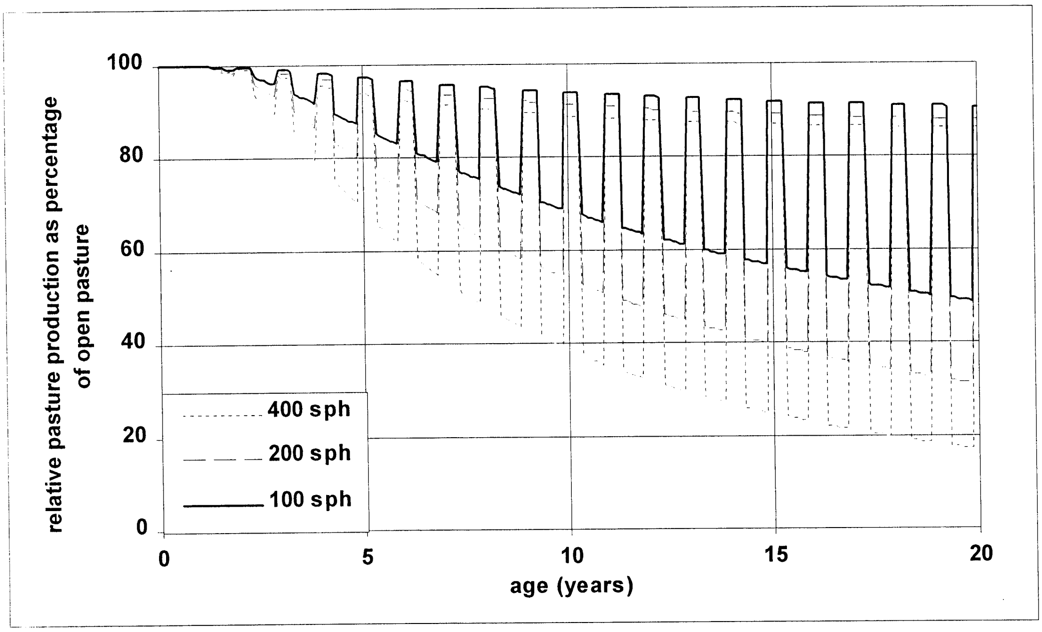

Figure 2. 8. Predicted relative pasture production in New Zealand grown poplar stands

2.3 Prediction of diameter and basal area for canopy closure estimation

In order to predict canopy development over time using the canopy closure model it is necessary to be able to predict basal area for a stand of given age and stocking. Therefore an equation was developed to relate age and stocking to mean dbh, from which mean basal area can easily be estimated.

The fitted equation was a form of the Schumacher function, where the upper asymptote varied with age, stocking and site quality (Figure 2. 9 and Figure 2. 10). Sites were classified as either "good", "medium" or "poor", such that the classification was consistent with that used for the stand height and volume functions. The fitted function was:

$$D = a/(1+(b(1-\exp(-c*A))*(N-400))*(\exp(-d*A^{-e}))$$

where:

D = dbh outside bark in cm, of tree of mean basal area
A = age (years)
a = 53.4942 (good sites)
= 42.5215 (medium sites)
= 32.2773 (poor sites)
b = 0.0009853
c = 0.08334
d = 4.8374
e = 0.9222

An approximation of an R^2 for the fitted function was 0.92.

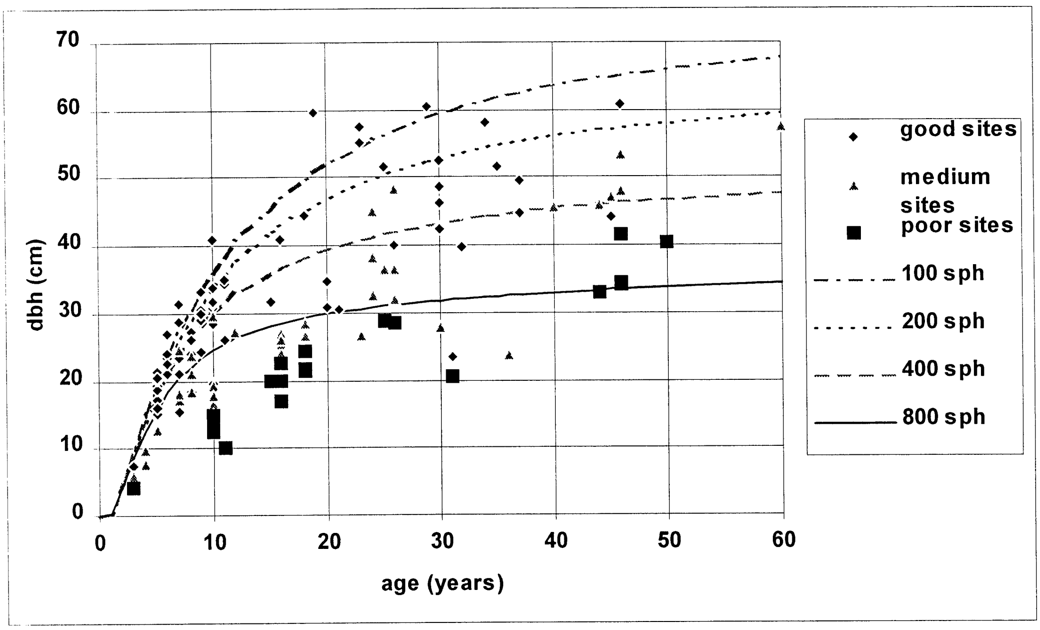

Figure 2. 9. Estimated diameter function for New Zealand grown poplar on good sites

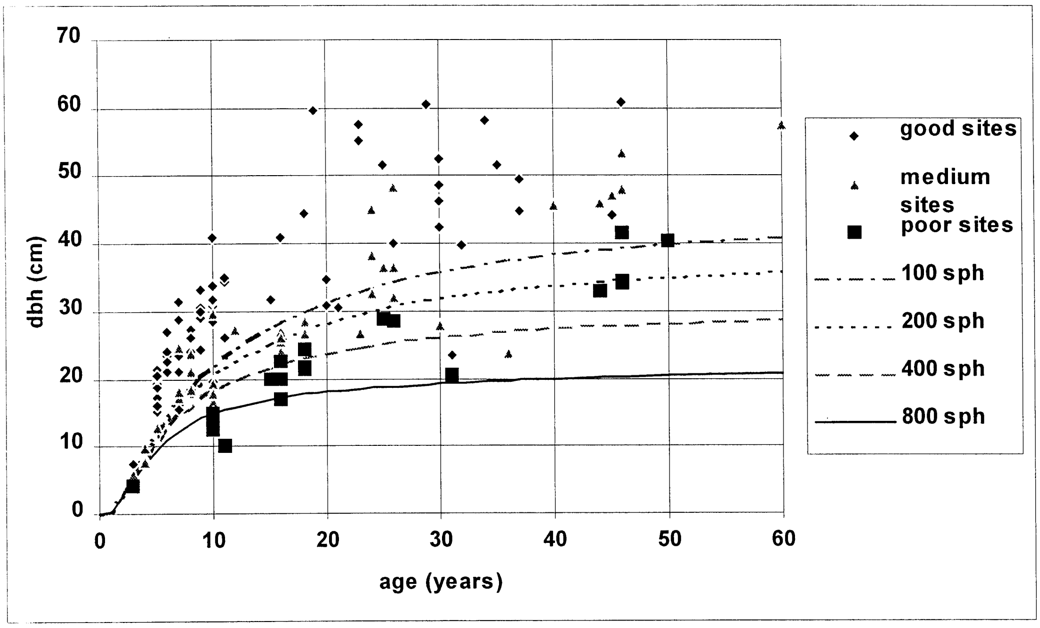

Figure 2. 10. Estimated diameter function for New Zealand grown poplar on poor sites

Basal area can be easily estimated using the predicted dbh from the dbh equation (Figure 2. 11 and Figure 2. 12). That is,

$$BA = N\pi(D/2)^2$$

where:

BA = basal area
N = stocking (stems/ha)
D = dbh outside bark in cm, of tree of mean basal area

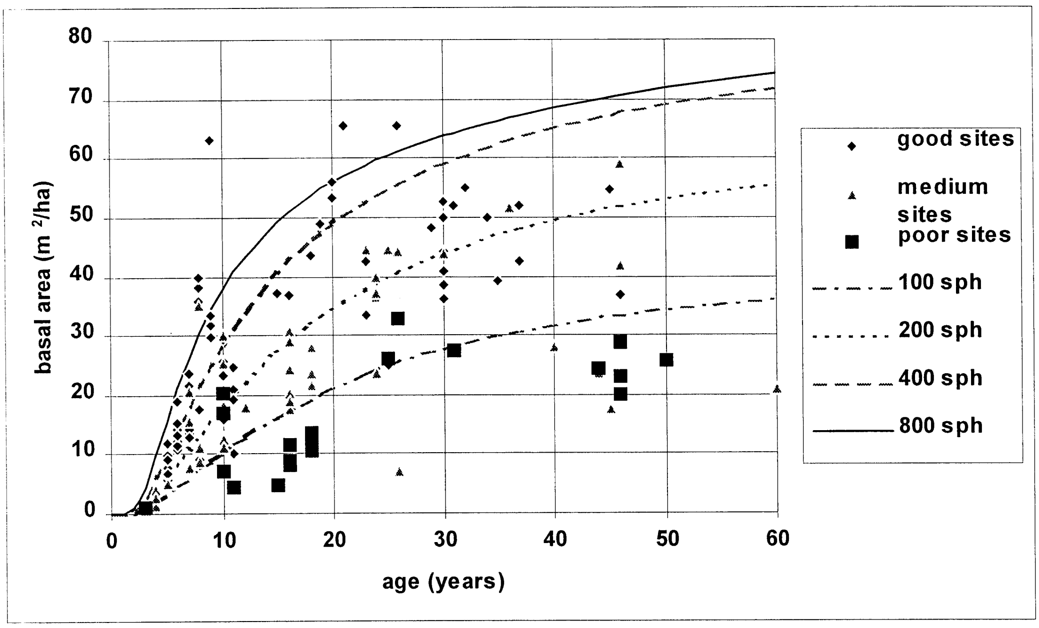

Figure 2. 11. Estimated basal area function for New Zealand grown poplar on good sites

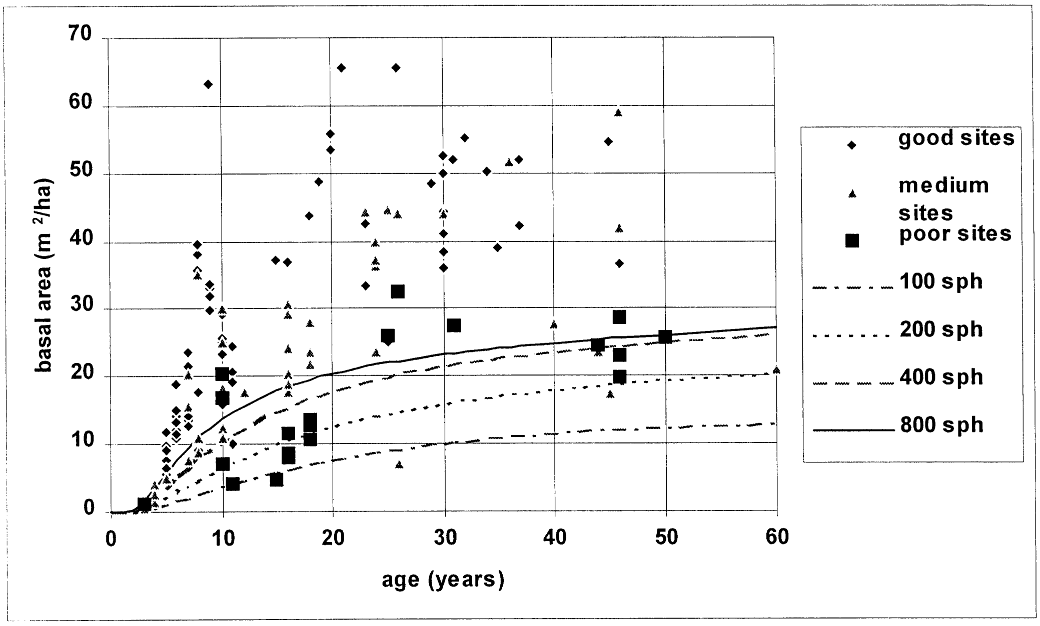

Figure 2. 12. Estimated basal area function for New Zealand grown poplar on poor sites

The dbh and basal area prediction model was estimated using a total of 151 data points. These were comprised of 57 of the 60 stands used for the height model, and an additional 94 stands, largely based on data recorded by van Melle and Chavasse (1972), for a variety of poplar clones.

Although species differences are also likely to affect diameter growth, a lack of data precluded the integration of a species variable into the model. In particular, the species commonly planted at present tend to be different from the species planted prior to the early 1970's. The older clones have been largely replaced by new cultivars which are resistant to poplar leaf rust and unpalatable to possums. The species in the data set were mostly old Italian hybrids (114 data points), with the balance comprised of old balsam poplar clones such as the Schreiner hybrids (23 data points), newer (post 1970's) black poplar clones and black/balsam poplar crosses (10 data points), and white poplar clones (4 data points).

PART 3: EVALUATION OF POPLAR AND *PINUS RADIATA* AGROFORESTRY AT THE FARM LEVEL USING THE AGROFORESTRY ESTATE MODEL (AEM)

3.1 Summary

Hypothetical poplar agroforestry projects were evaluated at the farm level using the Agroforestry Estate Model (AEM) for two East Coast farm types, Gisborne-Wairoa small farms and Gisborne-Wairoa large stations. Ten percent of the land area was planted on each farm type at a constant annual rate of planting over a ten year period. The results of the simulations were compared with *Pinus radiata* agroforestry projects planted on the same land area, at the same rate. The results indicated that discounted returns from poplar agroforestry were greater than those from pastoral farming, but lower than those from *Pinus radiata* agroforestry. The major advantages of poplars over *Pinus radiata* as an agroforestry species are the smaller impact on farm surplus during the implementation phase, due to lower silvicultural costs and less livestock displacement, and the possibility of shorter rotation lengths than those which are conventionally used for *Pinus radiata*. If only about half the project land area is planted in *Pinus radiata* however, then the resulting mix of *Pinus radiata* and farming has similar levels of livestock displacement, but higher profitability, than planting the entire project area in poplars. Projections of root biomass and rainfall interception suggested that poplars had slightly higher root biomass and caused a greater decline in water yields than *Pinus radiata* for at least the first 12 years of the project; but subsequently this trend was reversed. *Pinus radiata* root biomass was also lower than poplar root biomass following harvesting, due to faster decay and slower regrowth of roots. Sensitivity analysis indicated that improvements in the profitability of poplars are possible if significantly higher log prices can be realised. Profitability of poplars is also appeared to be quite sensitive to yields, and, to a lesser extent, understorey livestock carrying capacity and rotation length. Short rotation lengths of about 16 years appear to be most profitable for poplars, although the validity of this result depends on whether markets can be found for young wood and small logs.

3.2 Introduction

Agroforestry has a variety of impacts at the farm level, including reductions in soil erosion, water yields and livestock carrying capacity, increased labour requirements, and changes in farm cash flows. The objective of this chapter was to evaluate the integration of poplar agroforestry into farming practice in terms of these impacts. In order to do this, yield tables were created (Part 1) and understorey pasture relationships were estimated (Part 2) , to model both the timber resource and livestock carrying capacity over time. These relationships had not been previously established for New Zealand grown poplar plantations. The yield tables and understorey pasture relationships were used as inputs for the Agroforestry Estate Model (AEM), to model the farm level impacts of poplar agroforestry on the East Coast of the North Island. AEM is a simulation model, designed to show the effects of a sustained planting and felling programme on a farms physical and financial flows - such as livestock carrying capacity, labour requirements, wood flows and cash flows. AEM also has financial modules for evaluating the feasibility, financing, and profitability of an agroforestry project in relation to the whole farm. AEM is a simulation model only, and is not capable of optimising for a given objective function. However, the sensitivity of obtained results to the values of various inputs may be tested by re-running the model for different values of these inputs.

3.3 Method

The Agroforestry Estate Model (AEM) was used to evaluate hypothetical poplar and *Pinus radiata* agroforestry projects at the farm level for two East Coast farm types, Gisborne-Wairoa small farms and Gisborne-Wairoa large stations. The input data required for AEM included farm account data, planting and felling programmes, labour and non-labour costs of establishment and tending, livestock carrying capacity, yield tables and log prices. AEM does not calculate root biomass or changes in water yields; therefore these were calculated separately using simple predictive models.

3.3.1 Farm Accounts

Two farm types were chosen, Gisborne-Wairoa small farms and Gisborne-Wairoa large stations, corresponding to the two farm types recorded for the East Coast region by the Ministry of Agriculture and Forestry in biannual farm monitoring reports (MAF, 1998). The farm accounts used were also taken from data published by the Ministry of Agriculture and Forestry (MAF, 1998), with the exception of land values which were estimated from rural property sales statistics published by Valuation New Zealand (1997). Land values were estimated by multiplying the average 1997 grazing land price per stock unit for Wairarapa, Hawkes Bay and the East Coast ($184.7/lsu) by the livestock carrying capacity of the agroforestry project land for each of the two farm types (6.5 lsu/ha and 5.6 lsu/ha respectively for small farms and large stations). Land prices were not recorded separately for the East Coast, so the average for all three eastern North Island regions was used. Using the average price per stock unit rather than the average price per hectare should account for differences in land quality between the two farm types. Table 3. 1 and Table 3. 2 summarise the farm accounts for each of the two farm types.

Table 3. 1 Farm accounts for Gisborne-Wairoa small farms

Total farm area (ha)	**435**
Project land value ($/ha)	**1,201**
Total farm livestock (lsu)	**3,795**

Farm Income

	Sales ($)	Purchases ($)	Net
Sheep	52,305	1,188	51,117
Wool	24,869	0	24,869
Cattle	68,659	6,336	62,323
Other	4,100	0	4,100
		Gross Income	**142,409**

Farm Expenditure

	Fixed Costs ($)			Variable Costs ($)
Wages	4,723		Animal health	7,750
Electricity	2,999		Feed	3,600
Weed and pest	800		Fertiliser	16,163
Vehicles	7,600		Freight	2,700
Rep. and maint.	8,700		Shearing	8,792
Admin.	6,200		Seeds	0
Other	13,431		Other	0
Total	**44,453**		**Total**	**39,005**

Farm Surplus ($)	**58,951**
Gross Margin ($/lsu)	**27.25**

Table 3. 2 Farm accounts for Gisborne-Wairoa large stations

Total farm area (ha)	**1,514**
Project land value ($/ha)	**1,034**
Total farm livestock (lsu)	**11,315**

Farm Income

	Sales ($)	Purchases ($)	Net
Sheep	156,344	4,350	151,994
Wool	82,305	0	82,305
Cattle	143,354	15,200	128,154
Other	12,000	0	12,000
		Gross Income	**374,453**

Farm Expenditure

	Fixed Costs ($)			Variable Costs ($)
Wages	78,029		Animal health	20,000
Electricity	5,100		Feed	5,600
Weed and pest	3,500		Fertiliser	46,860
Vehicles	10,500		Freight	6,000
Rep. and maint.	24,600		Shearing	35,582
Admin.	18,500		Seeds	0
Other	25,040		Other	3,500
Total	**165,269**		**Total**	**117,542**

Farm Surplus ($)	**91,642**
Gross Margin ($/lsu)	**22.71**

3.3.2 Planting and Felling Programme

The planting programmes were based on planting ten percent of the total farm area over a ten year period. The average land area of Gisborne-Wairoa small farms was 435 hectares, while the average area of Gisborne-Wairoa large stations was 1514 hectares (MAF, 1998). Therefore, 43.5 hectares were planted on the small farm type at a rate of 4.35 hectares per year and 151.4 hectares were planted on the large farm type at a rate of 15.14 hectares per year. The same planting programmes were used for both the poplar and *Pinus radiata* agroforestry projects.

Two felling programmes were used for each agroforestry project, one designed to reach normality after the first rotation and the other based on a fixed rotation length of 20 years for poplar and 28 years for *Pinus radiata*. Normality is defined as the point in time when a forest reaches an equilibrium of areas being planted, treated and felled (Middlemiss and Knowles, 1997). From this point onwards, physical and financial flows associated with the forest, such as livestock units, labour inputs, wood flows, and net cash flow, will be constant. Normality is achieved by felling a forest at a constant annual rate, equal to the total forest area divided by the rotation length plus replanting delay, and replanting at the same annual rate. This required annual harvesting of 2.07 ha/year for the small farm poplar project, 1.50 ha/year for the small farm *Pinus radiata*, 7.21 ha/year for the large station poplar, and 5.22 ha/year for the large station *Pinus radiata*. Although it is unlikely that a landowner would actually smooth the planting and felling in this fashion, it is a useful way of illustrating the average annual effect after the first rotation of an agroforestry project on livestock, labour, wood supply and cash flow.

The felling programmes designed to reach normality were used to illustrate fluctuations in livestock, labour, wood supply and cash flow during the first rotation, as well as the steady state levels once normality was reached. The levels at normality give a good general indication of the relative impacts, on average, of the poplar and *Pinus radiata* projects. Such comparisons are more difficult to make with a fixed rotation length, as no steady state is achieved, and annual fluctuations continue indefinitely.

The planting and felling programmes of fixed rotation length were used to calculate the NPV and IRR of the agroforestry projects, and the effect on farm NPV. A fixed rotation length was used rather than a constant annual rate of harvest because variations in rotation age designed to action normality can significantly affect the rate of return. A fixed rotation length generally gives a higher return due to a more rapid rate of harvesting. In practice a landowner would probably use a fixed rotation, so the calculated rates of return should reflect this.

3.3.3 Labour costs

For the poplar regime, 400 unrooted stakes per hectare were planted, at a planting cost of 30c per stake and a releasing cost of 10c per stake(Stace, 1996). All 400 trees received form pruning at age one year in order to remove any double leaders or large branches. A second form pruning was also carried out at age three years, partly to correct any possum or wind damage. The labour costs of the two form pruning operations were estimated at 20c/tree and 50c/tree respectively (Peter Davies-Collie, pers. comm.). Three clear pruning lifts were conducted on 200 stems per hectare at ages four, five and six years. The estimated pruning costs were $0.80/tree for the first lift to 2.0 metres, $1.00/tree for the second lift to 5.0 metres, and $1.10/tree for the third lift to 6.5 metres. The 200 unpruned stems per hectare were thinned to waste at age five years, at a cost of $125/ha.

As little pruning of poplar trees has been carried out in New Zealand to date, the pruning costs given are preliminary estimates only. These estimates were based on figures for fertile alluvial sites in Northland (Peter Davies-Collie, pers. comm.), which were then adjusted down slightly to reflect the lower fertility and thus probable smaller branch size on East Coast hill-country farmland. The Northland estimates were reduced by 20c/tree for each pruning lift, as this was approximately the difference in *Pinus radiata* pruning costs between the two regions, and it was assumed that the difference would be similar for poplars.

The initial stocking rate and subsequent tending regime for poplar is also based only on preliminary estimates of what is likely to be optimal for the East Coast region. An initial stocking of 400sph is common on fertile alluvial sites in Northland (Peter Davies-Collie, pers. comm.), although a higher initial stocking might be considered more suitable for East Coast farmland, as poplars are very site specific and some mortality can be expected. In particular, poplars are susceptible to wind exposure and seasonal moisture deficits (New Zealand Poplar Commission, 1995), although careful selection of the correct clone for the site should reduce the risk. Despite the risks, an initial stocking of only 400sph was chosen, due to the high establishment and form pruning costs of poplar. Preliminary simulations using AEM indicated that the cost of planting 600sph would seriously affect the profitability of the project.

The final stocking of 200sph was lower than that of the *Pinus radiata* regime in order to ensure that large diameter logs are grown, as large diameters are likely to be required in order to ensure a saleable resource (Peter Davies-Collie, *pers. comm.*). A relatively low stocking should also reduce the number of dead branches on the stem, and thus reduce the incidence of bacterial black heart in the timber.

Other labour costs used for the poplar regime were a weed control cost of $15/ha at age one year, and an annual pest control cost of $10/hectare/year for the first ten years. Identical weed and pest control costs were also used for the *Pinus radiata* regime. A relatively high pest control cost was used as feral goats are a widespread problem on the East Coast (John Cawston, *pers. comm.*)

For the *Pinus radiata* regime, 1000 GF18 seedlings were planted per hectare, at a planting cost of 20c per tree and a releasing cost of 10c per tree. At age 4.8 years 400 stems were pruned to 2.2m at a cost of $1.10/tree, at age 6.2 years 350 stems were pruned to 4.5m at a cost of $1.30/tree, and at age 7.8 years 350 stems were pruned to 6.5m at a cost of $1.30/tree. The stands were thinned to 600sph at the time of the first pruning lift, and thinned to a final stocking of 350sph at the time of the final pruning lift. The thinning costs used were $125/hectare for the first thinning and $200/ha for the second (John Cawston, *pers. comm.*).

The initial stocking and subsequent tending regime for *Pinus radiata* was based on estimates for a 'typical' clearwood regime on the East Coast. Individual forest owners may use regimes which differ from this, for example, those receiving grants from the East Coast Forestry Project (ECFP) may be required to plant a higher initial stocking of around 1500sph (Bruce Willis, *pers. comm.*).

The estimated labour costs in hours/hectare/year and dollars/hour for poplar and *Pinus radiata* plantations are summarised in Table 3. 3 and Table 3. 4. These costs are identical to those previously quoted, but are stated in terms of time taken and an hourly wage rate in order that AEM can compute the physical labour requirements over time. In addition, a contract supervision rate of 20% is added to all labour costs listed.

Table 3. 3 Labour costs for poplar agroforestry regime on East Coast farmland

Operation	Year	Hours/ha/yr	Cost ($/hr)
Plant	1	8.00	15
Release	1	2.67	15
Weed control	2	1.00	15
Pest control	1-10	0.67	15
Form prune 1	2	5.33	15
Form prune 2	4	13.33	15
Prune 1	5	10.67	15
Prune 2	6	13.33	15
Prune 3	7	14.67	15
Thin 1	6	6.58	19

Table 3. 4 Labour costs for *Pinus radiata* agroforestry regime on East Coast farmland

Operation	Year	Hours/ha/yr	Cost ($/hr)
Plant	1	13.33	15
Release	1	6.67	15
Weed control	2	1.00	15
Pest control	1-10	0.67	15
Prune 1	5	29.33	15
Prune 2	7	30.33	15
Prune 3	8	30.33	15
Thin 1	5	6.58	19
Thin 1	8	10.53	19

3.3.4 Non-labour costs

In addition to labour costs, non-labour costs were estimated for the establishment of poplar and *Pinus radiata* plantations (Table 3. 5). The poplar establishment cost was $380/ha, this being comprised of 400 unrooted stakes at a cost of 90c per stake and 5c per stake for herbicide (Stace, 1996). The *Pinus radiata* establishment cost was $240/ha, corresponding to 1000 GF18 seedlings at a cost of 18c per seedling, and 6c per seedling for herbicide (Bruce Willis, *pers. comm.*). A weed control cost of $10/ha for herbicide at age one year was used for both poplar and *Pinus radiata.*

A fire insurance cost of $25/ha/year was included for both the poplar and *Pinus radiata* stands. It is unlikely that a poplar plantation could actually be insured due to uncertainty concerning the market value, but the insurance cost was nevertheless included in order to account for the risk of fire destroying the stand, assuming that the fire risk is similar in both poplar and *Pinus radiata* plantations.

Table 3. 5 Non-labour costs for poplar and *Pinus radiata* agroforestry regimes on East Coast farmland

	Poplar		*Pinus radiata*	
Operation	**Year**	**Cost ($/yr)**	**Year**	**Cost ($/yr)**
Establishment	1	380	1	240
Fire insurance	1-20	25	1-28	25
Weed control	2	10	2	10

An additional cost is the cost of buying and selling livestock as the understorey livestock carrying capacity changes over time. A price of $40/lsu was used for both buying and selling livestock.

3.3.5 Livestock carrying capacity

Canopy closure was predicted for the poplar regime using the poplar canopy closure model for good sites (Figure 3. 1.), and these canopy closure estimates were used to predict relative pasture production over time (Figure 3. 2). The effect of pruning on canopy closure was modelled by changing the height ratio to reflect the shorter green crown. This is likely to underestimate the effect of pruning because the height ratio variable only had a small effect on canopy closure, probably due to a lack of data from young, pruned poplar stands in the data set. The effect of thinning was modelled by reducing basal area in proportion to the number of trees removed. The effect of thinning is also likely to be underestimated, as canopy closure in a recently thinned stand is probably lower than canopy closure in an unthinned stand of the same basal area. This is because an unthinned stand will presumably have wide crowns in an effort to fully occupy the site, while the thinned stand will have narrow crowns due to crowding from other trees prior to thinning.

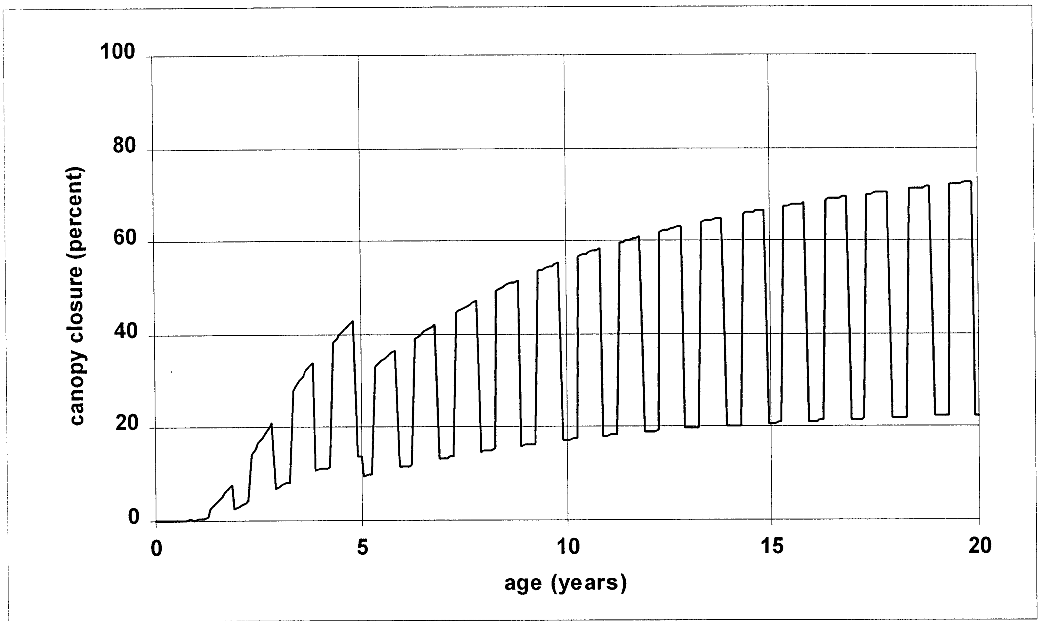

Figure 3. 1. Canopy closure in poplar agroforestry stand on East Coast farmland

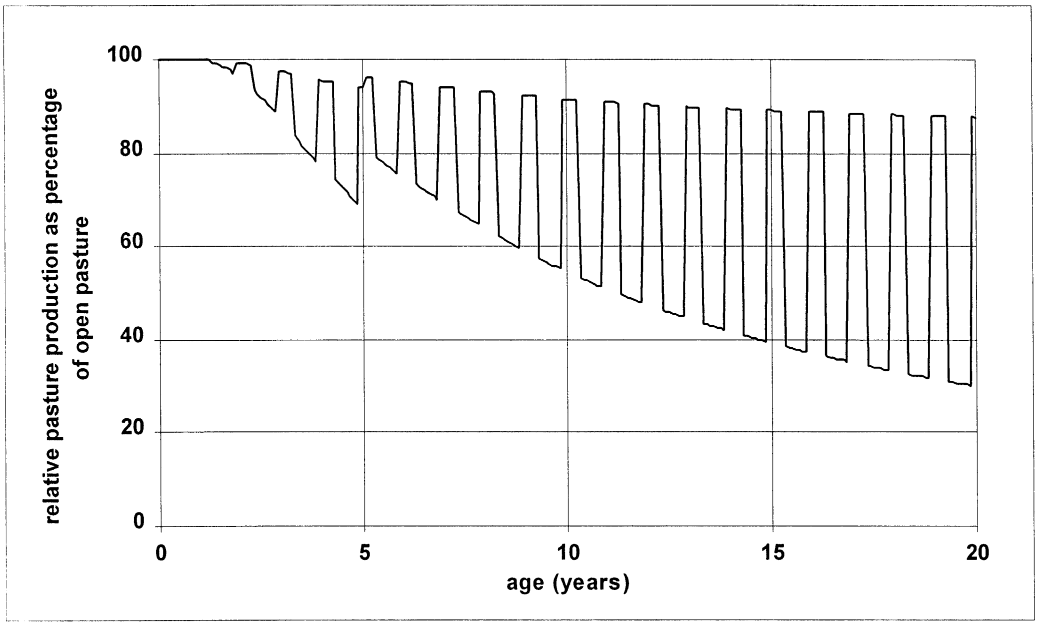

Figure 3. 2. Relative pasture production in poplar agroforestry stand on East Coast farmland

In addition to canopy closure, the percentage of ground area covered by slash from thinning and pruning is also likely to affect pasture production. This was ignored however, as poplar foliage is very palatable to stock, and will be readily eaten (New Zealand Poplar Commission, 1995). The feed value of the slash itself is assumed to compensate for lost pasture production on the ground that it covers. Pasture growth is also likely to be suppressed when poplars lose their leaves. This effect was also ignored, as the leaves may be eaten by stock, and should otherwise decompose relatively quickly.

Seasonal pasture growth data for the Gisborne plains (Figure 3. 3) was used to weight the monthly relative pasture production estimates and thus estimate total annual pasture production through time. Although seasonal pasture growth may be different on East Coast hill country from the Gisborne plains, no data was available for East Coast hill country. The livestock carrying capacity of land planted in poplars was estimated by assuming that the ratio of the carrying capacity in any given year to the initial carrying capacity was equal to the ratio of annual pasture production in that year to annual pasture production with no trees. That is:

$$SR_t / SR_0 = PP_t / PP_0$$

where:

SRt = livestock carrying capacity in year *t* (lsu/ha)
SR0 = livestock carrying capacity rate (lsu/ha)
PPt = annual pasture production in year *t* (kg DM/ha/yr)
PP0 = initial annual pasture production (kg DM/ha/yr)

This should be a reasonable assumption if the landowner is able to fully utilise all pasture that is produced over the year in the agroforestry plantations. This might mean increasing the livestock stocking rate under the trees during spring and making silage or hay on other parts of the farm to supplement the lower growth rates during mid to late summer and mid winter.

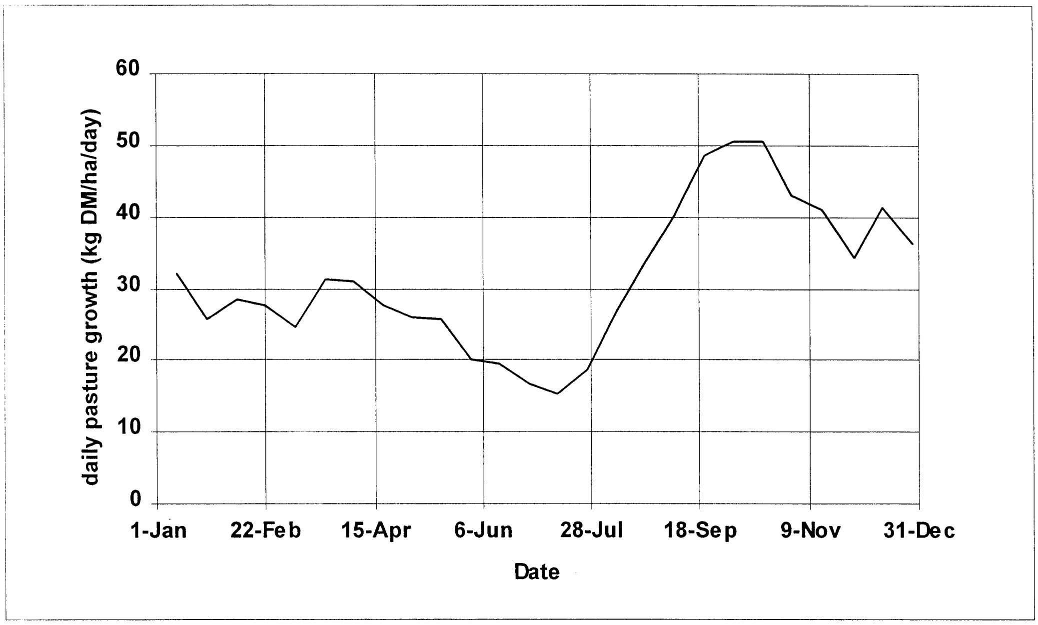

Figure 3. 3. Seasonal distribution of pasture growth rates on the Gisborne plains (Radcliffe and Sinclair, 1975)

The initial livestock carrying capacity on the agroforestry project land was assumed to be 6.5 lsu for small farms and 5.6 lsu for large stations. This was estimated by multiplying the average livestock carrying capacity reported by MAF (1998) for each of the two farm types by 0.75. The adjustment was based on the assumption that the land chosen for agroforestry would have a lower livestock carrying capacity than the average for the farm.

It was assumed that the poplar stands would need to be retired from livestock grazing for the first four years in order to avoid livestock damage to the trees, while the *Pinus radiata* stands would be completely retired from grazing for the first two years of the rotation, and would carry 50% of the initial carrying capacity in the third year. Livestock were reintroduced into the *Pinus radiata* stands earlier than for the poplar stands, as *Pinus radiata* is less palatable to livestock than poplars.

Livestock carrying capacity over time for the *Pinus radiata* agroforestry projects was estimated using the AGRO module in STANDPAK[1](Whiteside, 1990), which estimates pasture production based on relative production of open pasture (Percival and Knowles, 1986) and the proportion of ground area covered in slash. Figure 3. 4 summarises livestock carrying capacity over time for the poplar and *Pinus radiata* agroforestry projects for each of the two farm types. This livestock carrying capacity data is also presented in the Appendix.

[1] A stand modelling software package for *Pinus radiata*.

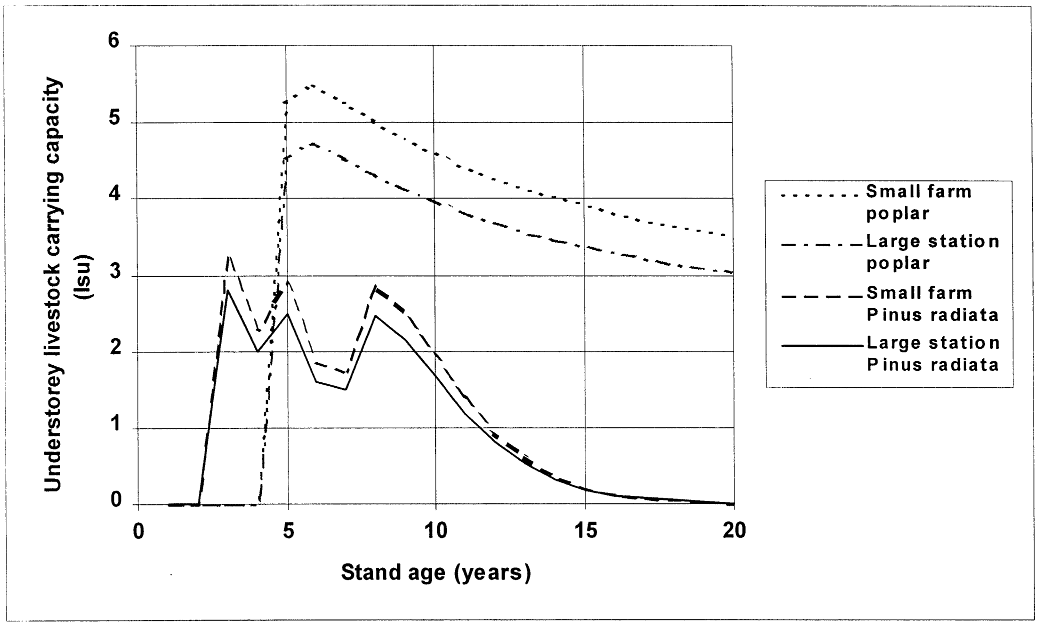

Figure 3. 4. Poplar and *Pinus radiata* understorey livestock carrying capacities for Gisborne-Wairoa small farms and Gisborne-Wairoa large stations

3.3.6 Yield Tables

The yield functions developed for New Zealand grown poplar plantations (Part 1) were used to generate volumes by log grade and age for the poplar regime, while yield tables for the *Pinus radiata* regime were generated using STANDPAK (Appendix 2). The poplar yields were estimated for a good site, as eight of the eleven East Coast stands used for the creation of the yield tables were classified as "good". Although wind exposure and seasonal moisture deficits can restrict growth on some East Coast sites, growth rates in the region are generally considered to be good.

Log prices used for poplar and *Pinus radiata* are displayed in Table 3. 6. The prices used for poplar are somewhat artificial however, due to weak market information on the value of poplar. Log prices used for *Pinus radiata* were based on prices published by the Ministry of Agriculture and Forestry (1998b). Twelve-quarter averages were used, rather than single quarter prices, as these are more likely to be indicative of long term log prices. Prices shown for all log grades are export prices at the wharf, except for S3L3, for which domestic prices at the mill door are shown. Export prices at the wharf were obtained by reducing fob export prices by $12 NZ per JAS[2] in order to remove wharf handling costs (Bruce Willis, pers. comm.), and converting prices from $NZ per JAS to $NZ per cubic metre using correction tables (Ellis *et al.*, 1996). The S3L3 log price was converted from $NZ per tonne to $NZ per cubic metre using a conversion factor of 0.95 tonnes per cubic metre.

Table 3. 6 Log grade prices for poplar and *Pinus radiata*

Poplar		***Pinus radiata***	
Log grade	Price (\$/m^3)	Log grade	Price (\$/m^3)
Pruned	100	Pruned (at wharf)	201
S-grade	70	A-grade (at wharf)	102
L-grade	40	K-grade (at wharf)	84
Pulp	35	S3L3 (at mill door)	67
		Pulp (at wharf)	46

Harvesting costs were estimated at \$43.20/m^3 for *Pinus radiata*, based on a cost of \$27/m^3 for logging, \$10.20/m^3 for transport (\$0.17/m^3/km multiplied by 60 km), \$4/m^3 for management, and \$2/m^3 for roading (Bruce Willis, pers. comm.). No information was available on the cost of harvesting poplars, therefore the harvesting costs were assumed to be the same as for *Pinus radiata*. It should be noted however, that because of lower volumes per hectare, particularly on sites less suited to poplars, it is likely that actual harvesting costs on a per cubic metre basis may be significantly higher than for radiata pine.

[2] Japanese Agricultural Standards

3.3.7 Root Biomass

In addition to the farm physical and financial flows, the environmental impacts of *Pinus radiata* and poplars were also modelled at the farm level. Root biomass was modelled as it likely to be closely related to soil stability and erosion rates. A simple model of root biomass was used, which estimated root biomass development from DBH and root decay from ultimate tensile strength of roots and time since clearfelling. Information on tree root biomass (Watson and O'Loughlin, 1990) was combined with information on root tensile strength (Hathaway and Penny, 1975; O'Loughlin and Watson, 1979) and root strength deterioration after cutting (Phillips and Watson, 1994) to provide the basis of a simple generalised model of the relative reinforcement provided by poplars and *Pinus radiata* over a series of rotations.

The mean DBH estimates required for the calculation of root biomass were generated for *Pinus radiata* using STANDPAK, and for poplars using the diameter function developed in Section 2.3.

3.3.8 Water Yields

The relative impacts of *Pinus radiata* and poplar agroforestry on water yields were estimated using a simple model based on mean monthly rainfall and percentage canopy closure. Poplar canopy closure, and hence rainfall interception, were estimated assuming that basal area development was equivalent to that of a "good" site.

Annual rainfall is quite variable on the East Coast, with rainfall generally increasing with altitude. Rainfall ranges from about 1000 mm on the Gisborne plains to well over 2000 mm in parts of the Raukumara range. Mean rainfall data from 1967-1986 for Mangatu Forest was used to represent a moderate rainfall site, while Ruatoria was used to represent a high rainfall site (New Zealand Meteorological Service, 1967-1986). Mean annual rainfall over this period was 1293 mm at Mangatu Forest and 1812 mm at Ruatoria. Despite the difference in the quantity of rainfall between sites, the distribution of rainfall over the year was quite similar for both, with higher rainfall generally occurring during the winter months (Figure 3. 5).

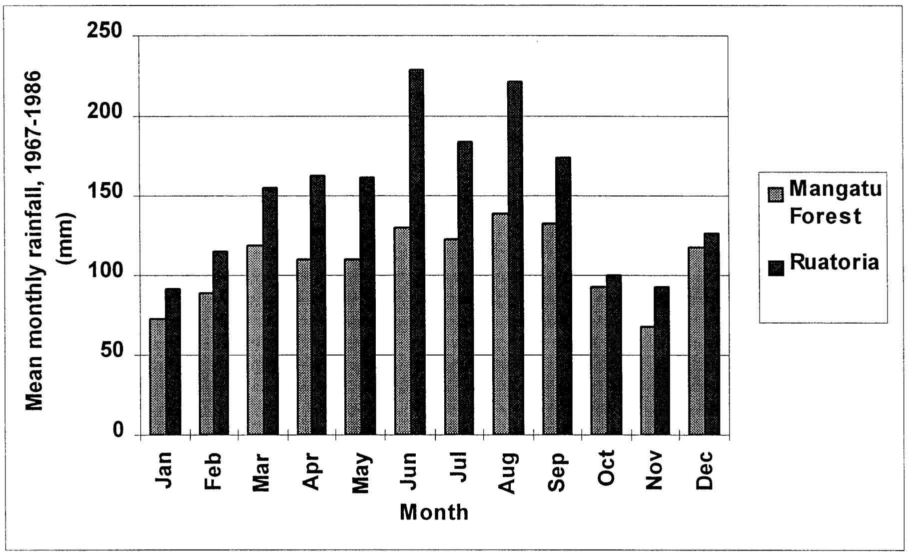

Figure 3. 5. Mean monthly rainfall for Mangatu Forest and Ruatoria, 1967-1986.

3.4 Results

3.4.1 Livestock

Gisborne-Wairoa small farms

The poplar agroforestry project has a much smaller impact on livestock carrying capacity than the *Pinus radiata* project, partly due to the higher tree stocking used in the *Pinus radiata* regime, and partly due to the inherent characteristics of the two species. The agroforestry project land initially carried 283 livestock units (lsu). At normality, this falls to 158 lsu, or 56%, on the poplar project, and 45 lsu, or 16%, on the *Pinus radiata* project. This represents a decline in total farm livestock of 3.3% under poplars, and 6.3% under *Pinus radiata*, both of which are significantly less than the proportion of total farm land area occupied by the project, of 10%. Figure 3. 6 displays the effect of both species on total farm livestock over a sixty year period. Over the first five years of the projects, more livestock are displaced under poplar than *Pinus radiata* due to the longer period before stock are allowed back into the stands. From 2003 however, the poplar regime has consistently higher livestock carrying capacity than the *Pinus radiata* regime.

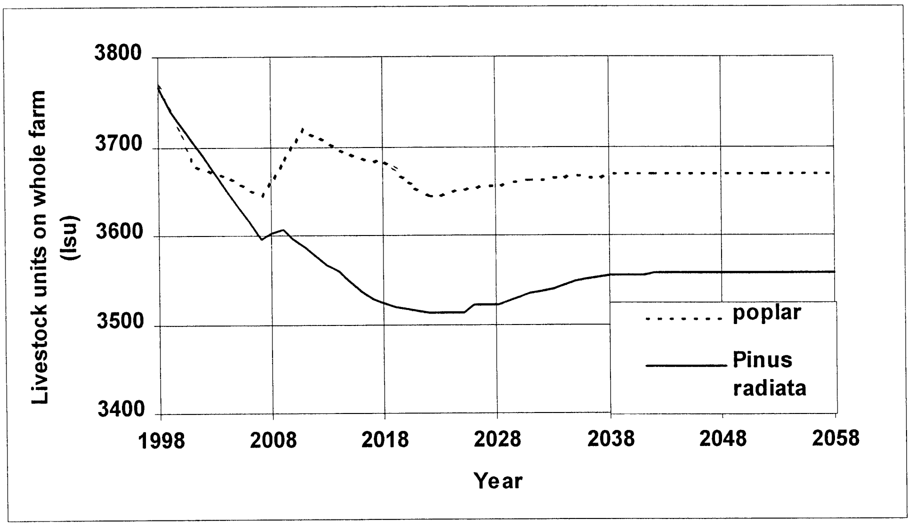

Figure 3. 6. Livestock carrying capacity on Gisborne-Wairoa small farms with poplar and *Pinus radiata* agroforestry projects

Gisborne-Wairoa large stations

The effects on livestock carrying capacity for the large station farm-type are similar to those on the small farm. That is, the loss in livestock carrying capacity at normality on the agroforestry project land is approximately twice as large for *Pinus radiata* as for poplar. Initially, the project land carried 848 livestock units. At normality, this falls to 473 lsu on the poplar project and 133 lsu on the *Pinus radiata* project, which again represents a decline in total farm livestock of 3.3% under poplars, and 6.3% under *Pinus radiata* (Figure 3. 7).

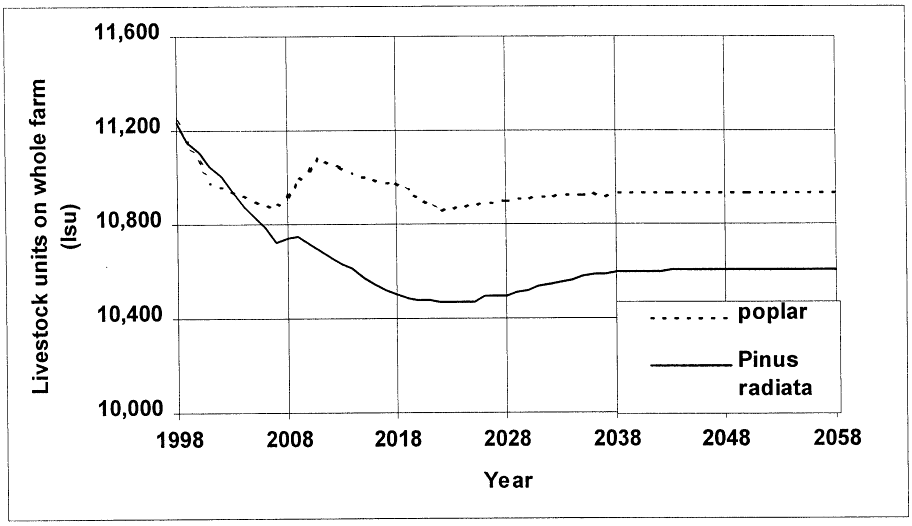

Figure 3. 7. Livestock carrying capacity on Gisborne-Wairoa large stations with poplar and *Pinus radiata* agroforestry projects

3.4.2 Labour requirements

Gisborne-Wairoa small farms

Labour requirement peaks at 45 days/year in 2007 for the poplar agroforestry project, and 73 days/year in 2007 for the *Pinus radiata* project (Figure 3. 8). Peak labour demand is higher for *Pinus radiata* primarily due to the greater number of trees tended per hectare. Although the peak labour demand is significantly higher for *Pinus radiata*, labour demands at normality are quite similar, at 21 days/year for poplar and 25 days/year for *Pinus radiata*. This is due to the shorter rotation length of poplar (20 years, compared to 28 years for *Pinus radiata*), meaning that the total silvicultural labour requirements for one rotation are averaged over a smaller number of years.

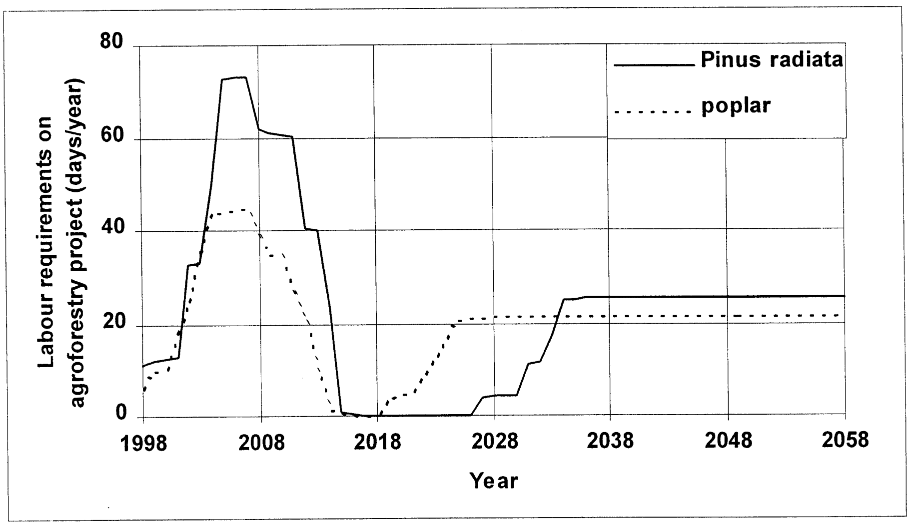

Figure 3. 8. Labour requirements for poplar and *Pinus radiata* agroforestry projects on Gisborne-Wairoa small farms

Gisborne-Wairoa large stations

Agroforestry labour requirements follow the same pattern on the large station farm-type as those on the small farm farm-type, only the magnitudes are about 3.5 times greater due to the larger project size. Labour requirements peak at 156 days/year in 2007 for the poplar agroforestry project, and 255 days/year in 2007 for the *Pinus radiata* project, while labour requirements at normality are 74 days/year for poplar and 88 days/year for *Pinus radiata* (Figure 3. 9).

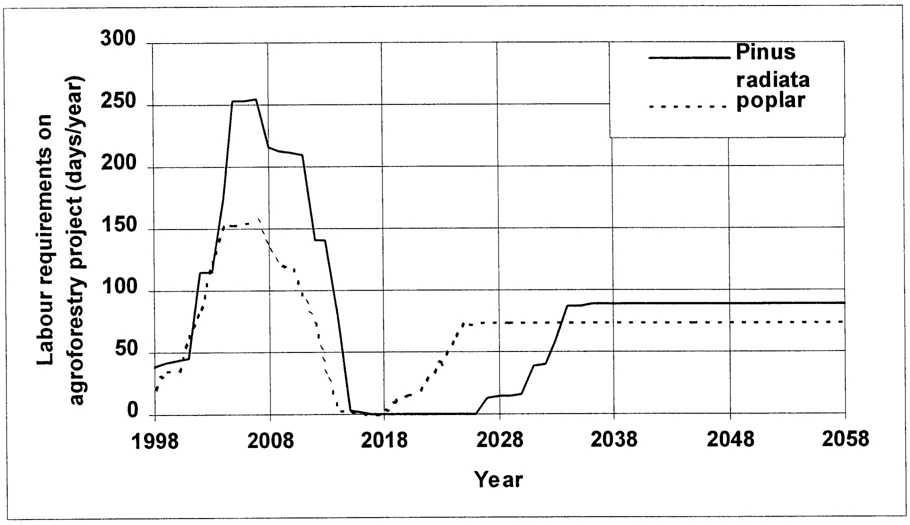

Figure 3. 9. Labour requirements for poplar and *Pinus radiata* agroforestry projects on Gisborne-Wairoa large stations

3.4.3 Wood flows

Gisborne-Wairoa small farms

Farm wood flows at normality are 1101m^3 for the *Pinus radiata* regime, compared with only 731m^3 for poplar (Figure 3. 10 and Figure 3. 11). That is, the mean annual increment (MAI) of *Pinus radiata* on a 28 year rotation appears to be about 50% high than the MAI of poplar on a 20 year rotation. The wood flows for poplar begin eight years earlier than those for *Pinus radiata* however, due to harvesting commencing at age 20 years, compared to 28 years for *Pinus radiata.* A higher proportion of the poplar volume is comprised of pruned logs than *Pinus radiata* (Table 3. 7), although due to lower log prices for poplar the average price of the poplar volume is still only \$75/m^3 compared to 109/m^3 for *Pinus radiata.*

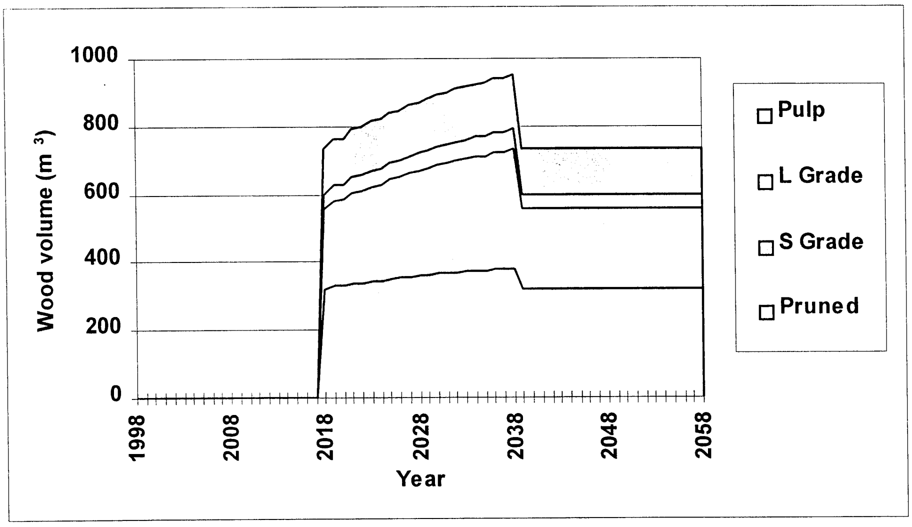

Figure 3. 10. Wood flows for poplar agroforestry project on Gisborne-Wairoa small farms

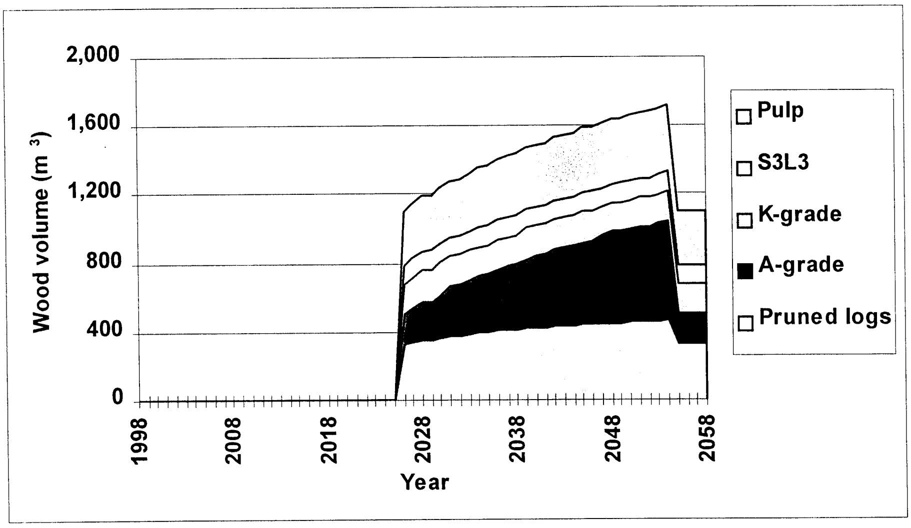

Figure 3. 11. Wood flows for *Pinus radiata* agroforestry project on Gisborne-Wairoa small farms

Table 3. 7 Wood flows by log grade at normality for poplar and *Pinus radiata* agroforestry on Gisborne-Wairoa small farms

Poplar				*Pinus radiata*			
log grade	price ($\$/m^3$)	volume (m^3)	percentage of volume	log grade	price ($\$/m^3$)	volume (m^3)	percentage of volume
Pruned	$100	319	44%	Pruned	$201	327	30%
S-grade	$70	236	32%	A-grade	$102	177	16%
L-grade	$40	41	6%	K-Grade	$84	172	16%
Pulp	$35	135	18%	S3L3	$67	110	10%
				Pulp	$46	315	28%
Total	$75	731	100%	**Total**	$107	1101	100%

Gisborne-Wairoa large stations

Farm wood flows follow the same pattern on the large station farm-type as those on the small farm farm-type, only the magnitudes are again 3.5 times greater due to the larger project size. Farm wood flows at normality are 3830 m^3 for the *Pinus radiata* regime, and 2545m^3 for poplar (Table 3. 8).

Table 3. 8 Wood flows by log grade at normality for poplar and *Pinus radiata* agroforestry on Gisborne-Wairoa large stations

Poplar				*Pinus radiata*			
log grade	price ($/$m^3$)	volume (m^3)	percentage of volume	log grade	price ($/$m^3$)	volume (m^3)	percentage of volume
Pruned	$100	1110	44%	Pruned	$201	1139	30%
S-grade	$70	822	32%	A-grade	$102	614	16%
L-grade	$40	144	6%	K-Grade	$84	597	16%
Pulp	$35	469	18%	S3L3	$67	384	10%
				Pulp	$46	1096	28%
Total	$74	2545	100%	**Total**	$109	3830	100%

3.4.4 Net cash flow on whole farm

Gisborne-Wairoa small farms

Minimum net farm cash flow and net farm cash flow at normality are summarised for both species in Table 3. 9. Minimum net farm cash flow is lower for *Pinus radiata* than poplar due to higher tending costs per tree, a greater number of trees tended per hectare and greater livestock displacement. Minimum cash flow is reached in 2007 for both species if contract labour was used, which is the same year that labour requirements are at a maximum. If on-farm labour was used, minimum cash flow is reached in 2007 for poplar, but not until 2025 for *Pinus radiata*, mainly due to understorey livestock displacement peaking in that year. The percentage changes in cash flow quoted are relative to the net farm cash flow with no forestry, which is the farm surplus from the original farm accounts of $58,951.

Farm cash flow at normality is significantly greater for *Pinus radiata* than poplar, due to both prices and yields being higher for *Pinus radiata*. The net farm cash flow at normality for poplar is only about 25-30 percent greater than the farm cash flow with no forestry, while net farm cash flow doubles using *Pinus radiata*. Figure 3. 12 and Figure 3. 13 summarise net farm cash flow over a sixty year time span for the poplar and *Pinus radiata* regimes.

Table 3. 9 Minimum net farm cash flow and net farm cash flow at normality for poplar and *Pinus radiata* agroforestry on Gisborne-Wairoa small farms

		Poplar		*Pinus radiata*	
		On-farm labour	Contract labour	On-farm labour	Contract labour
Minimum farm cash flow	cash flow	$52,401	$45,821	$49,736	$40,892
	% change from farming	-11%	-22%	-16%	-31%
Farm cash flow at normality	cash flow	$76,907	$73,773	$120,448	$116,686
	% change from farming	+30%	+25%	+104%	+98%

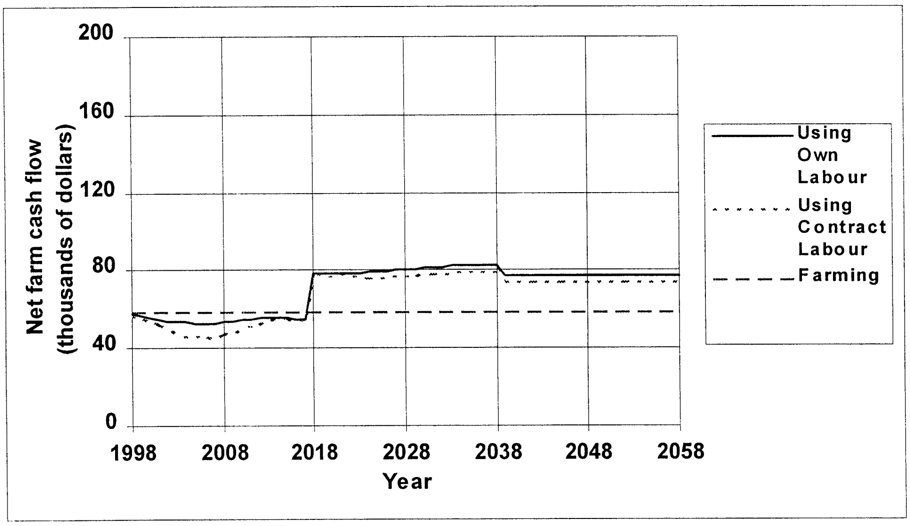

Figure 3. 12. Net farm cash flow for poplar agroforestry project on Gisborne-Wairoa small farms

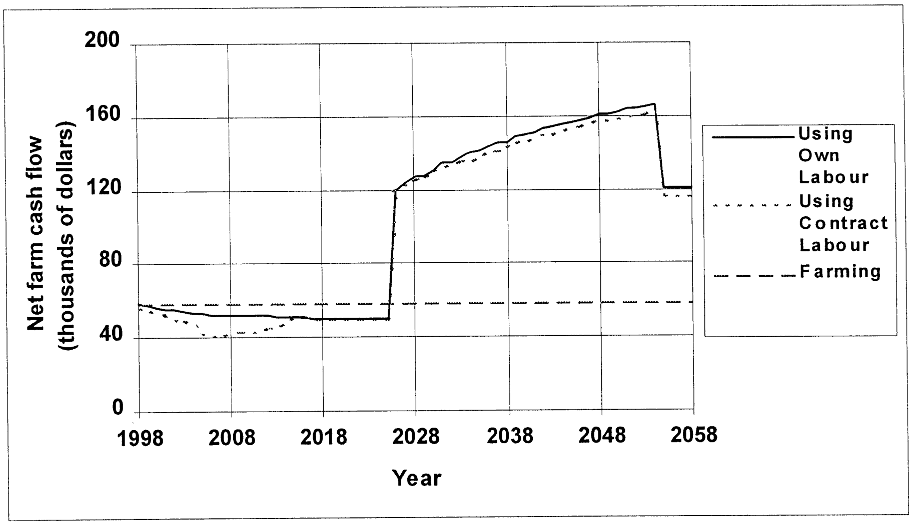

Figure 3. 13. Net farm cash flow for *Pinus radiata* agroforestry project on Gisborne-Wairoa small farms

Gisborne-Wairoa large stations

The effect on farm surplus of planting 10% of farm area in forestry is far greater for the large station farm-type than for the small farm type. The costs of establishment and the revenues from harvesting are both much larger in relation to the original farm surplus for large stations than for small farms (Table 3. 9 and Table 3. 10). This is because the large station surplus is only 1.5 times greater than the small farm surplus ($91,642 for large stations, compared to $58,951 for small farms), even though the total land area and agroforestry project area are about 3.5 times greater.

Minimum net farm cash flow occurs in 2007 for both species, and under both labour options. In this year the original farm surplus is reduced by nearly half for the poplar project and nearly two thirds for the *Pinus radiata* project, if contract labour is used. If on-farm labour is used, the reductions in farm surplus are about a fifth for poplar and a quarter for *Pinus radiata*. Net farm cash flow at normality for the poplar project is about 60-70% greater than the farm surplus with no forestry, while net farm cash flow at normality for *Pinus radiata* is over 200% greater. Figure 3. 14 and Figure 3. 15 summarise net farm cash flow over a sixty year time span for the poplar and *Pinus radiata* regimes.

Table 3. 10 Minimum net farm cash flow and net farm cash flow at normality for poplar and *Pinus radiata* agroforestry on Gisborne-Wairoa large stations

		Poplar		*Pinus radiata*	
		On-farm labour	Contract labour	On-farm labour	Contract labour
Minimum farm cash flow	cash flow	$72,706	$49,805	$67,130	$33,735
	% change from farming	-21%	-46%	-27%	-63%
Farm cash flow at normality	cash flow	$157,488	$146, 582	$321,489	$308,393
	% change from farming	+72%	+60%	+251%	+237%

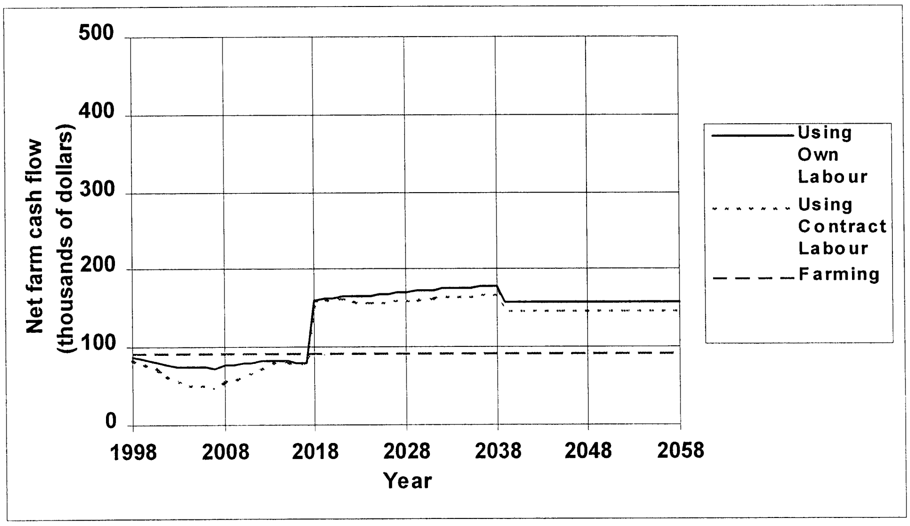

Figure 3. 14. Net farm cash flow for poplar agroforestry project on Gisborne-Wairoa large stations

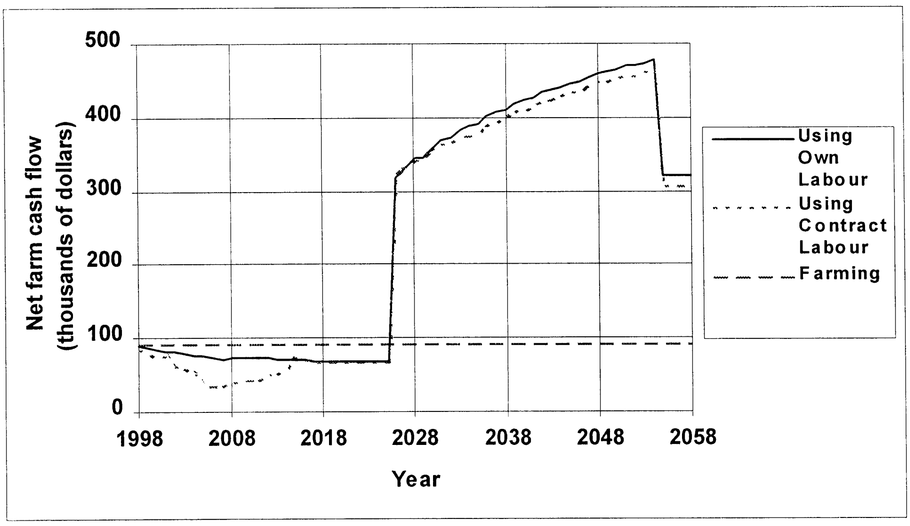

Figure 3. 15. Net farm cash flow for *Pinus radiata* agroforestry project on Gisborne-Wairoa large stations

3.4.5 NPV of the agroforestry project as a marginal investment

Gisborne-Wairoa small farms

Net present value (NPV) is the difference between revenues and costs, when these are discounted at a specified discount rate. NPV of the agroforestry project as a marginal investment is calculated using all costs and revenues associated with the agroforestry project including the cost of buying land and livestock at the start of the project, and revenues from selling land and livestock at the end of the project.

NPV may be used as a decision criterion to assist investors in choosing between projects, where the term "project" includes the initial purchase of land and livestock, as well as the implementation of the chosen land use. The project with the highest positive NPV at the relevant discount rate should be chosen; if none of the available projects have a positive NPV at this discount rate, then no project should be undertaken. Figure 3. 16 and Figure 3. 17 display NPV using contract labour and on-farm labour for a range of discount rates for both poplar and *Pinus radiata*.

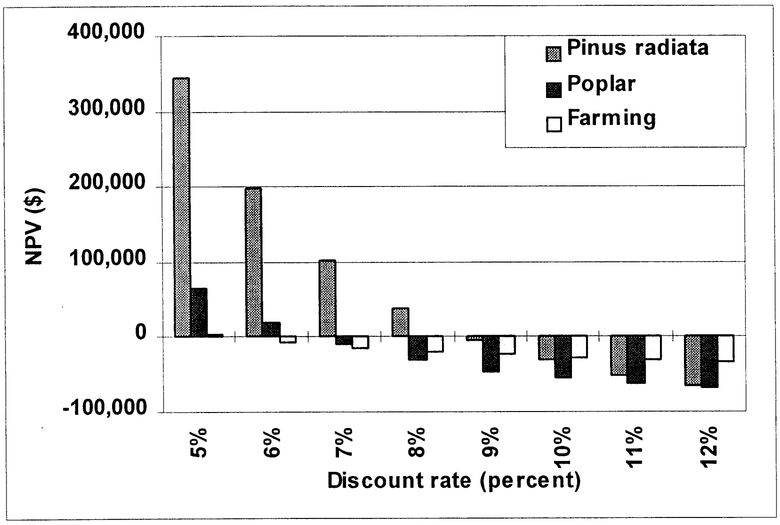

Figure 3. 16. Project NPV of agroforestry on Gisborne-Wairoa small farms using contract labour

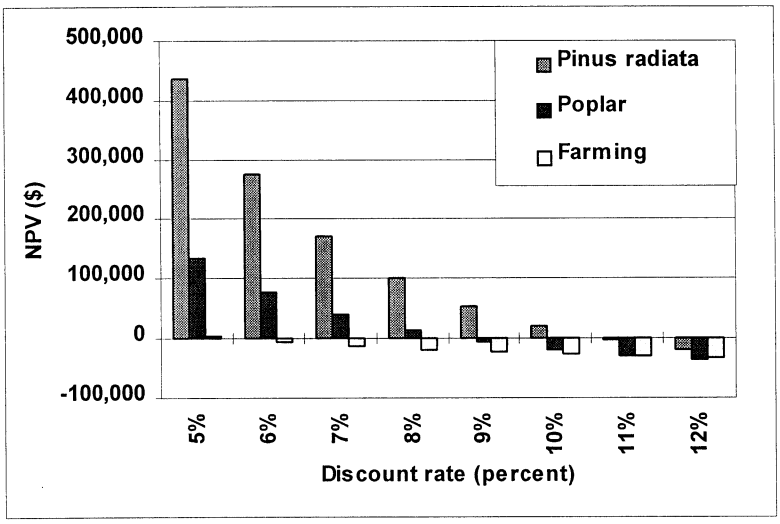

Figure 3. 17. Project NPV of agroforestry on Gisborne-Wairoa small farms using on-farm labour

Internal rate of return (IRR) is the discount rate at which NPV equals zero. At discount rates higher than this NPV will be negative, while at lower discount rates NPV will be positive. Table 3. 11 displays the IRR of farming and the agroforestry projects using on-farm labour and contract labour for the forestry labour requirements.

Table 3. 11 IRR of poplar and *Pinus radiata* agroforestry projects on Gisborne-Wairoa small farms

	Project		
	Poplar	*Pinus radiata*	Farming
On-farm labour	8.69%	10.80%	5.41%
Contract labour	6.61%	8.91%	5.41%

The *Pinus radiata* agroforestry project clearly has the highest NPV for all discount rates at which NPV is positive under both the contract labour and on-farm labour options. Therefore, using NPV as the decision criterion, *Pinus radiata* is the preferred option for discount rates less than 8.91% if contract labour is used, while at discount rates higher than 8.91% no project should be undertaken (either farming or forestry). If on-farm labour is used, the *Pinus radiata* project is the preferred option for discount rates up to 10.80%.

The poplar agroforestry project has a higher NPV than farming for all discount rates at which NPV is positive under both contract labour and on-farm labour. Therefore, poplar agroforestry is the preferred option if choosing only between poplar agroforestry and farming.

Using IRR as the decision criterion gives the same result, with *Pinus radiata* the preferred option regardless of whether contract labour or on-farm labour is used. Poplar agroforestry has a higher IRR than farming, regardless of whether contract labour or on-farm labour is used.

Gisborne-Wairoa large stations

Figure 3. 18 and Figure 3. 19 display the NPV for a range of discount rates for both species, while Table 3. 12 displays the IRR of farming and the agroforestry projects.

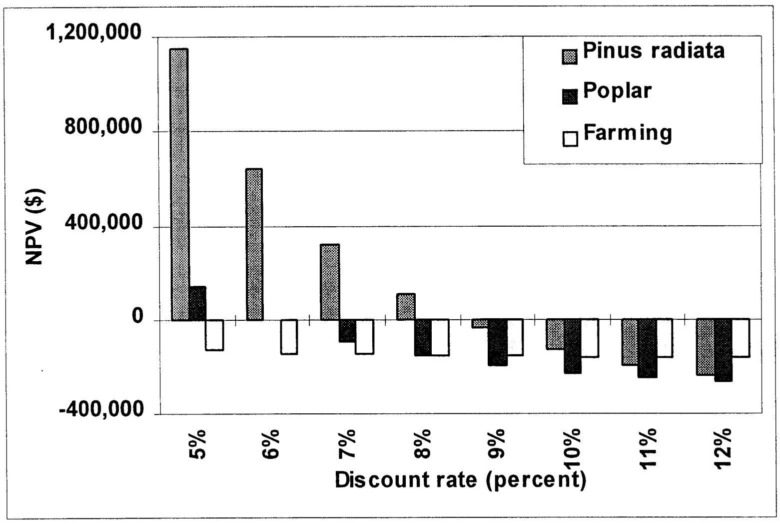

Figure 3. 18. Project NPV of agroforestry on Gisborne-Wairoa large stations using contract labour

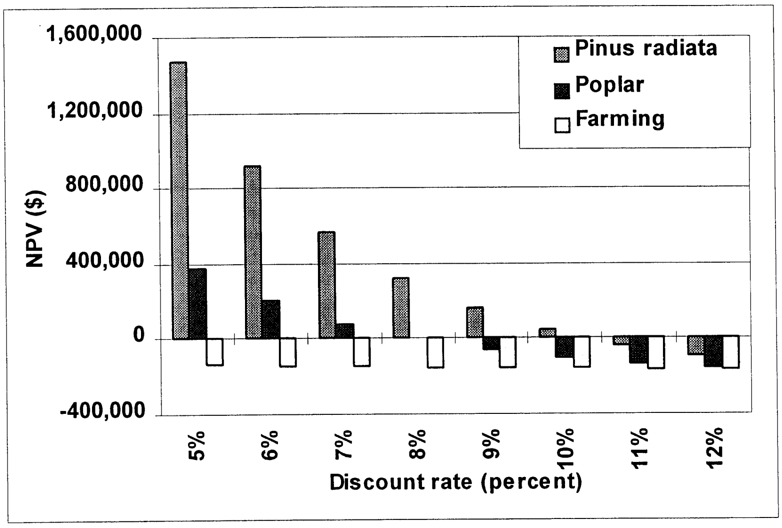

Figure 3. 19. Project NPV of agroforestry on Gisborne-Wairoa large stations using on-farm labour

Table 3. 12 IRR of poplar and *Pinus radiata* agroforestry projects on Gisborne-Wairoa large stations

	Project		
	Poplar	*Pinus radiata*	Farming
On-farm labour	8.00%	10.53%	1.46%
Contract labour	5.99%	8.71%	1.46%

The *Pinus radiata* agroforestry project again has the highest NPV for all discount rates at which NPV is positive under both the contract labour and on-farm labour options. The poplar agroforestry project has a higher NPV than farming for all discount rates at which NPV is positive; therefore poplar agroforestry is again the preferred option if choosing only between poplar agroforestry and farming.

The agroforestry IRR's are slightly lower for Gisborne-Wairoa large stations than Gisborne-Wairoa small farms, but the IRR for farming is much lower at only 1.46% for large stations compared to 5.41% for small farms. This indicates that given these land prices and farm accounts, the return on investment of farming on large stations is very poor compared to small farms. The IRR of both poplar and *Pinus radiata* agroforestry is far higher than the IRR of farming on large stations, regardless of which labour option is used in the analysis.

3.4.6 Effect on farm NPV

Gisborne-Wairoa small farms

Effect on farm NPV is calculated by subtracting net farm cash flow without forestry from net farm cash flow with forestry, generating a time series of the change in cash flow due to the implementation of the forestry project. Effect on farm NPV is the NPV of this time series. This is equivalent to taking the difference between the NPV for agroforestry and no-forestry, where NPV is calculated as in the previous section. The cost of land and the initial cost of purchasing livestock do not affect the effect on farm NPV, as these costs occur regardless of whether the land is used for farming or agroforestry. The costs and revenues of buying and selling stock during the rotation due to changes in understorey pasture do have an effect however.

Effect on farm NPV may be considered a relevant criterion in a landowners decision to change land use on land that is already owned, grazing the understorey with livestock that are also already owned. Figure 3. 20 and Figure 3. 21 summarise the effect on farm NPV of the poplar and *Pinus radiata* projects under contract labour and on-farm labour options. Table 3. 13 displays discount rates at which the effect on farm NPV equals zero.

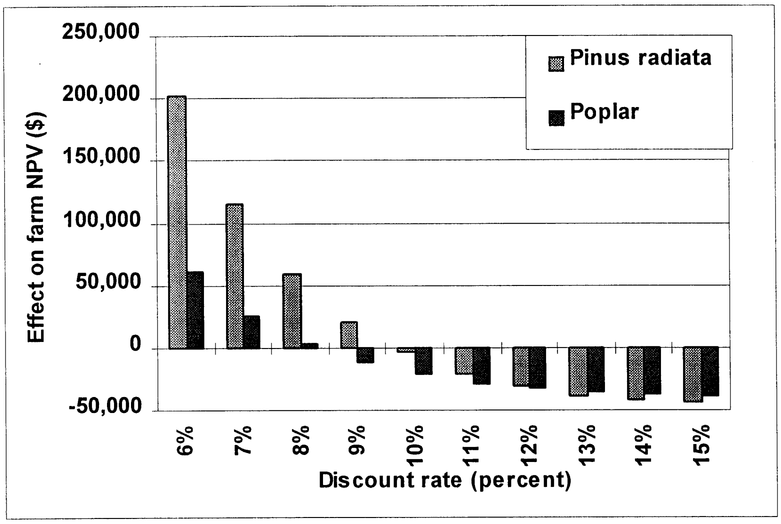

Figure 3. 20. Effect on farm NPV of Gisborne-Wairoa small farm agroforestry using contract labour

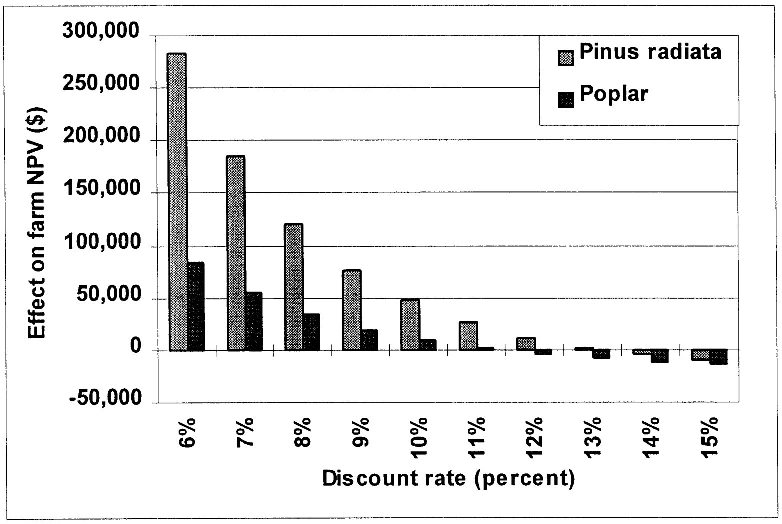

Figure 3. 21. Effect on farm NPV of Gisborne-Wairoa small farm agroforestry using on-farm labour

Table 3. 13 Discount rates at which effect on farm NPV equals zero for Gisborne-Wairoa small farms

	Project	
	Poplar	*Pinus radiata*
On-farm labour	11.13%	13.26%
Contract labour	7.19%	9.81%

These results once again indicate that the *Pinus radiata* project has a significantly higher return than poplar. Effect on farm NPV is greater for *Pinus radiata* than poplars at all discount rates for which effect on farm NPV is positive. Effect on farm NPV is positive for *Pinus radiata* at discount rates up to 9.81% using contract labour, and up to13.26% using on-farm labour. In contrast, poplars only had a positive effect on farm NPV for discount rates up to 7.19% using contract labour 11.13% using on-farm labour.

Gisborne-Wairoa large stations

Effect on farm NPV is once again greater for *Pinus radiata* than poplars at all discount rates for which effect on farm NPV is positive (Figure 3. 22 and Figure 3. 23). The discount rates at which there is no effect on farm NPV are also greater for *Pinus radiata* than poplars, regardless of which labour option is chosen (Table 3. 14). The effect on farm NPV, and the discount rates at which there is no effect on farm NPV, are greater for Gisborne-Wairoa large stations than Gisborne-Wairoa small farms for both agroforestry species. This is because the return on investment of farming on large stations is very poor compared to small farms, and so the effect on farm NPV of implementing agroforestry is greater.

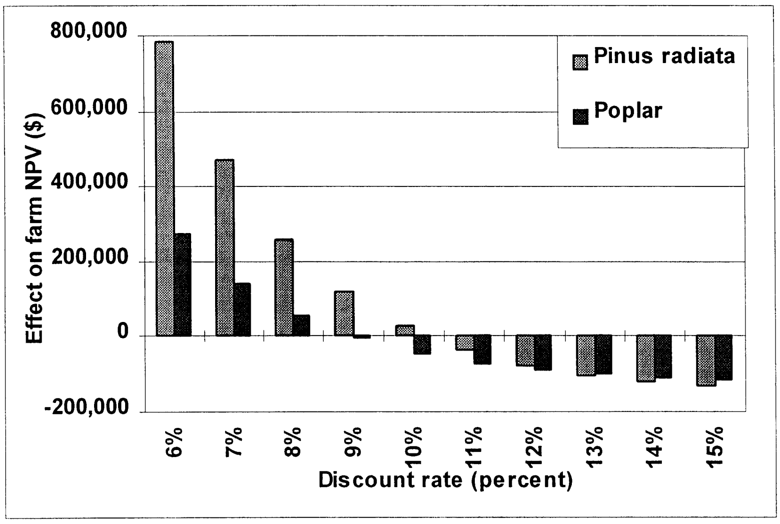

Figure 3. 22. Effect on farm NPV of Gisborne-Wairoa large station agroforestry using contract labour

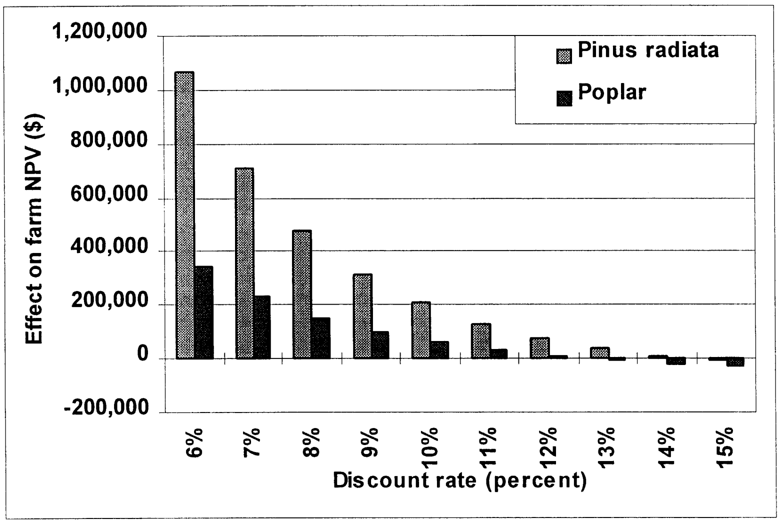

Figure 3. 23. Effect on farm NPV of Gisborne-Wairoa large station agroforestry using on-farm labour

Table 3. 14 Discount rates at which effect on farm NPV equals zero for Gisborne-Wairoa large stations

	Project	
	Poplar	*Pinus radiata*
On-farm labour	12.42%	14.46%
Contract labour	7.92%	10.40%

3.4.7 Root biomass

Root biomass development of a single hectare planted on a fixed rotation follows a pattern of almost linear growth followed by a sharp decline following harvesting (Figure 3. 24). When planting is implemented over a ten year period, total project root biomass follows a smoother profile with a smaller decline in biomass following harvesting, due to the staggered harvesting and replanting (Figure 3. 25).

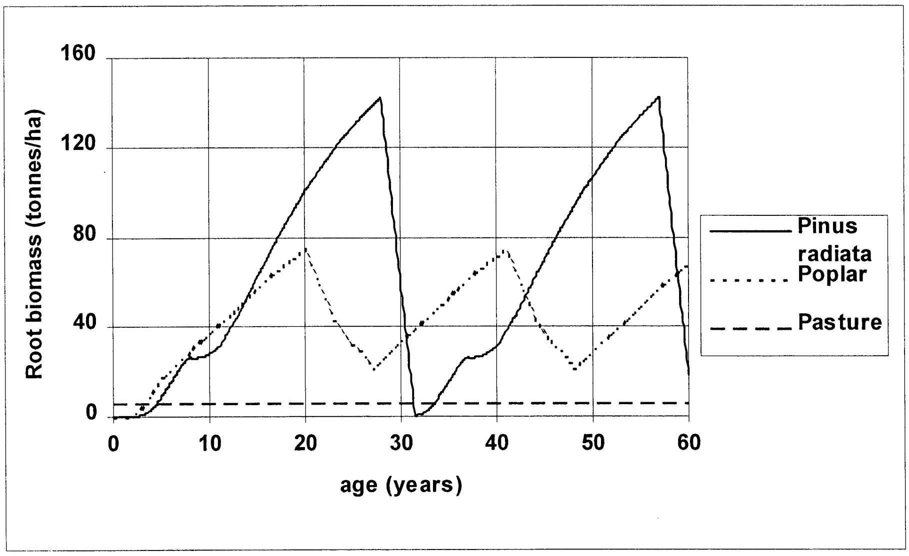

Figure 3. 24. Root biomass for a single hectare of *Pinus radiata* and poplars on a fixed rotation

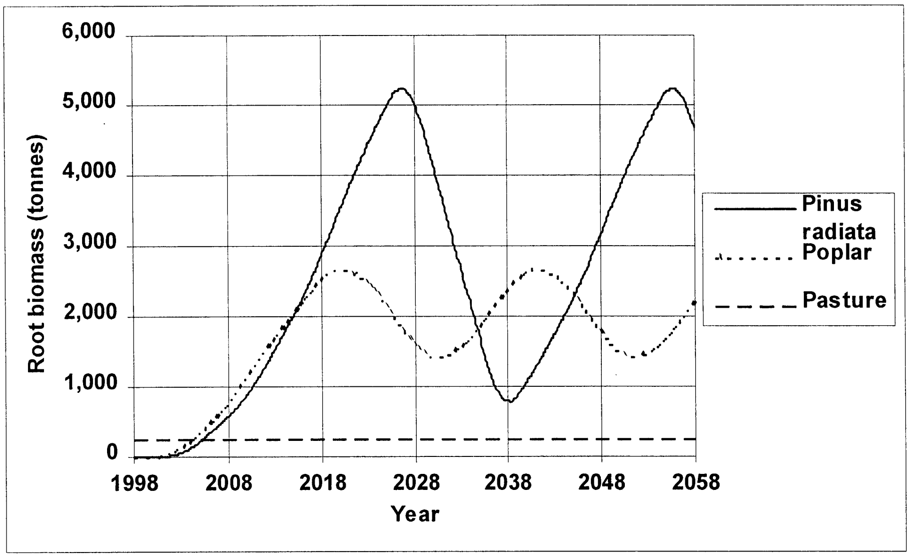

Figure 3. 25. Total project root biomass for Gisborne-Wairoa small farm agroforestry project

During the first 17 years of the project, the poplar project appears to have slightly higher root biomass than *Pinus radiata*, and from age 17 years until harvesting commences the *Pinus radiata* root biomass is greater. That is, the fast early growth of poplars more than compensates for the considerably lower stocking of the poplar stands. After the first rotation, the *Pinus radiata* project tends, on average, to have higher root biomass than the poplar, primarily due to the shorter rotation length of the poplar. The results for Gisborne-Wairoa large stations are identical to those displayed in Figure 3. 25, only the magnitudes are about 3.5 times larger due to the greater land area planted. Mean root biomass after the first rotation for Gisborne-Wairoa small farms (equivalent to values at normality for a constant rate of harvesting and replanting) is 3384 tonnes for *Pinus radiata* and 2036 tonnes for poplar. The equivalent values for Gisborne-Wairoa large stations are 11,779 tonnes and 7087 tonnes.

Despite higher average root biomass values, root biomass (or equivalent full-strength root biomass) after the *Pinus radiata* is harvested falls below that of the poplar project for a number of years. This is due to faster root decay caused by lower initial root strength of the radiata, and slower root growth of the new trees following replanting.

For comparison, Figure 3. 24 and Figure 3. 25 also illustrate approximate root biomass for pasture, using an estimate of 6.0 tonnes of dry matter per hectare. This value is consistent with published values for New Zealand pastures; eg., Matthew (1992) (5.4 t DM ha^{-1} for perennial ryegrass), and Francis *et al.*, (1992) (4.7 to 6.3 t DM ha^{-1} for ryegrass/ white clove pasture in Canterbury).

3.4.8 Changes in water yields

Figure 3. 26 shows the annual interception losses, based on mean annual rainfall for Mangatu Forest, for a single age class of poplars and *Pinus radiata* on a fixed rotation of 20 and 28 years respectively. Interception losses tend to be slightly greater for poplar during the first 10 years, and greater for *Pinus radiata* thereafter. At the end of the 20 year rotation poplar interception is estimated at 249 mm or 19 percent of total rainfall, while *Pinus radiata* interception at the end of the 28 year rotation is at 425 mm, or 33 percent of total rainfall. If rainfall data for Ruatoria is used, the results are similar, with maximum *Pinus radiata* interception of 330 mm, or 18 percent of total rainfall, and maximum poplar interception of 594 mm, or 33 percent of total rainfall.

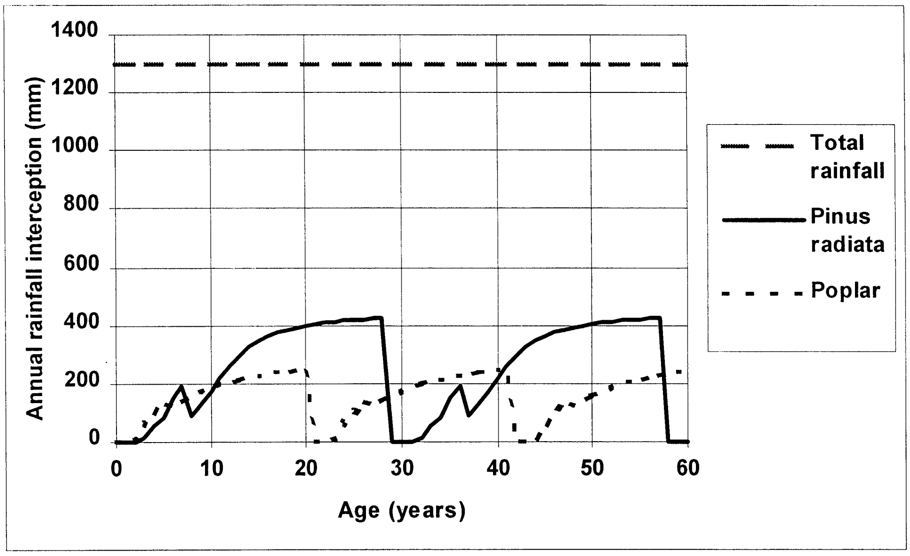

Figure 3. 26. Annual rainfall interception losses for a single age class of *Pinus radiata* and poplars on a fixed rotation

The annual volume of rainfall intercepted on Gisborne-Wairoa small farms over the whole agroforestry project, using mean rainfall data for Mangatu Forest, follows a similar pattern to projected root biomass (Figure 3. 27). Poplar interception losses are slightly higher than those for *Pinus radiata* during the first twelve years, due to the rapid canopy development of poplars in the first few years, which more than compensates for the lower stocking and loss of leaves during winter. After the first twelve years poplar interception losses tend, on average, to be less than those for *Pinus radiata*. This can be attributed to the longer rotation length and higher stocking of *Pinus radiata*, as well as the reduced interception losses by poplars during winter. The minimum interception loss between rotations is similar for both *Pinus radiata* and poplars at about 40,000 m^3/year. Once again, the results for Gisborne-Wairoa large stations are the same as for Gisborne-Wairoa small farms, only the magnitudes of the interception losses are 3.5 times greater.

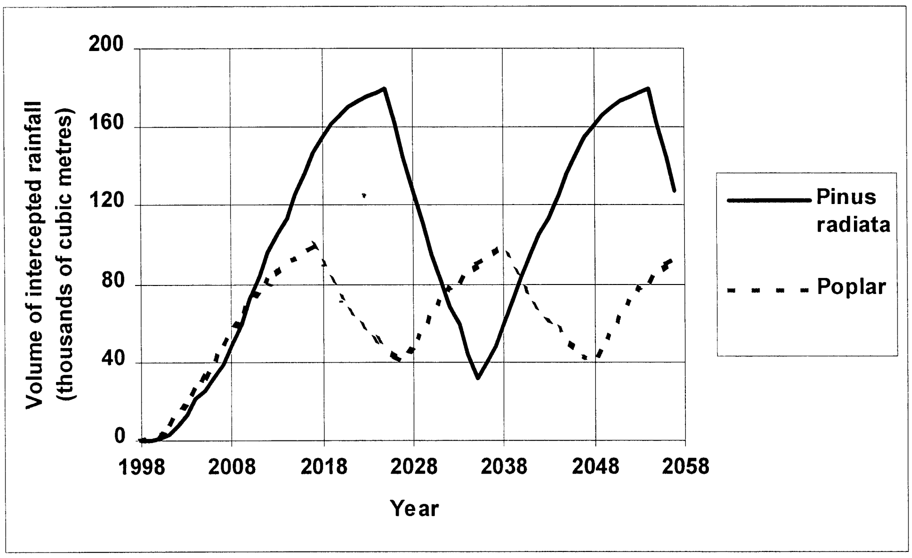

Figure 3. 27. Annual volume of intercepted rainfall on Gisborne-Wairoa small farm agroforestry project

3.4.9 Sensitivity analysis

The results presented in the previous sections are conditional on the values used for log prices, yields, livestock carrying capacity, labour and non-labour costs, rotation length, and various other inputs. Therefore some sensitivity analysis was conducted to test how much the internal rate of return of poplar agroforestry changes if the values of various inputs are altered. The values that were altered were land area planted, log prices, log yields, livestock carrying capacity over time, and rotation length. An analysis was also conducted to test the effect of the gross margin on the returns of poplar and *Pinus radiata* agroforestry compared to farming.

Land area planted

The results presented in section 3.1 indicated that for projects of equal land area, *Pinus radiata* agroforestry displaced, on average, about twice as many livestock as poplars. The profitability of *Pinus radiata* was however significantly greater than the profitability of poplars. In order to test which species was more profitable for a fixed level of average livestock displacement, the proportion of land planted in trees on the *Pinus radiata* project was reduced until the livestock displacement at normality was the same for the *Pinus radiata* and poplar projects. This meant that only 52.4% of the agroforestry project land was planted over a 10 year period for the Pinus radiata project. Some 2.28 hectares/year were planted on Gisborne-Wairoa small farms, giving a total planted area of 22.8 hectares, and 7.94 hectares/year were planted on Gisborne-Wairoa large stations, giving a total planted area of 79.4 hectares.

The results indicated that a 52:48 mix of *Pinus radiata* agroforestry and farming still appeared to be more profitable than planting the whole land area in poplars (Table 3. 15). This implies that the costs incurred by *Pinus radiata* due to greater livestock displacement per unit land area can be mitigated by simply planting a smaller land area, while still retaining greater profitability than poplars. Figure 3. 28 and Figure 3. 29 show that when only 52.4% of the project land area was planted in Pinus radiata, livestock displacement was lower than poplars during the first ten years, higher during the second ten years, and on average was the same.

Table 3. 15 IRR of poplar agroforestry and a 52:48 mix of *Pinus radiata* agroforestry and farming

	Gisborne-Wairoa small farms		
	Poplar only	52.4% *Pinus radiata* and 47.6% farming	Farming only
On-farm labour	8.69%	9.82%	5.41%
Contract labour	6.61%	8.41%	5.41%

	Gisborne-Wairoa large stations		
	Poplar only	52.4% *Pinus radiata* and 47.6% farming	Farming only
On-farm labour	8.00%	9.12%	1.46%
Contract labour	5.99%	7.82%	1.46%

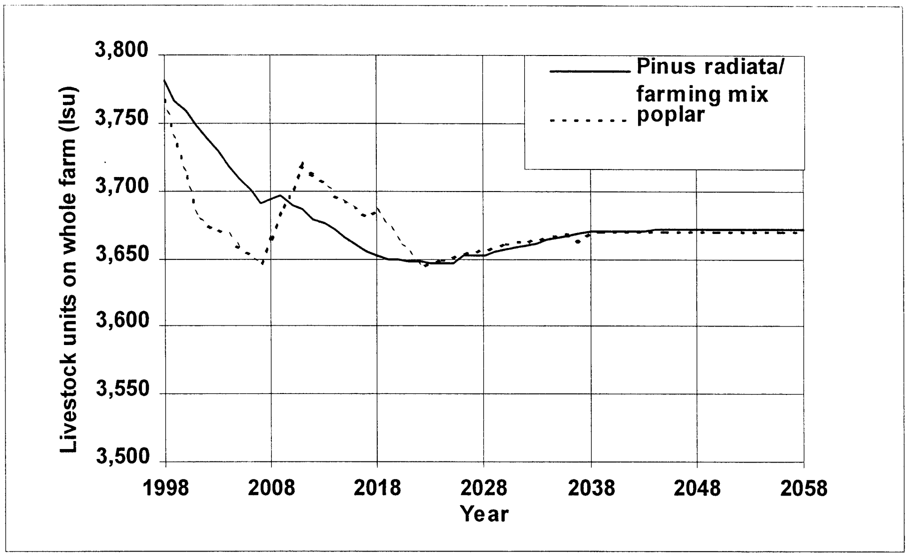

Figure 3. 28. Livestock carrying capacity on Gisborne-Wairoa small farms with poplar agroforestry and a 52:48 mix of *Pinus radiata* agroforestry and farming

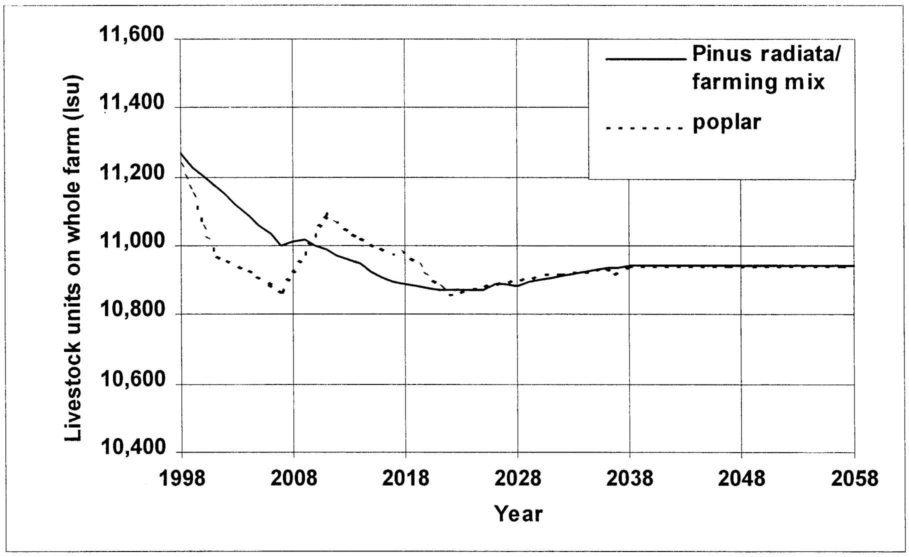

Figure 3. 29. Livestock carrying capacity on Gisborne-Wairoa large stations with poplar agroforestry and a 52:48 mix of *Pinus radiata* agroforestry and farming

In addition to greater profitability, a mix of farming and *Pinus radiata* agroforestry also has a smaller impact on farm surplus during the implementation phase than poplars (Figure 3. 30 and Figure 3. 31). On Gisborne-Wairoa small farms, using contract labour to plant 52% of the project area in *Pinus radiata* reduces farm surplus by a maximum of 16%, while planting the whole project area in poplars reduces farm surplus by a maximum of 22%. The corresponding maximum reductions in farm surplus for Gisborne-Wairoa large stations are 33% for *Pinus radiata* and 46% for poplars.

Net farm cash flows during harvesting and at normality are considerably greater for *Pinus radiata*, even though only just over half of the land area has been planted. On Gisborne-Wairoa small farms, net farm cash flow at normality for *Pinus radiata* is 53% greater than the initial farm surplus if contract labour is used, while net farm cash flow at normality for poplar is 25% greater. The corresponding increases in farm surplus at normality for Gisborne-Wairoa large stations are 121% for *Pinus radiata* and 60% for poplars.

The only remaining disadvantage of *Pinus radiata* in terms of cash flow was that harvesting occurred eight years later than for poplar, meaning that farm surplus remained depressed for eight years longer.

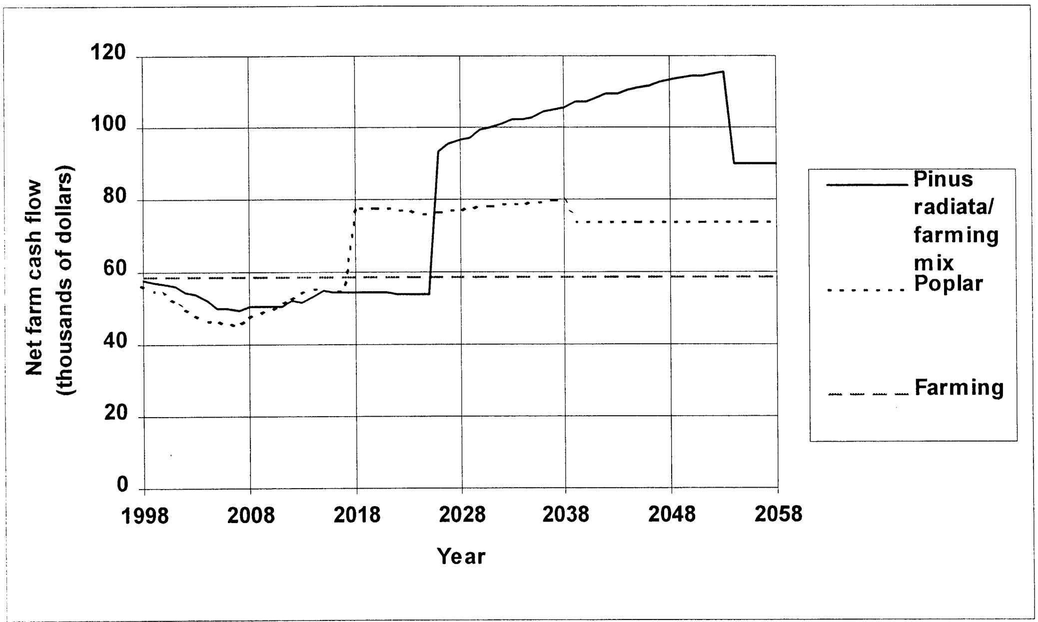

Figure 3. 30. Net farm cash flow for poplar agroforestry and a 52:48 mix of *Pinus radiata* agroforestry and farming on Gisborne-Wairoa small farms (contract labour option only)

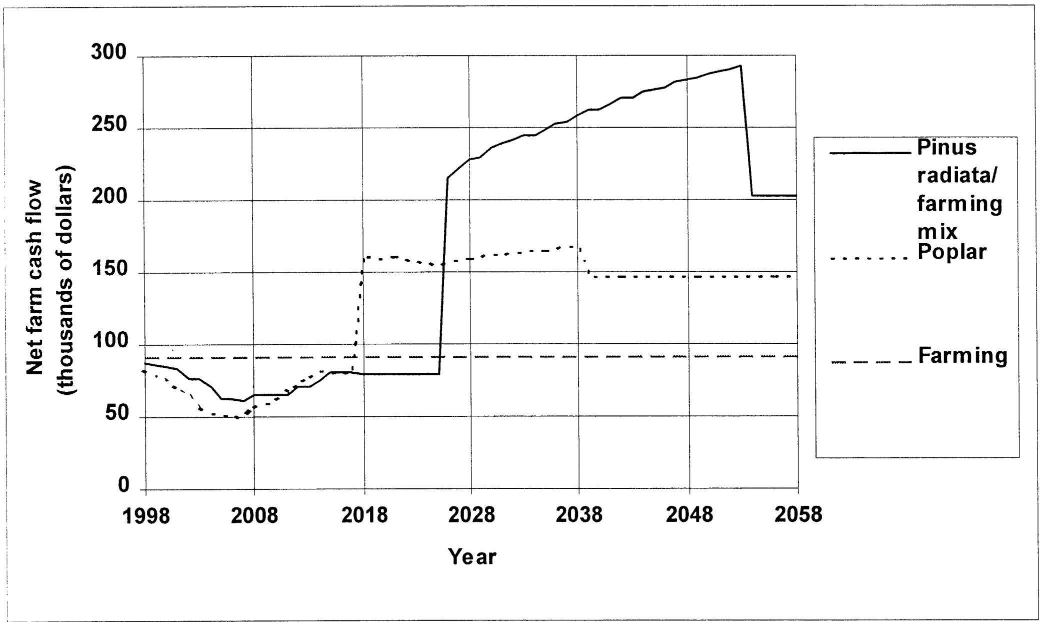

Figure 3. 31. Net farm cash flow for poplar agroforestry and a 52:48 mix of Pinus radiata agroforestry and farming on Gisborne-Wairoa large stations (contract labour option only)

Log prices

Two different scenarios were used to test the effect of log prices on internal rate of return. The first scenario assumed an increase in poplar pruned log prices of 50% from $100/m^3$ to $150/m^3$, while the price of other log grades remains the same. This could perhaps be achieved by the development of a domestic or export market requiring high grade pruned logs for premium uses such as veneer. The second scenario assumed a 50% increase in the price of pruned logs, and a 25% increase in the prices of the other three grades. This gives a price of $87.50/m^3$ for S-grade logs, $50/m^3$ for L-grade logs, and $44/m^3$ for pulp. Prices of these magnitudes might be possible if S-grade logs were manufactured into chopsticks for export to Korea and China, L-grade logs were utilised for particle board or fibre board manufacture, and pulp was accepted by domestic pulp and paper mills.

Table 3. 16 indicates that under the first scenario the IRR for poplar agroforestry would be similar to, or slightly higher than, that for *Pinus radiata*, while under the second scenario the IRR for poplar agroforestry would be 0.5-1.0% higher than that for *Pinus radiata*. This result was similar for both farm types.

Table 3. 16 IRR of East Coast poplar agroforestry at three levels of log prices.

	Gisborne-Wairoa small farms			
	Pinus radiata (original log prices)	poplar (original log prices)	poplar (scenario 1)	poplar (scenario 2)
On-farm labour	10.80%	8.69%	11.04%	11.68%
Contract labour	8.91%	6.61%	9.17%	9.86%
	Gisborne-Wairoa large stations			
	Pinus radiata (original log prices)	poplar (original log prices)	poplar (scenario 1)	poplar (scenario 2)
On-farm labour	10.53%	8.00%	10.50%	11.17%
Contract labour	8.71%	5.99%	8.68%	9.40%

Log yields

A further two scenarios were used to test the effect of log yields on internal rate of return. The first scenario used yields for a medium rather than a good site, while the second scenario used yields for a good site plus an extra 30% volume for all log grades.

The results in Table 3. 17 indicate that the IRR is significantly lower for medium sites than for good sites. If yields for good sites plus 30% are used, IRR is over 1% higher than IRR for good sites, but these returns are still lower than those received for *Pinus radiata*. The increase in IRR from raising yields by 30% is still significantly smaller than the increase in IRR from increasing pruned log prices by 50%. Once again, these results were similar for both labour options on both farm types.

Table 3. 17 IRR of East Coast poplar agroforestry at three levels of yields

	Gisborne-Wairoa small farms			
	Pinus radiata	poplar (medium site)	poplar (good site)	poplar (good site +30%)
On-farm labour	10.80%	5.69%	8.69%	9.87%
Contract labour	8.91%	3.19%	6.61%	7.90%
	Gisborne-Wairoa large stations			
	Pinus radiata	poplar (medium site)	poplar (good site)	poplar (good site +30%)
On-farm labour	10.53%	4.70%	8.00%	9.26%
Contract labour	8.71%	2.22%	5.99%	7.35%

Livestock carrying capacity

One of the supposed benefits of poplars as an agroforestry species is the relatively high growth rates of understorey pasture compared to other forestry species such as *Pinus radiata*. The effect of understorey pasture production on the internal rate of return was determined by simulating poplar agroforestry using *Pinus radiata* understorey pasture production tables (Table 3. 18). In effect, this tests the effect of the different rates of understorey pasture production of the two species on IRR, while holding forestry costs and revenues constant. The IRR of poplar agroforestry assuming no understorey pasture suppression was also calculated. This assumption is rather unrealistic, and represents an extreme case where the feed value of pruned branches and autumn leaf fall are able to fully compensate for lost pasture production. The agroforestry land is still assumed to carry no livestock for the first four years of the rotation however, in order to avoid livestock damage to trees.

The results indicate that although IRR falls when *Pinus radiata* understorey tables are used, the magnitude of the fall is relatively small. Even if no pasture suppression occurs at all under poplars, then the IRR of poplar agroforestry is still significantly lower than the IRR of *Pinus radiata* agroforestry, particularly for the large station farm-type. As no pasture loss is an unrealistic and rather extreme assumption, it can be concluded that the return on investment of East Coast poplar agroforestry is unlikely to exceed that of *Pinus radiata* due to poplar understorey pasture production exceeding expectations.

Table 3. 18 IRR of East Coast poplar agroforestry at three levels of yields

	Gisborne-Wairoa small farms			
	Pinus radiata	poplar (original understorey)	poplar (*Pinus radiata* understorey)	poplar (full understorey)
On-farm labour	10.80%	8.69%	7.86%	9.31%
Contract labour	8.91%	6.61%	5.80%	7.21%
	Gisborne-Wairoa large stations			
	Pinus radiata	poplar (original understorey)	poplar (*Pinus radiata* understorey)	poplar (full understorey)
On-farm labour	10.53%	8.00%	7.40%	8.44%
Contract labour	8.71%	5.99%	5.40%	6.42%

Rotation length

A further supposed benefit of poplars as an agroforestry species is relatively fast growth at an early age, thus allowing short rotation lengths to be used. A fixed rotation length of 20 years was used in the initial analysis. In addition to this, IRR was calculated for rotation lengths from 12 to 20 years for both farm types (Figure 3. 32 and Figure 3. 33).

For both farm types the optimal rotation length in terms of IRR was 15 years if on-farm labour was used, and 16 years if contract labour was used. On Gisborne-Wairoa small farms the IRR's at optimal rotation length were 9.68% for the on-farm labour option, and 7.07% for the contract labour option, while for Gisborne-Wairoa large stations the corresponding IRR's were 8.95% and 6.39%. Thus it appears that by shortening the rotation length, IRR can be increased by about 1% if on-farm labour is used, and 0.5% if contract labour is used. In each case the IRR was still somewhat lower than the corresponding IRR for *Pinus radiata* agroforestry.

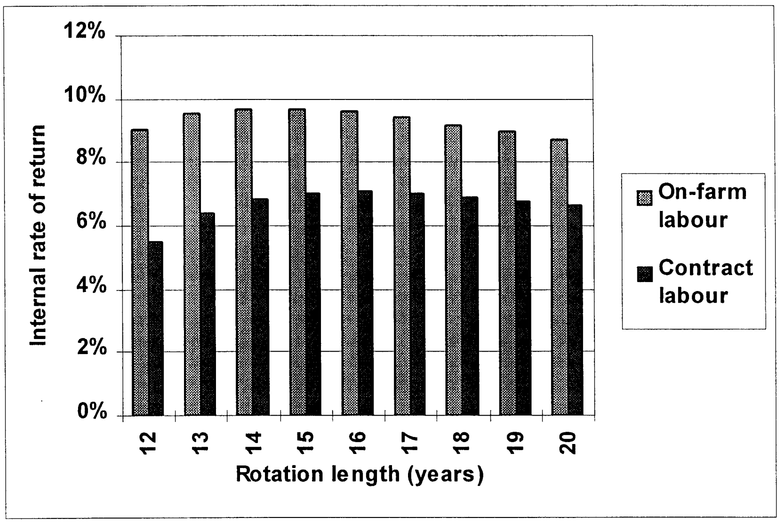

Figure 3. 32. IRR by rotation length for poplar agroforestry on Gisborne-Wairoa small farms

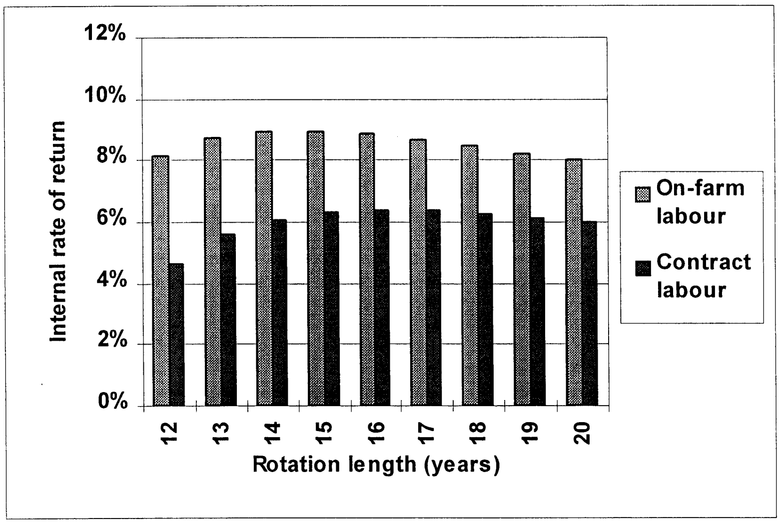

Figure 3. 33. IRR by rotation length for poplar agroforestry on Gisborne-Wairoa large stations

Gross margin

The comparative returns of agroforestry and farming are affected by gross margin per livestock unit received for farming, which is defined as income, less variable costs, per stock unit. If the gross margin is high, farming compares more favourably with agroforestry, while if the gross margin is low, farming compares less favourably. The gross margin at which the internal rates of return for agroforestry and farming are equal were identified for both farm types and both species (Table 3. 19). The actual gross margins are $27.25/lsu for small farms and $22.71/lsu for large stations.

These results indicate that a relatively small increase in gross margin on small farms would give farming a higher internal rate of return than poplar agroforestry, while on large stations the required increase in gross margin is much larger. In particular, an increase in gross margin of only $2.95/lsu on small farms would make farming more profitable than poplars, if contract labour is used. The gross margin at which the IRR for *Pinus radiata* agroforestry and farming are equal is higher than that at which the IRR for poplar agroforestry and farming are equal, for both farm types. This indicates that the superior returns of *Pinus radiata* agroforestry over farming are less sensitive to changes in gross margin than the superior returns of poplar agroforestry over farming.

Table 3. 19 Gross margins at which IRR for farming equals IRR for agroforestry ($/lsu)

	Gisborne-Wairoa small farms	
	Pinus radiata	poplar
On-farm labour	$39.20	$35.80
Contract labour	$34.70	$30.20
	Gisborne-Wairoa large stations	
	Pinus radiata	poplar
On-farm labour	$43.30	$39.80
Contract labour	$38.60	$34.10

3.5 Discussion

Results were presented for two different labour options; on-farm labour and contract labour. The on-farm labour option assumes that all forestry work can be carried out by existing labour units on the farm, while the contract labour option assumes that additional labour will be employed for all forestry work. The on-farm labour option is probably more relevant to small agroforestry projects, such as those on the small farm farm-type, while larger scale projects, such as those on the large station farm-type, are likely to require contract labour in a significant part, if not all, of the work.

However, even if on-farm labour is to be used, the costs of completing this work should not be ignored. Using the on-farm labour option assumes that the existing labour units are not being fully utilised, or if they are, they will not require additional compensation for carrying out forestry work. If all labour units were fully utilised before the implementation of agroforestry, then forestry work can only be carried out at the expense of work elsewhere on the farm. Even if the forestry work is carried out by a self-employed farm owner, this will still presumably be at the expense of other farm work. The reduction in livestock units resulting from the implementation of agroforestry will reduce farm labour requirements slightly, but this effect is likely to be small in magnitude compared to the forestry labour requirements. In addition, forestry labour requirements tend to be very uneven over time, meaning that it is unlikely that existing farm labour will be able to cover periods of peak labour demand, unless the rate of forestry planting is very gradual. In general therefore, the contract labour option is probably the most relevant, as it accounts for the full cost of forestry work, even if this cost is only the opportunity cost of a landowners time rather than an actual sum of money paid.

In terms of IRR, agroforestry appeared to be more profitable relative to pastoral farming on Gisborne-Wairoa large stations than Gisborne-Wairoa small farms. Examination of the farm accounts reveals that the large station farm surplus was only about 50% greater than that for small farms, despite having three times the number of livestock units. Fixed costs per stock unit were greater for large stations than small farms, while variable costs per stock unit were similar for both farm types. In contrast, revenue per stock unit was higher for small farms. Given this information, and the fact that the land prices used were proportional to the number of farm livestock units, the IRR for farming was naturally higher for small farms than large stations. Differences in wage costs probably explain why fixed costs per stock unit were higher for large stations than small farms. That is, small farms tend to be owner operated, while large stations are often owned by an absentee owner who buys all the farm labour. Farm accounts data reported by MAF (1998) indicates that Gisborne-Wairoa small farms spent, on average, $4,723 on wages, while Gisborne-Wairoa large stations spent $78,029. It is possible that the ratio of sheep to cattle partly explains the difference in revenue, as 40% of stock units on large stations were comprised of cattle, compared to 45% for small farms. If the farm accounts data is assumed to be accurate, it can be concluded that the improvement in profitability from land use change would be greater for Gisborne-Wairoa large stations than Gisborne-Wairoa small farms.

Although *Pinus radiata* agroforestry displaced about twice as many livestock as poplars when the same land area was planted for each, it was demonstrated that by planting only half of the project land in *Pinus radiata*, livestock displacement was about the same as that of planting the whole project in poplars, while profitability was still greater than that of poplars. This indicates that if a landowner intends to minimise livestock displacement or silvicultural costs, then planting a smaller land area of *Pinus radiata* may be more profitable than planting a species with greater understorey pasture production and lower tending costs, such as poplar. Of course, planting a smaller land area is a disadvantage if soil stabilisation is one of the primary reasons for planting. In this case it is desirable to cover as large a land area with trees as is affordable.

The total root biomass of the *Pinus radiata* regime appeared to be, on average, greater than that of the poplar, except for the first 17 years of the project and for a few years following the commencement of harvesting of the *Pinus radiata* . These periods may be particularly critical however, as a large proportion of erosion on the East Coast occurs during high intensity storms of short duration. Extensive slope failure may occur on steep sites if a severe storm occurs before the stand has reached the critical level of root biomass required to prevent large scale mass wasting. The faster decay and slower regrowth of *Pinus radiata* roots means that there is a greater length of time over which the stands are vulnerable if a severe storm occurs. Nevertheless, this result is offset somewhat by the shorter rotation length, hence more frequent harvesting, of poplars.

Site productivity will also have an on effect root biomass development; that is, root growth will be slower on infertile sites or shallow soils. As these factors are also common to steep, unstable slopes, development of tree roots may be slowest on sites that are in the greatest need of reinforcement. This point also highlights the need for careful matching of appropriate poplar clones to different sites, as many poplar clones tend to be quite site selective. Inappropriate choice of clone may lead to much slower root development than that of Pinus radiata. The results presented in this analysis were for poplars grown on "good" sites only, and so are only likely to be applicable for poplar clones correctly matched to the available site.

Bosch and Hewlett (1982) reviewed 94 catchment experiments worldwide, concluding that the approximate change in water yields for each 10 percent change in canopy cover was 40 mm for pine forest, and 25 mm for deciduous hardwoods. This approximation gives almost identical results to those derived from the model used in this study, provided that the interception fractions used for Mangatu and Ruatoria are 0.30 and 0.22 respectively. This result suggests that the reduction in canopy cover in poplar stands during winter does account for differences in interception losses between *Pinus radiata* and poplars. The interception fraction which gives the same result as Bosch and Hewlett varies between sites of different rainfall because these authors do not draw any conclusions about the effect of absolute rainfall levels on interception losses.

It is important to note that the projected root biomass and rainfall interception are indicative values only, and that the simple models used to produce the projections have a number of simplifying assumptions. For example the root biomass calculations assumed that the relationship between DBH and root biomass was the same for both *Pinus radiata* and poplars, and that the decline in root strength over time could be approximated by a linear function of the same gradient for both species. Differences in water yields between pasture and forest were assumed to be solely attributable to interception losses, and the interception fraction was assumed to be constant, regardless of the quantity or distribution of rainfall. In reality, the interception fraction is likely to be lower for sites of higher rainfall (although the absolute interception losses will still be greater), and will also depend on climatic factors such as windspeed and the average intensity and duration of rainstorms.

The profitability of poplar agroforestry was quite sensitive to changes in log prices. In particular, increasing prices for pruned logs had a significant effect on IRR, as these represent the most valuable log grade and the proportion of total recoverable volume comprised of pruned logs is relatively high. The profitability of poplars was also quite sensitive to changes in yields, but not to the same extent as for changes in log prices. This is to be expected, as any extra volume still incurs the harvesting and transport costs, but price rises give extra revenue with no associated increase in cost.

Sensitivity analysis also indicated that although the higher understorey livestock carrying capacity of poplars compared to *Pinus radiata* did have a positive effect on IRR, the magnitude of this effect was not as large as that for changes in log prices or yields. Even if no reduction in livestock carrying capacity occurred under poplars after age 4 years, poplars still did not appear to be as profitable as *Pinus radiata*. This indicates that errors in the estimation of understorey pasture production alone are unlikely to lead to a misleading result concerning the relative profitability of poplars and *Pinus radiata*.

Although understorey pasture production appears to be far greater under poplars than *Pinus radiata*, removal of livestock under poplars during the first 4 years of the rotation partly offsets the increased pasture production later in the rotation. The magnitude of this effect is greater than it may first appear, because the discounting of costs gives the first few years a higher weighting than subsequent years. This problem could be remedied to a certain extent by planting poles, or using seedling protectors in order to allow continuous livestock grazing, but the costs of these measures would be prohibitive at a tree stocking of 400 sph.

Although it appears that the profitability of poplars could be increased by using a rotation length shorter than 20 years, the validity of this result would depend on whether smaller, younger logs were acceptable for the markets in which they were being sold. A minimum small end diameter (sed) of 30 cm was used for pruned sawlogs, as this is commonly specified for *Pinus radiata*, but if the required minimum sed was larger then the optimal rotation length would become longer. In addition, the yields were calculated only for good sites, on which the pruned logs are able to meet the minimum sed specifications at a relatively young age. On medium or poor sites it may take longer to grow pruned logs of saleable dimensions.

The higher the gross margin for farming, the greater the benefits from planting species such as poplars which only have small losses in livestock carrying capacity. For example, the IRR of poplar agroforestry was closer to that of *Pinus radiata* on Gisborne-Wairoa small farms than Gisborne-Wairoa large stations. But if the gross margin for farming is too high, then poplar agroforestry will be less profitable than farming. For example, a small change in gross margin was required on Gisborne-Wairoa small farms to make farming more profitable than poplar agroforestry, but on Gisborne-Wairoa large stations the required change in gross margin was much larger.

It is important to note that the poplar yield tables used for this study were based on MARVL inventory assessments, and as such give indicative values only. *Populus* is a genus rather than a single species, so wide variation in growth rates can be expected. Despite this, due to data limitations the estimated functions do not account for differences in species or clone. Growth responses to pruning and thinning are also omitted from the yield tables. Time series data from silvicultural experiments would be required to estimate these relationships, which is beyond the scope of this study. Variations in yield between sites are also only indicative, as site quality was divided into only three broad groups labelled “good”, “medium”, and “poor”. Development of a site quality variable such as site index was also beyond the scope of this study.

A number of wood quality issues that have not been fully dealt with in this analysis are likely to be important in the evaluation of poplar profitability. Bacterial black heart is a common problem in poplar timber, which adversely affects both the physical and appearance properties of the wood (Williams *et al.*, 1986). Black heart is more likely to occur in closely spaced or old stands with large numbers of dead branches on the stem. Therefore wide tree spacings and short rotation lengths are desirable to minimise black heart. Branch size increases at wide spacings however, leading to lower quality sawlogs than those grown at close spacings. Tree spacing was used to predict sawlog quality for the poplar yield tables, but the relationship did not have a particularly good fit and needs to be further investigated. Furthermore, in the absence of reliable market information regarding the relative value of different poplar log grades, it is difficult to assess the importance of controlling sawlog branch size. Some further analysis of sawn logs would appear to be warranted in order to assess the incidence of internal defects such as black heart, and to validate the preliminary log grade allocation functions.

Uncertainty concerning future log prices probably represents the greatest risk for poplar growers, as no reliable market currently exists for New Zealand grown poplar, and the profitability of growing poplars as an agroforestry species appears to be particularly sensitive to price. This risk also needs to be taken into account when evaluating poplar agroforestry as a land use option. Currently there are many mature small plantings scattered throughout New Zealand, but these stands have little or no value at the present time. Well tended stands have a greater chance of being saleable, but the costs of tending mean that greater losses are incurred if a stand is unable to be sold.

Much of this analysis has focussed on the profitability of poplar agroforestry, as measured by NPV and IRR, but agricultural landowners may have a variety of objectives besides pure profitability when investing in agroforestry. For example, they may seek to maximise soil protection, or minimise the negative effects on livestock carrying capacity, labour requirements, or farm surplus. Alternatively, a combination of these objectives may be desired. Ultimately, the objectives of individual landowners will determine which land use, or which mix of land uses, is the most desirable.

3.6 Conclusions

In general, both the negative and positive impacts of agroforestry tend to be of a smaller magnitude for poplars than *Pinus radiata*. The profitability of poplar agroforestry on Gisborne-Wairoa small farms and Gisborne-Wairoa large stations appeared to be potentially greater than that of pastoral farming, but lower than that of *Pinus radiata* agroforestry. The difference between poplar and *Pinus radiata* was predominantly due to higher yields and higher log prices for *Pinus radiata*, which more than offset the higher silvicultural costs and greater livestock displacement. The major advantages of poplars over *Pinus radiata* for agroforestry are smaller reductions in farm surplus during the establishment phase, due to lower silvicultural costs and less livestock displacement, and the possibility of shorter rotation lengths than those which are conventionally used for *Pinus radiata*. Poplars may be a desirable option for landowners whose objectives are consistent with these advantages. If only about half the project land area is planted in *Pinus radiata* however, then the resulting mix of *Pinus radiata* and farming has similar levels of livestock displacement, but higher profitability, than planting the entire project area in poplars.

Estimates of root biomass indicated that the erosion control benefits of poplars are as least as great as for *Pinus radiata* for the first 17 years of the project, and also for a period of several years after the harvesting of *Pinus radiata*. This result is conditional on the use of fast growing poplar clones that are correctly matched to the chosen site. Reductions in water yields for poplars appeared to be as least as great as for *Pinus radiata* for the first 17 years of the project and, on average, lower thereafter.

Sensitivity analysis indicated that significant improvements in the profitability of poplars are possible if higher prices could be realised through the development of domestic and export markets for poplar wood products. Profitability of poplars is also quite sensitive to yields, meaning that correct choice of site and clone are important factors. Understorey livestock carrying capacity is considerably higher for poplars than *Pinus radiata*, although this appears to be a less important factor in determining profitability than log prices or yields. Short rotation lengths of about 16 years appear to be most profitable for poplars, although the validity of this result depends on whether markets can be found for young wood and small logs. At the current time, an absence of markets for New Zealand grown poplar adds considerable risk to the decision to grow poplars for timber production.

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Appendices

Appendix 1. Poplar and *Pinus radiata* understorey livestock carrying capacities for Gisborne-Wairoa small farms and Gisborne-Wairoa large stations

	Livestock carrying capacity (lsu/ha)			
	Poplar		*Pinus radiata*	
Age (years)	**Small farm**	**Large station**	**Small farm**	**Large station**
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	0.00	0.00	3.25	2.80
4	0.00	0.00	2.28	1.98
5	5.26	4.53	2.87	2.48
6	5.50	4.74	1.85	1.61
7	5.26	4.54	1.74	1.49
8	5.02	4.32	2.85	2.46
9	4.80	4.13	2.50	2.16
10	4.61	3.97	1.93	1.67
11	4.43	3.82	1.38	1.19
12	4.28	3.69	0.93	0.80
13	4.15	3.57	0.60	0.52
14	4.03	3.47	0.37	0.32
15	3.92	3.38	0.22	0.19
16	3.82	3.29	0.13	0.11
17	3.73	3.22	0.07	0.07
18	3.65	3.15	0.04	0.04
19	3.58	3.08	0.02	0.02
20	3.51	3.03	0.01	0.01

Appendix 2. Yield tables for poplar and *Pinus radiata* agroforestry projects on the East Coast of the North Island

	Poplar log grade volumes for good site (m^3/ha)				
Age (years)	Pruned	S-Grade	L-Grade	Pulp	Total
12	75	50	9	52	186
13	93	55	9	53	210
14	107	62	10	55	234
15	119	70	12	56	257
16	129	79	14	58	280
17	137	88	15	59	299
18	143	97	17	61	318
19	149	106	18	63	336
20	154	114	20	65	353
21	159	122	21	66	368
22	163	129	22	68	382
23	166	135	23	70	394
24	169	141	24	71	405
25	172	147	25	72	416
26	175	151	26	74	426
27	177	156	27	75	435
28	179	160	27	76	442
29	180	163	28	77	448
30	182	167	29	77	455
31	183	170	29	78	460
32	184	172	30	79	465
33	185	174	30	80	469
34	186	176	30	80	472
35	187	178	31	81	477

	Pinus radiata log grade volumes (m^3/ha)					
Age (years)	**Pruned**	**A-Grade**	**K-Grade**	**S3L3**	**Pulp**	**Total**
20	70	2	92	65	195	424
21	91	4	101	78	195	468
22	135	7	111	80	176	509
23	153	22	116	80	179	550
24	168	35	127	64	194	588
25	183	50	129	61	203	626
26	196	89	121	54	204	664
27	207	104	119	65	204	699
28	218	118	114	74	210	734
29	228	132	119	77	211	766
30	237	147	124	76	214	797
31	244	161	132	72	217	826
32	252	201	113	74	215	855
33	258	213	110	76	226	883
34	264	227	109	79	229	909
35	270	240	116	74	234	933
36	275	252	115	80	236	957
37	279	270	118	72	240	980
38	284	284	118	71	243	1000
39	287	296	119	71	246	1021
40	291	307	118	71	251	1039