Impact of the ETS on Forest Management

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June 2008

Report produced for MAF Policy under

CC MAF POL_2008-10 (110-1) Objective 1

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Executive Summary

We evaluated the impact of carbon trading on forest management. Questions examined were: whether to plant at all; what species and silviculture to use; and when to harvest.

Revenue from annual sales of carbon units greatly increases the profitability of all species and regimes. Indeed, if the price remains at $30 per tonne of carbon dioxide equivalent then nearly all forestry investments – regardless of site quality – are capable of paying $3000/ha for the land and still achieving a reasonable real rate of return.

If the price of carbon is zero, the most profitable species/regimes are, in order: radiata pine grown on a clearwood regime; radiata pine grown on a framing regime; radiata pine with a plant-and-leave regime; Douglas-fir; *Eucalyptus nitens;* and indigenous forestry. This ranking alters substantially with higher carbon prices. Radiata regimes which have higher volume become favoured over regimes that produce trees of large piece-size or clearwood. Eucalypt regimes become relatively more profitable than low-volume radiata regimes. Radiata pine, however, remains the most profitable species under almost every conceivable scenario.

With regard to the details of radiata pine regimes, a rising carbon price favours late thinning, production thinning, and high final stocking – and discourages pruning. As the carbon price increases, there is a general lengthening of optimum rotation age. These trends apply across all site qualities.

The benefits of carbon trading are less pronounced for stands that were planted in the 1990s compared with future stands, because much of the carbon sequestration has already taken place with no payment. Nevertheless, carbon trading is still worthwhile.

Whatever the date of planting, there are still some risks in “opting in” to the ETS, particularly with regard to cash-flow difficulties at time of harvest. Most of these risks can be avoided or mitigated by careful estate planning, albeit with a reduction in profitability.

Growers can choose to retain sufficient units to cover any future liabilities, and to avoid situations where carbon liabilities at harvest greatly exceed expected revenues from the sale of timber. Alternatively, they may choose to modify their estates (by mixing species, regimes, or age-classes) so as to smooth out the future profile of their carbon stocks. Planting a normal forest achieves zero risk – because there are no further carbon losses – but it is more profitable to achieve normality by harvesting rather than by planting alone.

Tree-breeding promises some carbon advantages, particularly where the gain is through volume growth rather than the lesser benefit of increased wood density.

Introduction

The *Climate Change (Emissions Trading and Renewable Preference) Bill* presages major changes in the way forestry is practised in New Zealand. The costs and revenues of carbon sequestration may cause fundamental shifts in species, regimes, age classes, forest profitability and risk. Policy-makers, forest owners and those seeking to buy NZ Emission Units should be alerted to some of these likely changes.

The Bill proposes optional entry into the trading scheme, so it is important to assess situations both with and without the inclusion of carbon. This comparison may guide growers in their choice of whether or not to “opt in”, and may inform MAF and other policy-makers of the likely extent of the scheme’s adoption.

There are many factors to consider, some of which may be of trivial importance but others of which are likely to be critical. The price of carbon, for example, is important but unknown – so should be modelled against all likely values. Likewise, discount rate always has a highly significant effect on forest profitability, so this should also be varied. Less obvious is site quality: sites may span the spectrum from highly productive locations, suitable for high volumes of harvestable wood as well as carbon sequestration, to very inaccessible and unproductive areas where traditional forestry has never before been considered.

There are differences related to date of forest establishment: if there were trees present on December 31st 1989, then no credits are available under Kyoto or under the NZETS. Furthermore, no NZUs are to be issued for carbon gains prior to 2008, therefore even a Kyoto-compliant stand cannot benefit from any carbon gained up to the present date – which might amount to the bulk of the carbon attained in a normal rotation. Given that units need to be surrendered at harvest for the loss of carbon, it is questionable whether existing mid-rotation stands can take as much advantage of the ETS as recently planted stands, and whether a commercial market for carbon sequestration will alter rotation lengths to the same degree.

Regarding regime changes, it is not possible to assess all combinations of factors but the following need to be considered: genotype, initial stocking, pruning (or absence of pruning), intensity and timing of thinning, final stocking, and rotation age. These need to be examined at least for the dominant species (radiata pine).

The advent of the ETS may promote alternative species, given that radiata pine has traditionally been chosen for reasons of timber quality and value and not primarily for volume growth or standing volume. There are very many alternative species, so it is wise to limit the study to a few that give a generic insight into the differences between species: there are those that accumulate biomass quickly, and those that can achieve high standing volumes but do so over a much longer time frame. New Zealanders’ enduring affection for indigenous species must also be allowed for – shrubland regeneration to native forest is an option.

Risk is a factor that will be at the forefront of growers’ minds; carbon is a new addition to forestry, and it is uncertain how the price will change – especially in post-2012 protocols. If the price does not remain at a reasonably high level, then regimes that are dedicated largely to carbon sequestration will be very vulnerable. Also, if too many units are sold early in a rotation, and the price rises immediately prior to harvest, there may be insufficient revenue to purchase the units that need to be surrendered over the harvest period.

Lastly, it is necessary to address forest estate considerations. With medium and large forest companies, decisions are usually made not at the stand level – but at the estate level. The profitability of the entire forestry operation takes priority over the optimisation of individual stands. A mixture of species, regimes and age-classes could increase the quantity of carbon that could safely be traded, ie there could be strategies that maintain or enhance estate profitability while simultaneously reducing risk.

All these considerations have been included in the following study. Although the results are intended to have universal application (given that MAF was the principal client), to some extent certain scenarios are also tailored to apply to the special circumstances of the other major clients (Blakely Pacific and Proseed) who provided operational data for the project.

Approach

A class of Year Four students at the School of Forestry, University of Canterbury was tasked, as part of their Management Case Study, with optimising profitability under a range of inputs in a carbon-trading environment. It was envisaged that – when the same calculations are performed independently by a large number of teams – anomalous results would become conspicuous and, furthermore, a large number of independent minds could generate a range of useful insights. This report is both a summary of the students' work and an independent re-examination of the same factors that they used.

There were many thousands of combinations of all the possible inputs, even if each was limited to only three options (eg, good site, medium site and poor site); there were an infinite number of combinations if a continuous scale was employed (eg, rotation age, carbon price, discount rate). The strategy was to vary one input at a time in order to discover the sensitivity of profitability to each factor and to provide an overall understanding of how carbon changes forestry, and finally to choose a combination of those factors that would most likely give the best results. These would be tested at an estate level.

Although the purpose of the study was to assess management changes resulting from carbon, the process included a "zero carbon price" scenario. In other words, it also evaluated traditional forestry for the production of timber. Grades and prices for radiata pine were matched as closely as possible to published MAF prices (average of last 12 quarters). For details, refer to Appendix E3.

Land Expectation Value[2] was taken as the measure of profitability, except where the trees were already established or for estate-level analysis (in which case Net Present Value was used).

[2] Land Expectation Value (LEV) is a special case of the better-known Net Present Value (NPV) – it assumes a perpetual series of rotations on land that is currently bare of trees. It is the maximum that can be paid for land to achieve a given rate of project return.

Models that were used. For New Zealand's two major species (radiata pine and Douglas-fir), we had the great benefit of being able to use the so-called Calculators[3], which are capable of estimating carbon sequestration for both the first and subsequent rotations, in addition to other physical and financial details of stand growth. The Calculators were customised for the purposes of this study, as described in Appendix A. To incorporate other species a generic model was constructed (courtesy of Mark Kimberley and Peter Beets of Scion) which was capable of estimating carbon sequestration using the radiata pine allocation model C_Change, but using species-specific yield tables and density estimates. The data from these Calculators were transferred to purpose-made financial spreadsheets (Appendix B).

Discount rates. These were varied between 6%, 8% (base case) and 10%.

Carbon price. For an analysis of regimes in radiata pine, this was varied from $7.50/tonne of CO_2-e, to $15 (base case) to $30. For risk analysis, these were varied linearly and exponentially between $0, $30 (base case) and $250. A fixed cost ($60/ha/year) was assumed for the costs of measurement, auditing, registration and trading the carbon.

Rotation ages. These were varied between 10 and 25 years for *Eucalyptus nitens*, 25 and 40 years for radiata pine, and 40 and 60 years for Douglas-fir. The rotation age that gave the highest figure (LEV or NPV) was identified for later comparison.

Date of planting. For radiata pine, two planting dates were assumed: 1995 and 2008. The former was typical of the planting boom of the 1990s and would represent a situation where most of the sequestered carbon in the stand could not be traded and where the NZUs that could be generated might be required for surrender at harvest. (For the 1995 plantings the domestic and international "fast-forest fix" rule was applied). In contrast, 2008 represents the new-land planting scenario where all future carbon gains and losses must be taken into account.

Site quality. This was determined on a two-dimensional scale: using height index and volume index as listed in Table 1, together with corresponding latitudes and wood densities.

TABLE 1
Site quality features used

	Height Index[1]	Volume index[2]	Wood density[3]	Latitude
Good radiata	32.6	32.6	460	38
Average radiata	30.2	29.0	440	38
Poor radiata	23.7	18.2	420	44.5
Douglas-fir	31.3	18.4	418	42
E. nitens	25.6	n/a	472	n/a

1. Height index (or Site Index) is the MTH at age 20 for radiata pine, and 40 for Douglas-fir. The height at age 15 was used for *E. nitens*.
2. Volume index (m^3/ha/yr) for radiata pine used the 300 Index and for Douglas-fir the 500 Index.

[3] Green Solution Calculators were developed by Leith Knowles *et al* at Scion, Rotorua. They are proprietary to the Future Forests Research cooperatives (Radiata pine theme and Douglas-fir theme) and also to the Farm Forestry Association – both the *University of Canterbury School of Forestry* and *Piers Maclaren & Associates* are registered users. Last-minute adjustments were required to be made to these Calculators, in consultation with Mark Kimberley of Scion, to reliably incorporate and fine-tune carbon prediction.

3. Wood density (kg/ m^3) for outerwood at breast height at age 20 (radiata) and age 30 (D-fir) or for whole tree at age 12 (*E. nitens*)

The Average site for radiata pine represents an average New Zealand ex-farm site, Good sites were assumed to be ex-farm sites from the Central North Island, and the Poor Site was typical of South Canterbury. The Douglas-fir site is an average New Zealand site, while the *Eucalyptus nitens* site is a good Southland site. The indices for all radiata and Douglas-fir site types were extracted from the national PSP table that is included in the Calculators. Indigenous sequestration was taken be 3 tonnes CO_2-e per hectare per year as assumed in the proposed ETS regulations.

Silviculture. Three standard regimes were developed for radiata pine (clearwood, framing, plant & leave) following an initial analysis that considered the following factors one at a time:

- **Initial stocking.** This was varied from 800 to 1150 (base-case) to 2000 stems/ha for radiata pine, but students were allowed to investigate further outside this range.

- **Timing of thinning.** This was varied between Mean Top Height of 8 m (early thin) and MTH of 14 m (late thin).

- **Pruning**. Variations with and without pruning were evaluated. For simplicity, pruning was mostly constrained to a two-lift regime and the timing calculated on the basis of DOS while maintaining an adequate green crown.

- **Final crop stocking.** The nominal final crop stocking (ie stocking after thinning, excluding natural mortality) was varied from 250, 375 (base-case) and 600 stems/ha, but students were encouraged to investigate further. Indeed, many regimes did not include thinning and therefore the actual final stocking was a function of the initial stocking and the expected mortality, which in turn depended greatly on site and rotation age.

Genetic deployment. It was assumed that radiata pine breeds were available that could provide an increase of 5% in terms of 300 Index and 6% in terms of age 10 wood density, and the objective was to calculate the breakeven cost of planting stock for the superior genotypes.

Alternative trading systems. The standard case involved trading carbon annually as it is sequestered, and surrendering the required units at harvest. Alternatives investigated were "trading only up to minimum long-term carbon stocks" (ie to the level retained on site after harvest, thus requiring no surrender of units); and "trading up to the long-term average for a normal forest" (ie trading the carbon in a stand as if it were part of a "normal" forest).

Estate considerations. Students were given free rein to investigate combinations of species, rotation ages and regimes that would maximise the revenue from both carbon and timber while minimising risk. Suggested options included:

- ❖ Planting the entire estate simultaneously in a single regime or species;
- ❖ Planting successively to end up with a "normal" forest;
- ❖ Planting the entire estate simultaneously (or in blocks), but achieving normality by harvesting;
- ❖ Planting a mixture of species or regimes;
- ❖ Planting without any intention of harvest.

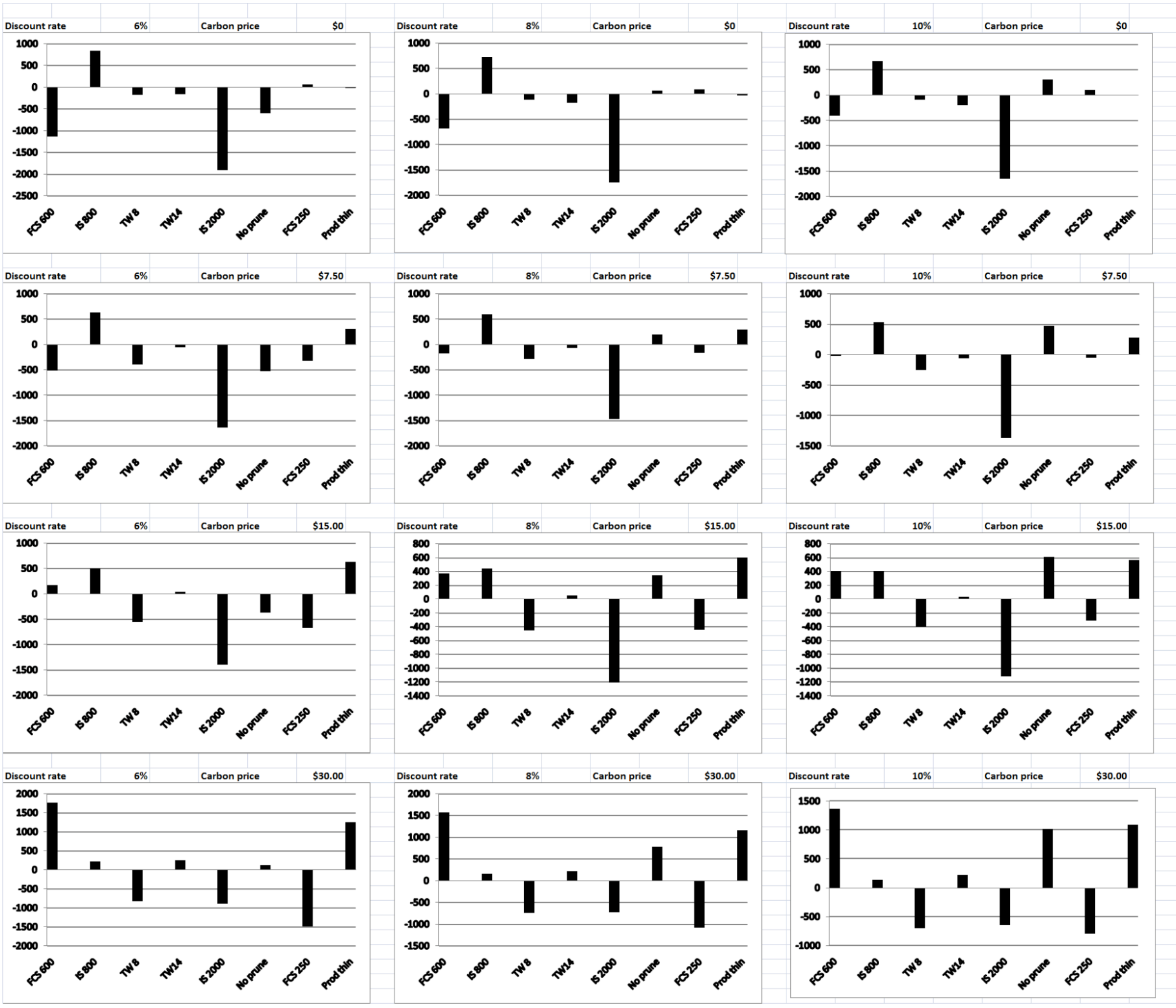
Results

a) Initial examination of silviculture for radiata pine

The base-case regime (Plant 1150 stems, prune in 2 lifts to 6.5 m, thin at MTH 11 m to 375 stems/ha – see Appendix C for details) was varied in regime details. The results are listed in Appendix D and summarised in Figure 1.

FIGURE 1

Changes in LEV caused by regime variations (all for average site) for different combinations of discount rate (6%, 8%, 10%) and carbon price ($0, $7.50, $15, $30/t CO_2-e)



Code:

FCS 600	Nominal final crop stocking of 600 stems/ha
IS 800	Initial stocking of 800 stems/ha
TW 8	Thinning to waste at MTH of 8 m
TW 14	Thinning to waste at MTH of 14 m
IS 2000	Initial stocking of 2000 stems/ha
No prune	Pruning is omitted but thinning is as normal
FCS 250	Nominal final crop stocking of 250 stems/ha
Prod thin	Production thinning at MTH of 20.5 m

Initial stocking

Reducing the initial stocking to 800 stems/ha from the base-case (1150 stems/ha) improves the profitability in all situations, but the advantage becomes less significant with higher carbon prices. This is because it reduces costs in the base-case regime. On the other hand, carbon benefits are linked to high biomass volumes, which is loosely associated with higher stockings. Likewise, increasing the initial stocking to 2000 stems/ha is an unprofitable move under non-ETS conditions, but less so with very high carbon prices.

Final crop stocking

In the absence of carbon trading, final stocking can be profitably reduced from the base-case (375 s/ha) to 250. The carbon benefit of higher volumes, however, negates the advantages of this move. Similarly, a very high final stocking of 600 s/ha is normally unprofitable but becomes increasingly profitable at even modest carbon prices.

Timing of thinning

In all situations, it is unprofitable to thin at MTH of 8 m (compared with the base case of about 12 m MTH). This unprofitability is accentuated with carbon price, because extra-early thinning reduces stand volume. Conversely, delayed thinning (MTH of 14 m) is also normally unprofitable but becomes worthwhile with rising carbon prices.

Presence or absence of pruning

Pruning is normally a profitable activity at low discount rates. With rising carbon prices, however, reductions in stand volume make it increasingly unprofitable.

Production thinning

Given the assumptions used in this study (namely that production thinning revenues would exactly cover costs) and in the absence of any income from carbon, production thinning is normally a slightly unprofitable activity. But as carbon prices rise the effect of delayed thinning makes it become an increasingly valuable option.

B) Species and Regimes

Following the initial evaluation three standard regimes were specified for radiata pine to represent contrasting silviculture:

- **Clearwood** (Plant 800 stems/ha, prune to 5.5 m in 2 lifts, thin to 250 stems/ha at age 7.8 years).
- **Framing** (Plant 800 stems/ha, thin to 375 stems/ha at age 7.8 years).
- **Plant & leave** (Plant 800 stems/ha, no thinning).

Regimes adopted for other species:

- **Douglas fir** (Plant 1650 stems/ha, thin to 500 stems/ha at age 15).
- **Eucalyptus nitens** (Plant 900 stems/ha, no thinning).
- **Indigenous (regenerating shrubland)**

The LEV values for six combinations of species and regimes (Appendix C), at four carbon prices, and three discount rates are given in Table 2. Figures in brackets are optimum rotation ages. The "zero dollars scenario" assumes that no carbon trading is taking place, ie there are no carbon measurement and transaction costs.

TABLE 2

The LEV ($/ha) of forestry (revenue from timber plus carbon) for different species/regimes (on an average site)

(figures in brackets are optimum rotation ages)

Price of carbon	$0.00			$10.00			$20.00			$30.00		
Discount rate	6%	8%	10%	6%	8%	10%	6%	8%	10%	6%	8%	10%
Radiata – clearwood	4117 (25)	1215 (25)	-241 (25)	5484 (27)	2386 (25)	784 (25)	8114 (33)	3378 (26)	2473 (26)	10,903 (33)	6647 (30)	4254 (29)
Radiata – framing	3054 (25)	863 (25)	-247 (25)	5064 (25)	2565 (26)	1217 (25)	8403 (31)	3866 (29)	3417 (29)	12,132 (40)	8201 (36)	5810 (36)
Radiata – plant/leave	2417 (31)	421 (27)	-480 (25)	5801 (33)	3166 (31)	1715 (31)	10,642 (40)	5009 (35)	4798 (35)	15,715 (40)	11,038 (40)	8,076 (40)
Euc. nitens	-451 (20)	-1193 (19)	-1562 (18)	1642 (25)	287 (23)	58 (22)	4963 (25)	2641 (25)	2566 (25)	8285 (25)	6427 (25)	5076 (25)
Douglas-fir	384 (40)	-1917 (40)	-2817 (40)	1148 (43)	-1814 (44)	-2454 (40)	3030 (45)	-757 (44)	-1431 (40)	4959 (47)	1359 (44)	-396 (42)
Indigenous	-	-	-	374	281	225	748	562	450	1496	1124	900

Note: LEV was modelled across a limited range of rotation lengths as described elsewhere. Where the LEV occurs at the extreme of this range, it is possible that the optimum age might be outside the range and therefore under- or overestimated.

Stands grown for timber only

Where the price of carbon is zero, the most profitable species/regimes are, in order: radiata pine grown on a clearwood regime, radiata pine grown on a framing regime, radiata pine with a plant-and leave regime, *Eucalyptus nitens* and Douglas-fir. (Douglas-fir is more profitable than eucalyptus if a very low discount rate is used; Indigenous forestry was assumed not be sold for timber and so it earns no revenue). Of these, only the first two were capable of paying more than $3000/ha for land, and even then only at the low discount rate of 6%. Douglas-fir and eucalypts were unprofitable at any realistic land price or discount rate.

For radiata pine and Douglas-fir, the optimum profitability was mostly at the earliest rotation age allowed.

Stands grown for both timber and carbon

Revenue from annual sales of carbon units greatly increases the profitability of all species and regimes. Indeed, if the price reaches $30 then all investments are capable of paying $3000/ha and still achieving an 8% or even a 10% rate of return (except for Douglas-fir and indigenous forestry where the return is still low, but low prices for land suitable for those species could perhaps compensate). Indeed, the land-price hurdle (assuming 8% real rate of return) could be overcome by the following carbon prices:

Clearwood regime – need a $13.08/t CO_2-e price to afford to pay $3000/ha
Framing regime – need $11.70/t
Plant-and-leave – need $9.55/t

Note that there is a crossover of profitability with increased carbon price and discount rate. The order of profitability described in the timber-only section (ie using zero carbon price and a low discount rate) is substantially altered at a combination of very high carbon price and discount rate: the most profitable option is radiata pine plant-and-leave, followed by radiata framing, *Eucalyptus nitens*, radiata clearwood, indigenous reversion and finally Douglas-fir. Crossover points occur at the following prices (assuming 8% discount rate):

Plant-and-leave passes framing when carbon reaches $5/t CO_2
Plant-and-leave passes clearwood when carbon reaches $6/t CO_2
Framing passes clearwood when carbon reaches $7/t CO_2
Eucalypt passes clearwood when carbon reaches $34/t CO_2

Rotation age

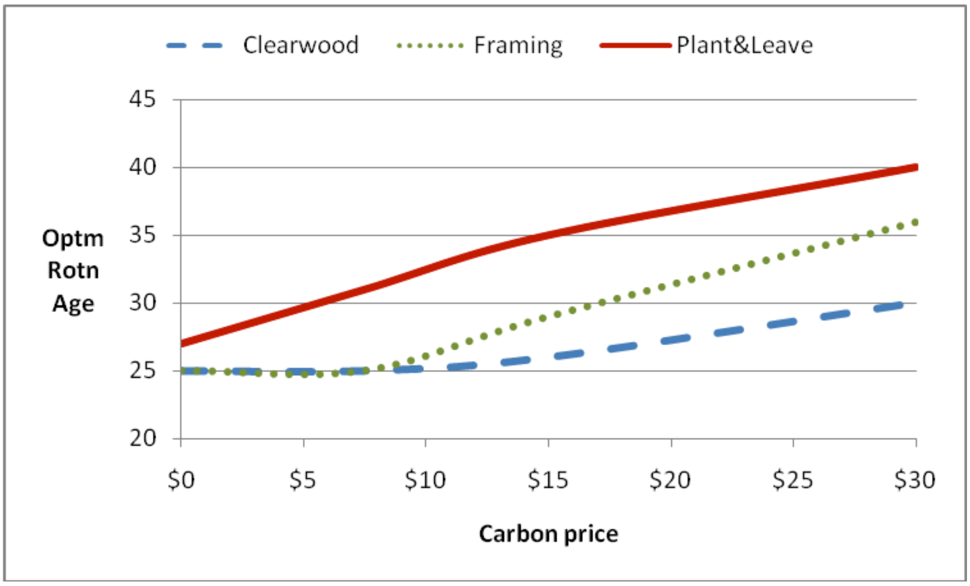
There are very clear, consistent trends in rotation age to be seen in Table 2. As is well known from many previous studies, optimum rotation age declines with increased discount rate (high discount rates favour early returns). The more recent result is that an increased price for carbon lengthens rotations, sometimes greatly.

Figure 2 illustrates the shallowness of the peak – there is a "plateau of profitability" whereby a small change in inputs will greatly affect the optimum age.

As the carbon price increases, there is a lengthening of optimum rotation length – which can become substantial at the highest prices, lengthening rotations by 15 years or more. The trends towards increased rotation length with rising carbon prices are illustrated in Figure 3. These are for specific situations (average site, 8% discount rate) but apply across the spectrum of possibilities.

FIGURE 2
Optimum Rotation Age for three radiata regimes on an average site with a $15/t carbon price and 8% discount rate

FIGURE 3
Optimum rotation ages for 3 radiata regimes (at 8% discount rate) for different carbon prices



c) Stands planted in 1995

For stands planted in 1995, the NPV values for three standard radiata pine regimes, four carbon prices, and three discount rates are given in Table 3.

TABLE 3

For stands planted in 1995, the NPV ($/ha) of forestry (revenue from timber plus carbon) for three standard regimes on average site (figures in brackets are optimum rotation ages)

Price of carbon	$0.00			$7.50			$15.00			$30.00		
Discount rate	6%	8%	10%	6%	8%	10%	6%	8%	10%	6%	8%	10%
Radiata – clearwood	15052 (25)	10792 (25)	8118 (25)	15568 (26)	11459 (25)	8893 (25)	17250 (27)	12936 (25)	10328 (25)	21101 (30)	16217 (30)	13264 (27)
Radiata – framing	11068 (25)	7891 (25)	5901 (25)	11948 (26)	8870 (25)	6963 (25)	14006 (29)	10694 (26)	8686 (25)	18679 (36)	14859 (31)	12469 (29)
Radiata – plant/leave	9265 (31)	6201 (27)	4560 (25)	11254 (31)	8044 (29)	6207 (25)	14384 (33)	10919 (31)	8817 (31)	21739 (40)	17481 (40)	14800 (40)

Regardless of the price of carbon, there is limited scope for changing already-established stands. With the exception of rotation age, there is no point in examining regime variations (initial stocking, timing of thinning, etc). There are only two decisions to make: whether to register for the ETS, and if so, whether to extend the rotation.

Table 3 provides answers to both these questions: firstly, it indicates that "opting in" is indeed a profitable decision (except possibly for the cashflow factor to be discussed later); and secondly that rotations may increase by as much as fifteen years depending on the regime, carbon price and discount rate. Increases in rotation length tend to be less than those for 2008 planting.

Net Present Value is given here because Land Expectation Value applies only to bare land. Without carbon, it can be seen that the value of the existing forest , including the crop value and the land price, ranges from $15,052 per hectare (for a clearwood regime at a low discount rate) to a modest $4,560/ha (high discount rate, plant-and-leave regime). The latter figure is not substantially greater than the price of bare land, despite the crop being 13 years old. In contrast, assuming annual trading for carbon sequestration, "opting in" to the scheme offers substantial benefits to growers of existing Kyoto-compliant stands. In terms of Net Present Value, it can be seen that the gain could amount to $10,000 or more. This would provide a major boost to forest values.

d) Site quality

For three different site qualities, the LEV values for four carbon prices and three discount rates are given in Table 4. Figures in brackets are optimum rotation ages. The radiata clearwood regime is used here as it is the most common existing regime in New Zealand, but the same trends occur with other regimes. Two lifts are used but the timing of the pruning and the DOS sizes attained vary with the site quality (as a result of both 300I and SI). Regime details are provided in Appendix C.

TABLE 4

The LEV ($/ha) of forestry (revenue from timber plus carbon) for radiata pine clearwood regime on three site qualities

(figures in brackets are optimum rotation ages)

Price of carbon	$0.00			$7.50			$15.00			$30.00		
Discount rate	6%	8%	10%	6%	8%	10%	6%	8%	10%	6%	8%	10%
Good site	5767 (25)	2116 (25)	271 (25)	6900 (25)	3519 (25)	1217 (25)	9094 (26)	5050 (25)	2823 (25)	13,835 (30)	8882 (28)	6049 (26)
Avg site	4117 (25)	1215 (25)	-241 (25)	4855 (25)	1883 (25)	357 (25)	6753 (29)	3378 (26)	1615 (25)	10,903 (33)	6647 (30)	4254 (30)
Poor site	634 (25)	-938 (33)	-1549 (30)	718 (38)	-960 (33)	-1634 (33)	1906 (39)	-116 (38)	-1015 (33)	4378 (40)	1708 (40)	334 (39)

Table 3 demonstrates that even on a good site a superior radiata pine clearwood regime cannot afford to pay $3000 per hectare and still make 8% real return on the investment – unless carbon is included. A poor site cannot justify the cost of land at any positive value, given a discount rate of 8% or higher. But a combination of high carbon prices and a low discount rate enables even the poor sites to easily overcome the $3000 threshold. At such a combination a good site can afford to pay prices similar to those currently being paid for dairy conversion (ie >$10,000/ha).

Note how the rotation ages tend to be longer for poorer quality sites as well as for lower discount rates and higher carbon prices.

e) Genetic deployment

Wood density does not increase the LEV of forestry via increased revenues in timber, because density is not included in the log specifications used. In contrast, an increase in productivity improves both the quantity and the value of harvested wood. When payment is added for carbon sequestration, both density and productivity are advantageous with the latter generating 60% or more of the gain in LEV. The lower the price of carbon, the greater the importance of productivity as opposed to wood density. These behaviours are all clearly apparent in Table 5.

TABLE 5

The LEV ($/ha) gain through genetic improvement as a result of increased productivity and/or wood density. (Clearwood regime on average site).

Price of carbon	$0.00			$7.50			$15.00			$30.00		
Discount rate	6%	8%	10%	6%	8%	10%	6%	8%	10%	6%	8%	10%
Base case	4117	1215	-241	4861	1891	363	6762	3392	1627	10,903	6647	4254
300I: +5%	4621	1489	-87	5451	2282	621	7439	3886	1988	11,735	7302	4782
WD: + 6%	4117	1215	-241	4965	1970	428	6994	3557	1758	11,421	7036	4560
Both	4621	1489	-87	5553	2367	691	7671	4055	2129	12,253	7706	5092

The increase in revenue resulting from genetic improvement means that growers can afford to pay more per plant and end up with the same LEV. With the genetic improvement, iteration was used to increase the establishment costs until the LEV coincided with the base case. A back-calculation of these shadow establishment costs showed the increase in prices in Table 6 that could be afforded per seedling with genetic improvement. This result assumes an average site and a discount rate of 8%, and a density measurement age of 10 years.

TABLE 6

Increase in price of seedlings (cents) that could be afforded as a result of genetic improvement (for a clearwood regime on an average site (at 8% discount rate)

Price of carbon	$0.00	$7.50	$15	$30
Base case	0	0	0	0
300I: +5%	29	42	53	74
WD: + 6%	0	8	18	45
Both	29	51	71	120

f) Risk

The profitability of forestry increased with a rising carbon price, no matter whether it was rising linearly or exponentially. “Opting in” was worthwhile even if carbon prices decline to zero. The risk of “opting in” is dictated not by the future price of carbon, but by other factors: the liability associated with unpredicted carbon loss (not all of which is insurable, such as disease-induced risk); cash-flow constraints; and the choice of a regime which may be sub-optimal or valueless if the price of carbon collapses. The risks can also go the other way: a grower may be locked into a species or regime which is sub-optimal if the price rises, but the former situation is more likely to cause concern.

A plant-and-leave regime is distinctly superior to any other radiata regime, given even a modest price for carbon, but a fall in the carbon price creates a second-rate crop. Unlike a framing regime, it has not been thinned so piece-size is lower than sawmillers would prefer. Moreover, the tall spindly trees would be very unstable and liable to windthrow.

A similar dilemma concerns pruning: pruning is a disadvantage in a high-carbon, low-clearwood price environment but if the relativity of these prices should reverse, there is no going back.

Unlike other types of risk normally encountered in business, this one has a unique feature: the probability of a given price level cannot be calculated from the track-record of the historic price because it is a totally new commodity.

The key component of risk which appears to exercise the minds of prospective participants in the ETS is the necessity to surrender units at harvest corresponding to the fall in carbon stocks. To quantify this risk in order to compare regimes, we devised a *Risk Index* whereby:

"The Risk Index is the ratio of the value of units that must be surrendered at harvest relative to the value of the harvested wood"

A risk index of greater than 100%, for example, might place a forest grower in an invidious cashflow position necessitating borrowing. Table 7 illustrates the trade-off between profitability and risk, using the risk index as a guide.

TABLE 7
The inverse correlation between profitability and risk
(at 8% discount rate)

	$0/t CO_2			$30/t CO_2		
Regimes	Max LEV	Rotation	Risk (%)	Max LEV	Rotation	Risk (%)
Clearwood	1215	25	0	6647	30	47
Framing	863	25	0	8200	36	70
Plant & Leave	421	27	0	11,038	40	80
Douglas-fir	-1917	40	0	1359	44	30
E. nitens	-1193	19	0	6427	25	162

Table 7 illustrates the gain that can be achieved by switching from a clearwood regime to a framing regime or – even better – to a plant-and-leave regime, but the table also indicates that the risk rises from 47% to 70% to 80%.

The risk from Douglas-fir is very low (30%) but the returns are also very low. The risks from eucalypts are extremely high (162%) but the profitability is still low in comparison to a radiata crop. This suggests that estate-modelling portfolios that incorporate Douglas-fir would reduce the overall risk, but at considerable cost. On the other hand, there would be no advantage in adding eucalypts to the mixture of radiata pine because risk would be greatly increased with no benefit to profitability.

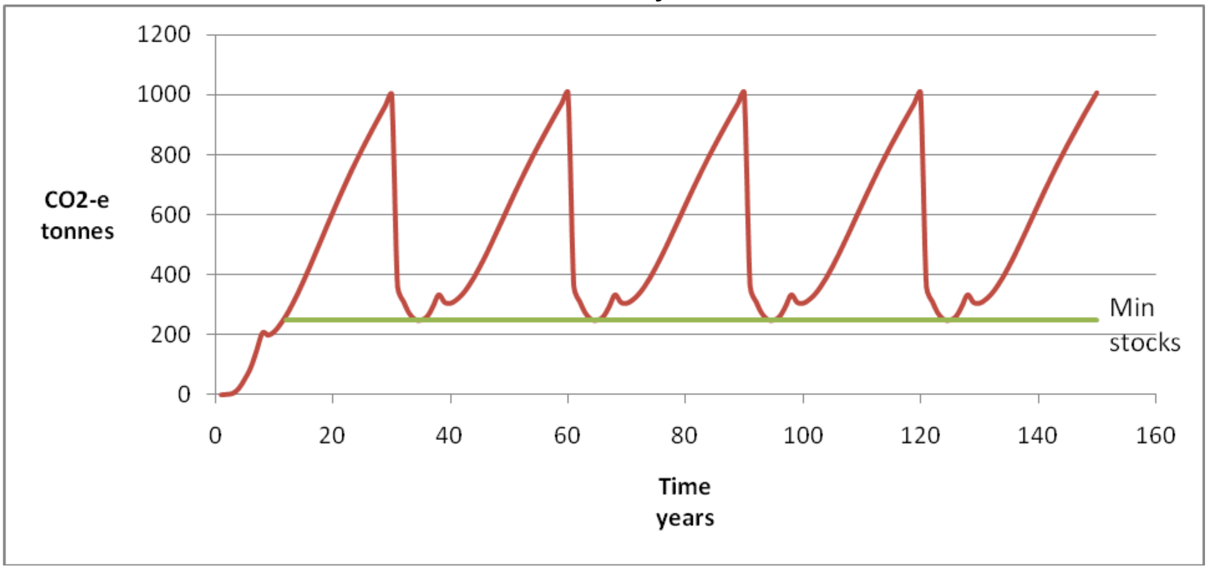
g) Alternative carbon trading strategies

The grower may choose to sell credits in the year they were sequestered. Alternatively, a proportion could be retained to use at harvest, or to mitigate other types of risk. (For example, another type of risk is that the standing carbon stocks decline as a result of fire or disease).

The grower might decide to sell only up to the minimum level of stocks that is likely to be present over the long term (Figure 4). This can be expressed as the carbon remaining in roots, stumps and slash after harvest. Selling such credits has a very low risk because at least that level of carbon[4] is likely to persist throughout a cycle of successive rotations. The *risk index* in this strategy would be zero, because no credits must be bought following harvest.

FIGURE 4

Carbon stocks (tCO2-e) for a radiata pine clearwood regime on a 30-year rotation showing the minimum level of stocks

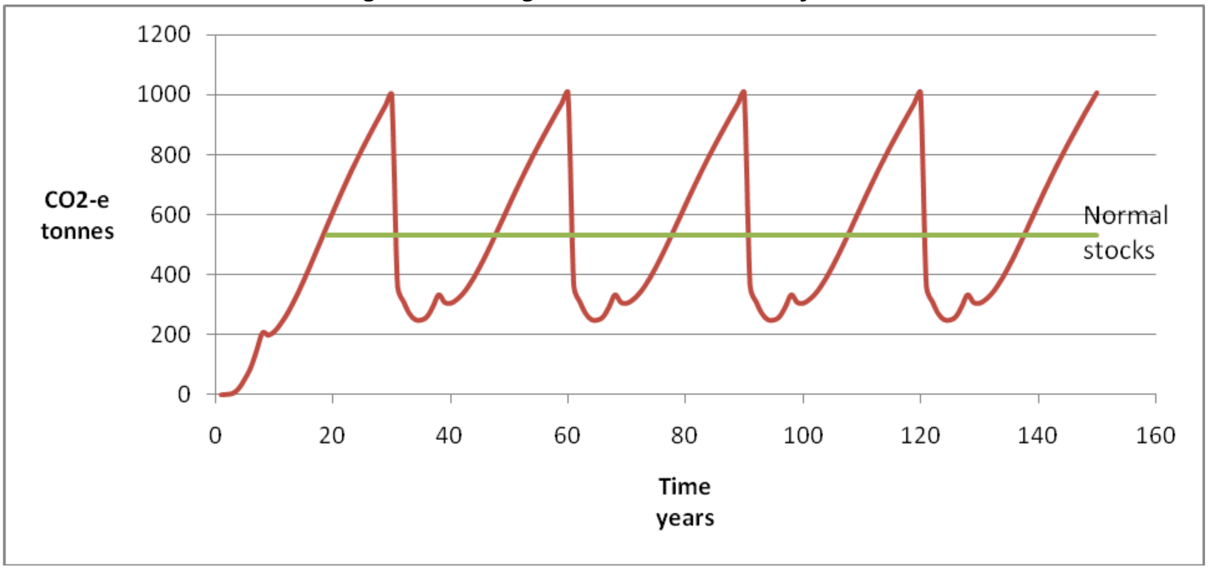


Another approach might be to trade an amount that is intermediate between the maximum achieved immediately prior to harvest and the previously described "minimum stocks" level (Figure 5). In the expectation that there may be a succession of new plantings following an initial planting, an owner might plant a stand with the confidence to trade carbon up to the forest's steady-state level – a "normal" forest in the jargon.

[4] The minimum level of carbon does not occur immediately following harvest, but a few years later as a result of decay. Growth of the replacement trees eventually compensates for – and then overtakes – this decay loss. The point in a rotation where this minimum level is reached is typically about age 5 in a clearwood stand.

FIGURE 5

Carbon stocks (tCO2-e) for a radiata pine clearwood regime on a 30-year rotation showing the "long-term average" or "normal" level of stocks



A normal forest is carbon-neutral: in other words, harvest liabilities in the oldest stand are counter-balanced by sequestration in all the other stands (Figure 6). If successive plantings failed to eventuate, the grower of the intended normal forest would incur harvest carbon-liabilities (but less than for the sell annually strategy), but receive less than the maximum credits payable.

FIGURE 6

Stylised image of a normal forest where the carbon loss from the oldest stands (undergoing harvest) is counter-balanced by the carbon gains in all the other stands

Table 8 illustrates these options for an average site, established in a clearwood regime. The normal forest option was not evaluated for 1995 plantings because this option is not available for these stands; ie, the opportunity to plant in 1996, 1997, 1998… has gone.

TABLE 8

NPV/LEV ($/ha) for Various carbon-trading strategies

Price of carbon	$0.00			$7.50			$15.00			$30.00		
Discount rate	6%	8%	10%	6%	8%	10%	6%	8%	10%	6%	8%	10%
1995												
Sell annually	15,036	10,778	8017	15,533	11,428	8870	17,202	12,887	10,293	20,703	16,109	13,230
Sell up to min stocks	15,036	10,778	8017	15,036	10,778	8107	15,036	10,778	8107	15,036	10,778	8107
2008												
Sell annually	4117	1215	-241	4829	1857	327	6731	3343	1591	10,903	6647	4254
Sell up to min stocks	4117	1215	-241	4035	1258	-149	5061	2145	639	7030	3927	2215
Sell up to normal	4117	1215	-241	4711	1760	241	6462	3149	1419	10,039	6092	3810

A few obvious results can be seen from Table 8: carbon trading strategies are irrelevant if the price of carbon is zero – the figures are the same for each strategy for a given year of planting. Secondly, the carbon price is irrelevant in 1995 stands if the "sell up to minimum stocks" option is chosen, because this level has already been exceeded. Thirdly, for 2008 annual trading yields the highest profit, followed by selling up to the normal forest average, and lastly selling up to minimum stocks.

Less obvious results are that while there is a substantial profitability drop by adopting the most risk-averse strategy (minimum stocks); the loss from trading only up to the average of a normal forest is relatively trivial. This is because the revenue from forgoing the full amount of carbon credits occurs in the latter part of the rotation, and its effects are diminished by the discount rate.

Given a hypothetical $3000/ha price for forestry land, it can be seen that several of the options are profitable for 2008 new-land planting, depending on the exact carbon price and choice of discount rate. In particular the almost risk-free "minimum stocks" option becomes profitable at 8% discount rate and $30/t carbon price. This is likely to hold great appeal for risk-averse growers, despite the considerable loss of revenue from carbon sales relative to annual trading.

Growers in the middle of the risk-averse spectrum may prefer to choose to sell up to the normal forest – they would lose only a small proportion of their profit, and incur only a modest cash-flow risk (and no risk if they maintain planting to develop a normal forest).

Figure 7 illustrates the cashflow profile of a 30-year rotation of radiata pine grown on a clearwood regime, with annual carbon trading at $30/t CO_2-e. In the first rotation, it can be seen that there is generally a positive cashflow, except for the establishment and silvicultural periods. There is a large boost in revenues following harvest, with a negative cashflow following harvest and for the subsequent 5 years. The cashflow deficit following harvesting should not be a problem provided that there is careful budgeting – the revenue from the sale of timber greatly exceeds the carbon liabilities with this regime, so the money can be used to purchase the credits required later. Note that this favourable situation applies only to the clearwood regime, and to the carbon price of $30/t, because in this case the timber revenues from harvest exceed the carbon liabilities after harvest.

FIGURE 7

Cashflow profile for a 30-year clearwood stand, with annual trading at $30/t

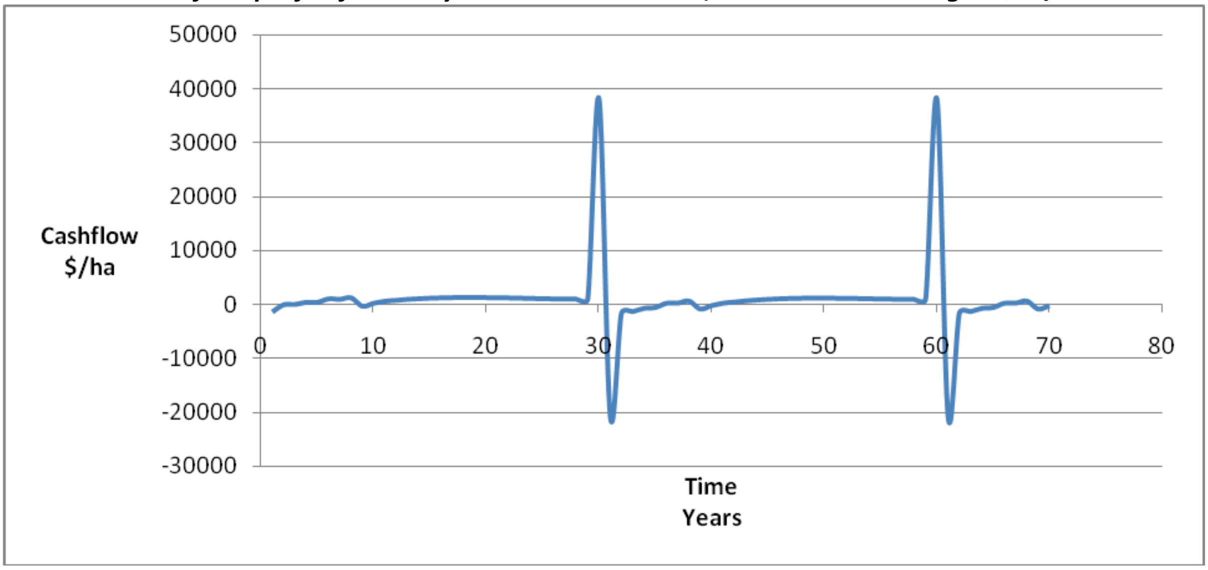
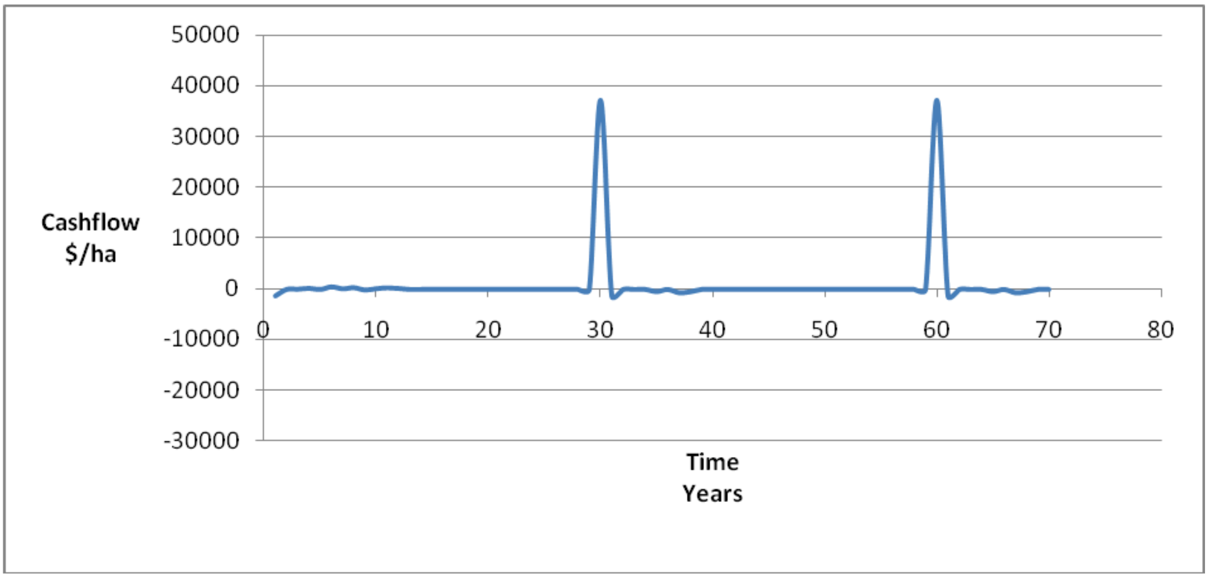


Figure 8 illustrates the cashflow profile of a similar stand, where carbon is traded only up to the minimum level of carbon stocks. It can be seen that cashflow is generally positive. As previously stated, banking the carbon credits in excess of this level implies that there is no subsequent carbon liability.

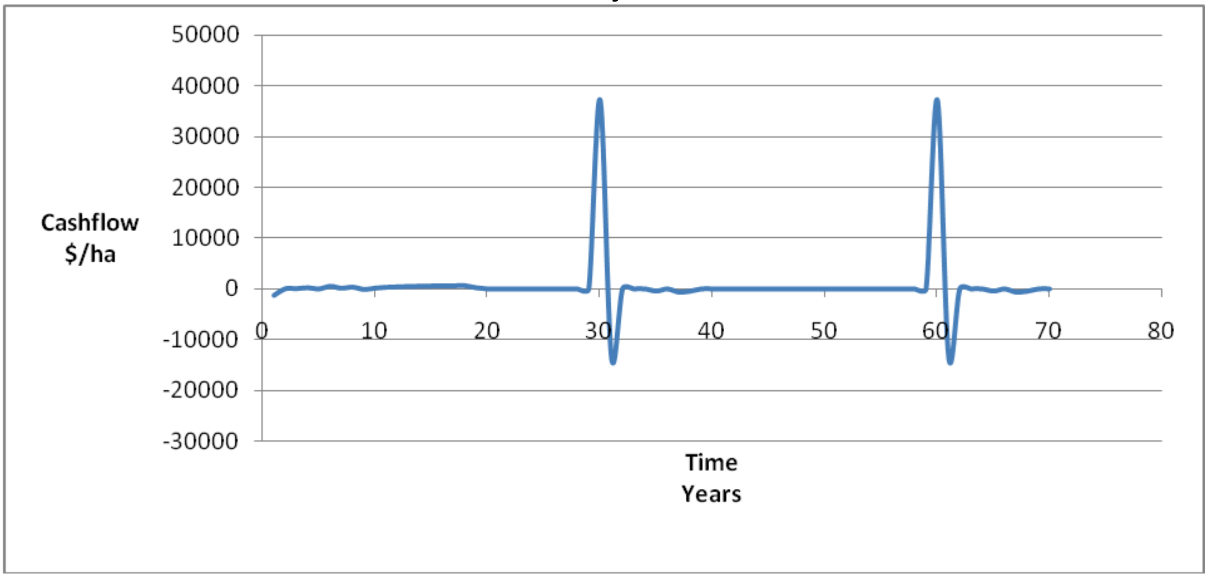
FIGURE 8

Cashflow profile for a 30-year clearwood stand, with trading only up to the level of minimum stocks



The compromise position, ie where trading is up to the level reached in a normal forest, is illustrated in Figure 9. It includes a slight cashflow advantage (relative to Figure 8) from years 12-19 in the initial rotation, and a lower harvest liability (relative to Figure 7). There would be no harvest liability if planting continued to create a normal forest – the increase in carbon stock in other stands would offset the reduction in carbon stock in the stand being harvested.

FIGURE 9
Cashflow profile for a 30-year clearwood stand, with trading only up to the level reached in a normal forest



h) Estate modelling strategies

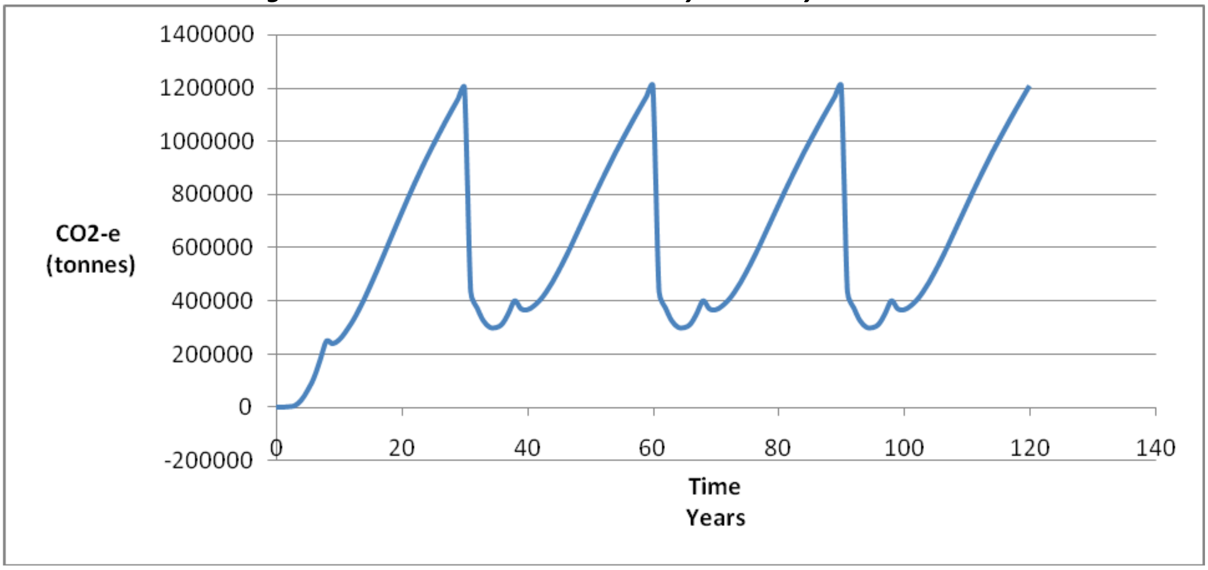
Alternative strategies were evaluated for a 1200 ha estate. It was assumed that all land was purchased in 2008 at a cost of $3000/ha. The surrender index calculated at the estate level differs from the risk index used at the stand level. Surrender index is defined as the percentage of the cumulative credits received that have to be surrendered – it is calculated using the initial high point in carbon stocks and the subsequent low point.

Planting and harvesting the entire estate simultaneously in a single regime or species

The outcomes of this option are exactly equivalent to stand-level evaluations, as given earlier, but scaled up by 1200 ha. They are useful merely for comparison. For example Fig 10 shows the total carbon stocks for the clearwood regime under this strategy. It has the same shape as Figures 4 and 5. The surrender index is calculated using the initial high point in carbon stocks (1.2 million t CO_2-e) and the subsequent low point (0.3 million t CO_2-e); ie, 0.9 out of the 1.2 million tonnes (75%) have to be surrendered.

FIGURE 10

Carbon stocks (tCO2-e) for 1200 ha estate planted simultaneously with a radiata pine clearwood regime and harvested simultaneously on a 30-year rotation



None of the species/regime combinations have a positive NPV at an 8% discount rate when only forestry is considered (Table 9). However with carbon at \$30/t CO_2-e, only Douglas-fir fails to have a positive NPV. Trading to the long-term minimum removes the risk of carbon surrender on harvest but causes a large reduction in NPV.

TABLE 9

NPV under various carbon-trading strategies
for different species/regimes when 1200 ha estate is planted and harvested simultaneously
(Using \$30/t carbon price and 8% discount rate)

	Don't trade	Trade carbon every year		Trade to long-term minimum	
Regimes	NPV (\$ million)	NPV (\$ million)	Surrender index (%)	NPV (\$ million)	Surrender Index (%)
Clearwood	-2.14	4.38	75	1.15	0
Framing	-2.56	6.24	77	1.20	0
Plant & leave	-3.09	9.65	77	2.57	0
Douglas fir	-5.90	-1.97	86	-4.88	0
E. nitens	-5.03	4.11	73	-0.59	0

In practice, it is rarely possible to deploy sufficient resources to establish a large area of forest in a single year. There are constraints imposed by cashflow, labour, planting stock, capital equipment and expertise. These re-occur throughout the rotation and subsequent rotations as further operations are scheduled (releasing, pruning, thinning, harvesting).

Planting successively to end up with a "normal" forest

If a 30-year rotation is assumed, then one thirtieth of the estate can be planted every year. Once harvest has begun, there will be no liabilities because the carbon loss from the oldest stand undergoing harvest will be exactly compensated by the carbon gain from the total of the immature stands. This situation can continue indefinitely.

The advantages of planting a normal forest estate are obviously that the cashflow risk from carbon liabilities after harvesting is removed – the surrender index is 0 (Figure 11 – there is no change in carbon stocks once normality has been achieved). The disadvantages include the fact that much of the land has not been occupied by trees for most of the first rotation. We assumed that unoccupied land was rented for pasture at $150/ha/yr: if the profitability of trees exceeds this level, then there has been some economic loss in not planting trees. (And if it does not, then it would be irrational to plant the trees at all!)

FIGURE 11

Carbon stocks (tCO2-e) for 1200 ha estate planted successively over 30 years with a radiata pine clearwood regime to end up with a "normal" forest

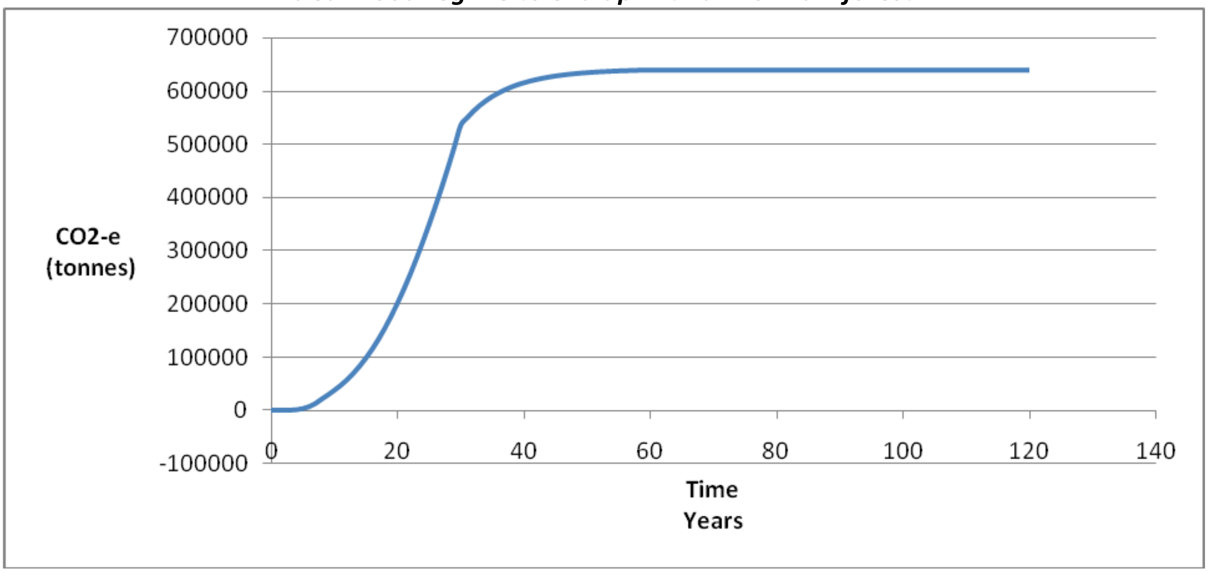


TABLE 10

NPV for different species/regimes when 1200 ha estate is (a) planted successively to end up with a "normal" forest; or (b) the estate is planted in blocks and normality is achieved by harvesting

(Using $30/t carbon price and 8% discount rate)

	Normal forest via planting		Normal forest via harvesting	
Regimes	NPV ($ million)	Surrender index (%)	NPV ($ million)	Surrender Index (%)
Clearwood	1.08	0	2.46	10
Framing	1.43	0	3.01	0
Plant & leave	2.31	0	4.16	0
Douglas fir	-1.41	0	-1.73	22
E. nitens	1.27	0	1.69	0

Table 10 shows that the establishment of a normal forest by planting greatly reduces risk but does so at a cost in terms of NPV compared to planting all area at once (Table 9) because of temporarily unplanted land.

Plant the entire estate simultaneously (or in blocks), but achieve normality by harvesting

The problem of unoccupied land identified in the preceding section can be overcome by planting the entire area simultaneously and achieving normality by varying the timing of harvest.

This strategy can be illustrated by a simple example. Assume that the optimum rotation age for radiata pine on a given site is 30 years, but the species can be harvested anytime between 25 and 54 years without great economic loss. The entire estate could be planted out at once, and harvesting commenced at age 25 on $1/30^{th}$ of the area. Every year thereafter, a further $1/30^{th}$ is felled and replanted. After 54 years, therefore, an estate is developed where each annual age-class is equally represented and the entire forest is normalised on a 30-year rotation. After age 54, there is no carbon gain, nor any carbon loss. The forest is carbon neutral and therefore risk-free (at least in terms of the liability associated with surrendering credits at harvest).

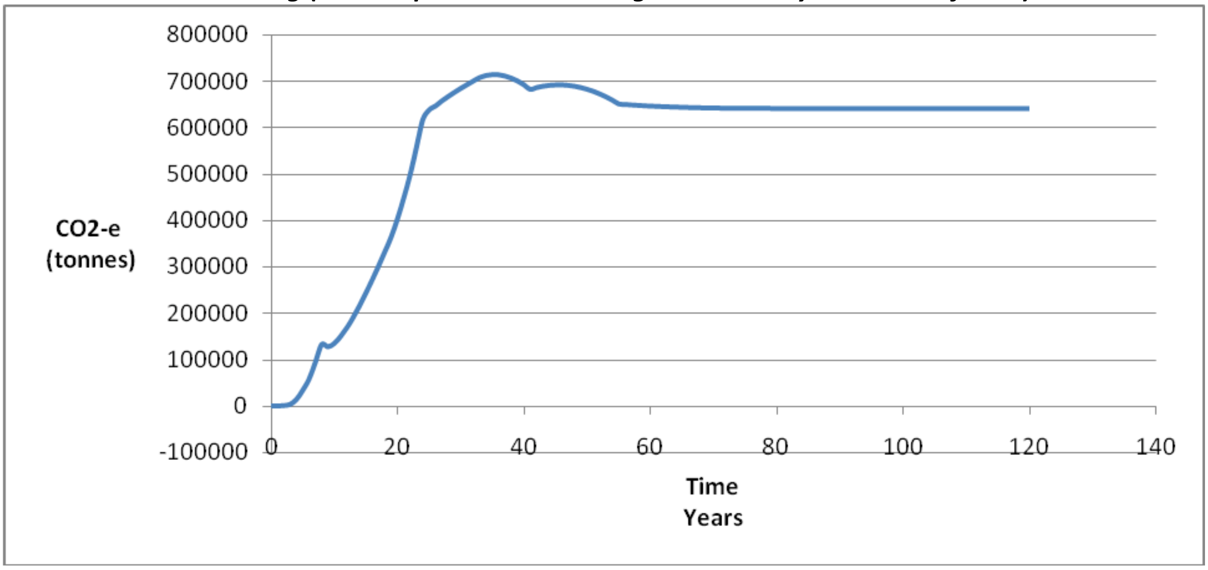
This simple strategy presupposes that there is a wide range of near-optimum harvest ages available with the species or regime, so that no great economic loss results from the fluctuations in harvest age that will occur until normality is reached. For example, a sceptic may well argue that 54 years is too long to delay harvest for radiata pine, and that the real economic limits of rotation age lie between 25 and 40 years.

A compromise solution that will achieve a normal forest in only two rotations involves manipulations in both planting and harvesting dates. For example, 16/30 of the forest could be established immediately with the remaining 14/30 established in 16 years time. The initial planting would be harvested, 1/30 of the forest area per year, between age 25 and 40. The second block of planting would be harvested, 1/30 of the area per year, between age 25 and 38. After 54 years a normal forest is achieved. This is the general approach that has been followed here.

The result is that, given the greater profitability of trees compared to pasture, it is more profitable to achieve normality via variations in harvesting dates rather than by successive plantings on bare land (Table 10). This option is not entirely risk-free, as there may[5] be periods where there are carbon liabilities (see Figure 12 – the surrender index of 10 % is calculated as the reduction from the peak of 713,000 to the long-run level of 640,000 t CO_2-e; ie = 100 * 73,000/713,000) but these are small and can be always be offset by the combination of timber revenues and carbon gains in the non-harvested part of the estate.

FIGURE 12

Carbon stocks (tCO2-e) for 1200 ha estate planted is planted in blocks and normality is achieved by harvesting (radiata pine clearwood regime with 30 year normal forest)



The exact magnitude and timing of each harvest, and the exact cashflow profile of this management option, will depend on the precise choice of site and regime as well as the long-term strategy of the company. For example, how urgent is the need to achieve normality – ie over how many rotations? How restrictive are the predicted cashflow shortfalls?

The ranking of the various species and regimes stays virtually the same for each of the foregoing three estate-modelling strategy options (Table 11). *E. nitens* moves up a rank in the "normal forest by planting" scenario because its shorter rotation results in the whole 1200 ha being planted sooner.

[5] The surrender index is zero under this option in cases (Framing, Plant & leave, *E. nitens*) where the target rotation age is at or near the top of the range of rotation ages at which harvesting can occur.

TABLE 11

Rankings of regimes/species under three estate-modelling strategies

Ranking	Plant all at once	Normal forest by planting	Normal forest by harvesting
1	Plant & Leave	Plant & Leave	Plant & Leave
2	Framing	Framing	Framing
3	Clearwood	*E.nitens*	Clearwood
4	*E.nitens*	Clearwood	*E.nitens*
5	Douglas-fir	Douglas-fir	Douglas-fir

Plant a mixture of species or regimes

Tables 3 and 7 show that, in the absence of carbon trading, the most profitable regime given the existing timber prices is provided by radiata pine grown for clearwood. It is also clear that, given an extremely modest price for carbon (ie $6/t), the "plant-and-leave" radiata pine option is to be preferred were it not for the implied risk. As previously stated, the extra risk is both one of a high risk index (ratio of cost of carbon liabilities relative to timber revenue) and one of a low-value crop should the carbon market disappear.

The exact trade-off between maximising profitability and minimising risk will depend on the risk aversion of the investor. If "hedging" is required to reduce risk (albeit at some cost to profitability) this can be done in various ways including the normalisation strategy already discussed. Hedging can also be performed by blending species or regimes with different levels of profitability and risk.

In their reports, some students advocated an equal split between clearwood and plant-and-leave, while others favoured a single compromise regime – such as framing. Still others suggested including an element of Douglas-fir. Various combinations are summarised in Table 12.

TABLE 12

The rotation ages, net cashflows, and risk of some estate mixtures (all 1200 ha planted simultaneously with an equal area planted in each species/silviculture and harvested at the optimum rotation age for that species/silviculture)

(Using $30/t carbon price and 8% discount rate)

Regimes	Rotation age (years)	NPV ($million)	Surrender Index (%)
Clearwood + Framing	30+36	5.31	71
Clearwood + P&L	30+40	7.01	70
Framing + P&L	36+40	7.94	73
Clearwood + Framing + P&L	30+36+40	6.75	67
Framing +	36+44	2.14	68

Douglas-fir			
Framing + *E.nitens*	36+25	5.18	74
Framing + Douglas-fir + *E.nitens*	36+44+25	2.79	63

The unsurprising conclusion from Table 12 is that a mixture of species/regimes will give an NPV equal to the weighted average of the NPVs of the component regimes given in Table 9. However the level of the surrender index is lower than that of the component regimes because of the split in rotation ages.

Plant without any intention of harvest

The introduction of the ETS might encourage some growers to reap their rewards purely from the yield of carbon credits, without any intention of harvest. At some time in the future, there is little doubt that any sort of simultaneously-planted forest would eventually experience periods where growing stock would decline, with an implied carbon liability. The owner of the "no-harvest" forest might intend to "farm" carbon during his (or his company's) lifetime and leave the liabilities to a successor. Would this be a sensible, albeit selfish, strategy?

Unfortunately, the existing models are inadequate to address the benefits or dis-benefits of this option. There are little data for over-mature plantation forests in New Zealand. We cannot quantify the risks of windthrow, the profile of collapse and decay in senescent stands, and the recruitment of replacement trees following such a collapse. We can be sure that only a portion of the sequestered carbon would be lost (analogous to the loss from harvest) and that it would eventually be compensated, at least in part, by subsequent regrowth.

A tentative result is that existing growth models imply that:

- *E. nitens* would have a higher NPV under a no-harvest strategy than under a harvesting strategy – this is a reflection of the log price assumptions used; ie, pulplogs only.
- The NPV for the radiata pine plant-and-leave regime is higher than that of *E. nitens* under a no-harvest strategy.
- Radiata pine regimes have a higher NPV under a harvest strategy than under a no-harvest strategy.

Further Discussion

Reliability of calculated values

Little reliance should be placed on the absolute values of individual LEVs as recorded in this report. With slightly different assumptions it would be easy to generate slightly different numbers. For example, the establishment cost of tree stocks delivered to the site is assumed to be 50c[6] – a round number and one that could easily be contested, resulting in an immediate change to LEV. Perhaps more importantly, site quality parameters use broad-brush estimates that may not apply to any particular stand although they are probably typical of the resource. Again, it is possible (even probable) that growth models and carbon relationships will be refined over time, giving somewhat different values.

Despite that reservation, the results of this study do not depend greatly on absolute estimates: the profitability relationships are unlikely to appreciably change. For example, it should always be the case that optimum rotation age increases with carbon price and reduces with discount rate. The discipline of calculating exact numbers for hypothetical scenarios has enabled such relationships to be clarified.

Choice of species and regime

Whatever regimes are chosen, it is clear that without carbon payments, forestry could not – at current returns for logs – be justified on poor sites unless extremely low discount rates are used. Forestry struggles to pay for realistic land prices even on average sites. Yet when carbon price is included, the case for forestry becomes very strong. Best of all are radiata pine regimes which favour volume per hectare over large piece-size.

The economic case for alternative species and regimes is currently weaker than for radiata pine, but with high carbon prices some non-radiata species (for example, *E. nitens*) may become preferable to the most commonly employed radiata regimes.

Unsurprisingly, it was discovered that – even without revenue from carbon sequestration – the base-case radiata regime were found to be sub-optimal, at least as estimated by the Calculator. There were found to be benefits in reduced initial stocking, final crop stocking and rotation age. The latter held true even at low discount rates, but high discount rates greatly favoured early returns and therefore shortened rotation lengths even further.

The improvements suggested by use of the Calculator should be treated judiciously. Lower initial stockings reduce establishment costs and enhance individual-tree diameter growth, thus providing clear benefits, but the disadvantages are less obvious and are not adequately simulated: these include a lower selection ratio at time of thinning, less than full site occupancy, and loss of mutual protection against exposure. Again, models consistently suggest short rotation ages (25 years or less) on better sites, but growers realise that wood quality (corewood, spiral grain, density, stiffness, etc) are inadequately modelled and that widespread sale of such young trees would sour

[6] Establishment costs (cents/tree) excluding labour but including cost of seedlings & transportation, land preparation, and herbicide for releasing.

the market, despite the fact that there are limited existing price premiums to compensate growers for older trees. As regards final crop stocking, 250 s/ha may be ideal if clearwood prices are high but is sub-optimal if framing regimes are required. The accepted strategy in New Zealand has long been to sacrifice volume per hectare for higher volume per tree, but the decline in clearwood prices (as has occurred recently as a result of the sub-prime mortgage crisis in the US housing market) has recently tilted the table towards framing regimes and higher stockings.

Carbon trading clearly provides another incentive to achieve and maintain a higher volume throughout the rotation. The higher the price, the more this tendency is expressed. Translated into management practices, this implies higher initial stockings, later thinnings (including production thinnings), and higher final stockings. In a world of carbon trading, there is a strong case for eliminating pruning and perhaps even dispensing with thinning. Carbon trading will certainly lengthen rotations, sometimes dramatically. This study, however, does not show a major threat to the pre-eminence of radiata pine, especially when it is grown for high volumes throughout the rotation.

Stands planted in 1995

Although there are definite advantages to a grower in "opting in", even if a stand is already up to 18 years through a 25-year rotation, this presupposes a fixed price for carbon. The grower obtains the carbon revenue (less the measurement and transaction costs) for sequestration occurring during CP1 but must surrender an equal amount of units at harvest. At best, the grower gains only "the time-value of money" but, at worst, runs a serious risk because if the price of carbon rises it may be too expensive to re-acquire the necessary units for surrender. The problem here is not one of profitability – the value of forestry improves under any carbon price scenario – but one of cash-flow.

One possibility is for an existing forest grower to harvest only a proportion of the estate, relying on growth from the remainder to cover the carbon liabilities. Subsequent harvests would need to involve a progressively lesser area, or else be spaced at increasing intervals, because a greater quantity of units per hectare would need to be surrendered as the harvest-age increased. This would be a variation of the "plant the entire estate simultaneously but achieve normality by harvesting" scenario evaluated for 2008 planting.

If the grower does decide to opt in, it would be wise to review the intended rotation age as the optimum may be substantially later than originally intended. A series of harvesting coupes may be a better option than a single clearfelling operation – but this would need to be costed out in local detail, in view of the minimum economic harvest size.

Limitations

One obvious limitation of this study is the restricted number of species investigated. The main reason for this is the difficulty in acquiring hard data for alternative species on growth, costs and prices, and in modelling that data. Mostly this is because the information is simply unavailable: domestic timber supply in New Zealand is totally dominated by radiata pine and to a lesser extent Douglas-fir. Cost and price data for alternative species are non-existent and growth models are still at a primitive stage.

The discovery that carbon stocks from alternative species can be modelled, provided that a reliable yield table has been developed, has led to the use of *E. nitens* in this study. It would have been simpler if the General Forest Carbon predictor used to evaluate *E. nitens* (Appendix E7) had used the same template as the radiata and Douglas-fir calculators, but this problem was not insuperable.

Where indigenous sequestration was assessed (Table 2) the assumption used in the draft ETS regulations of 3 tCO_2 per hectare per year were copied, but this is obviously an unsatisfactory approximation or simplification.

The absence of a clear policy environment has complicated this technical study and made conclusions less robust than might have been the case. At time of writing, we cannot be sure that the ETS will be passed in its present form, let alone how it will survive the post-2012 international negotiations. There may, for example, be a considerable premium paid for carbon sequestration of a certain *vintage* whereby an emitter who releases carbon in a given year must sequester it in that year. If this philosophy becomes widespread, it may totally alter the ability of a grower to "bank" carbon credits and smooth over periods of negative growth in carbon stocks.

Recommendations

It would be very useful for similar studies in future years to employ a standardised "carbon calculator". This would be similar to the existing radiata pine and Douglas-fir Calculators, but simplified and custom-designed for carbon (many of the current inputs and outputs have no relevance to this type of analysis and might serve only to bewilder those unfamiliar with the software). A user would merely have to input a yield table in a suitable format for any new species, and read off the results.

To provide such yield tables, considerably more work is required in mensuration and modelling of alternative species.

Even for the two dominant species, there is a scarcity of information for very young ages (Douglas-fir, and radiata pine on poor sites) and there is an absence of data for over-mature stands. A good case could be made for the establishment of Permanent Sample Plots in a representative range of very old stands – with some agreement that these stands would be allowed to remain standing until they have collapsed of natural causes. Only then can we hope to model the consequences of the "no harvest" strategy considered here.

References

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Acknowledgements

The authors are very grateful to MAF for the funding that enabled this study to take place, to Blakely Pacific and Proseed for providing information, to the students who so enthusiastically participated in these somewhat arduous evaluations, and to key people from Scion (Mark Kimberley, Peter Beets, Graham West) without whom the basic tools would have been lacking.

Appendix A – Customisation of the Calculators

The User Interface of the Radiata Pine and Douglas-fir Calculators is shown in Appendices E1 and E2. The Log Specification screens used are shown in Appendices E3 and E4. The Economics screens are shown in Appendices E5 and E6. For *Eucalyptus nitens*, the Forest Carbon Predictor is shown in Appendix E7.

Those inputs that were deliberately varied are described under the appropriate headings. For inputs that were fixed, and which have some bearing on the outcome, the following were used:

Seedling Survival:	95%
Altitude:	300m
Establishment costs:	50c/tree (72 c/tree for Douglas-fir)
Labour cost:	$40/hr
Labour supervision:	12% (office) and 10% (contractor)
Clearfell yield:	85% (radiata) and 88% (Douglas-fir)
Plant time per plant:	1.036 mins (radiata) and 1.05 mins (D-fir)
Release time per plant:	0.145 mins (radiata) and 0.15 mins (D-fir)
Slope:	28^o
Hindrance:	2
Additional costs:	Zero

Note that some of the above inputs were unrealistic (labour cost, slope) but these were artificially set to result in realistic establishment and silviculture costs. The costs estimated by the Calculators were based on 1985 workstudy regressions from the NZFS and have become unreliable in their unadjusted form.

Appendix B – Transferring data to custom-made financial spreadsheets

Data were transferred from the Calculators (for radiata pine or Douglas-fir) or the Forest Carbon Predictor (for *E. nitens*) to the financial spreadsheets. These data included the following:

- Quantity of carbon contained in the stand for every year of the first and second rotations. The values estimated by the C_Change model include carbon in the stemwood, stump, roots, branches, foliage and litter. The carbon in mineral soil, the vegetation prior to planting, and the understorey is excluded. Second rotation stands start with a considerable level of carbon as a result of the debris remaining after harvesting the first rotation. The carbon is expressed as CO_2-equivalents.
- Cost and timing of silvicultural operations. These are dependent on the state of the stand (eg number of stems per hectare treated and size of trees) and therefore would be difficult to estimate accurately without a holistic model. It was considered that the Calculators could not accurately simulate harvesting costs because they are insensitive to piece-size which could be of crucial importance if very long rotations are being considered, so an algorithm was constructed to simulate harvesting costs using proprietary data that was sensitive to piece size, combined with model estimates of that statistic.
- Prices of harvested logs. The mill-door price for radiata pine was taken from the January 2008 MAF 12-quarter averages, but some grades on the Calculator had to be combined to correspond with the published prices. This involved some guesswork in terms of log specifications for the combinations. More importantly, it was not possible to use MAF's pruned log grades (P1 and P2) because these are highly insensitive to the high

proportion of clearwood that would be expected in very old stands (it was anticipated that carbon trading might increase rotation length). Instead, pruned prices were determined by Pruned Log Index, using a base price of $112/m^3$ (for PLI 4) and an increase of $10 for every unit gained in PLI.

For Douglas-fir, the default values of log-grades and prices supplied by the Calculator were used, as these were fairly recent and were originally obtained by interrogation of industry sources. For *Eucalyptus nitens*, a pulpwood price was obtained from Southwood Exports and log grades were limited to pulpwood.

Various financial and policy-related details were programmed into the financial sheets, depending on the exact matter under investigation:

Discount rates and carbon prices. These could be readily varied, and a facility provided the means to allow carbon prices to change (linearly or exponentially) over time.

1995 or 2008 plantings. Given that no credits exist prior to 2008, profitability will vary according to the date of stand establishment. To investigate this, 1995 and 2008 plantings were simultaneously estimated for each run.

Reduction in tradable carbon. It was assumed that only 90% of the estimated carbon would be saleable, because of sampling uncertainty. This deduction was built into all the calculations.

Fast-forest fix. For 1995 plantings, it was assumed that a grower would not need to pay back more units than had been obtained and sold.

Alternative trading strategies. Some financial sheets were customised to allow trading only up to the minimum stocks attained, or else up to the long-term (normalised) forest situation.

Appendix C – Regime combinations tested

For regime details

For regime analysis, we divided sites into three components (North Island high quality, North Island medium quality, and poor South Island) with regimes roughly corresponding to those used by Blakely Pacific. Blakely Pacific uses an initial stocking of 1150 and a final crop stocking of 375 for clearwood and framing. Thinning to the final crop stocking is performed at MTH 11 m. Pruned height is 6.5 m, which – given only two pruning lifts – results in relatively high DOS predictions of 20 and 19.0 cm (poor site); 20.6 and 18.0 cm (medium site); and 21.4 and 18.0 cm (good site).

The "base case" for each site was the above situation, but this was varied as follows, with the central figure (where appropriate) being used as the base:

Initial stocking: 800, 1150, 2000 s/ha
Final stocking: 250, 375, 600 s/ha
Timing of thinning: MTH of 8, 11, and 14 m
Production thinning: yes (at age 13) or no
Rotation length: 25 to 40 years
Timing of planting: 1995 or 2008
Price of carbon: %7.50, $15.00, $30.00
Discount rate: 6, 8, 10%

For site and species comparisons

In a later comparison, regimes were constructed that differed from those tailored for the Blakely Pacific estate. The major changes were: a reduction of the initial stocking to a more cost-effective 800 s/ha, a reduction of the final stocking to a more clearwood-oriented 250 s/ha, an earlier thin at age 7.8, pruned height of only 5.5 m to allow pruning to be achieved in two lifts with a low DOS.

<u>Good site.</u> Latitude 38°, 300 Index of 32.6, Site Index of 32.6, outerwood density of 460 (as measured at age 20). Initial stocking 800 s/ha, pruned at age 4.61 and 6.07 to achieve DOS sizes of 18.2 and 18.2 cm and a pruned height of 5.5 m. Thinned to 250 s/ha at age 7.8.

<u>Average site.</u> Latitude 38°, 300 Index of 29.0, Site Index of 30.2, outerwood density of 440 (as measured at age 20). Initial stocking 800 s/ha, pruned at age 5.10 and 6.63 to achieve DOS sizes of 17.8 and 18.0 cm and a pruned height of 5.5 m. Thinned to 250 s/ha at age 7.8.

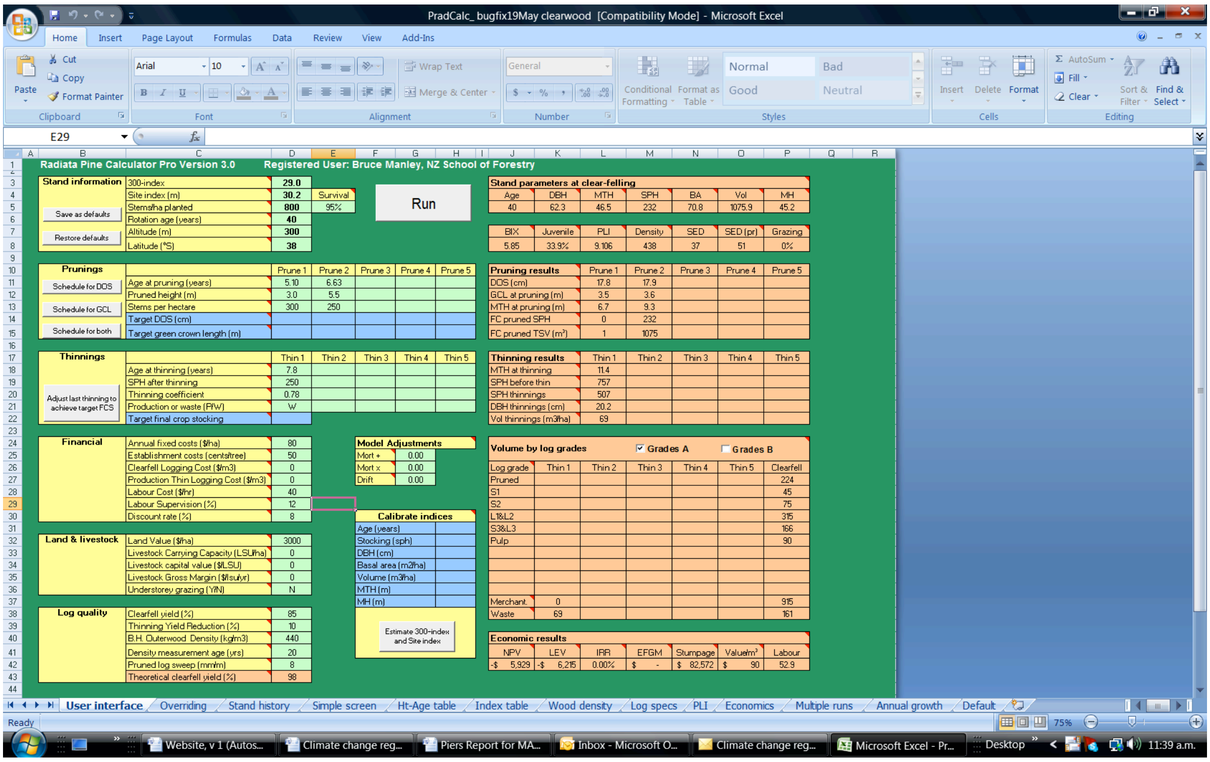
<u>Poor site.</u> Latitude 44.5°, 300 Index of 18.2, Site Index of 23.7, outerwood density of 420 (as measured at age 20). Initial stocking 800 s/ha, pruned at age 7.28 and 8.89 to achieve DOS sizes of 16.7 and 16.7 cm and a pruned height of 5.5 m. Thinned to 250 s/ha at age 7.8.

Appendix D – LEVs ($/ha) for regime inputs

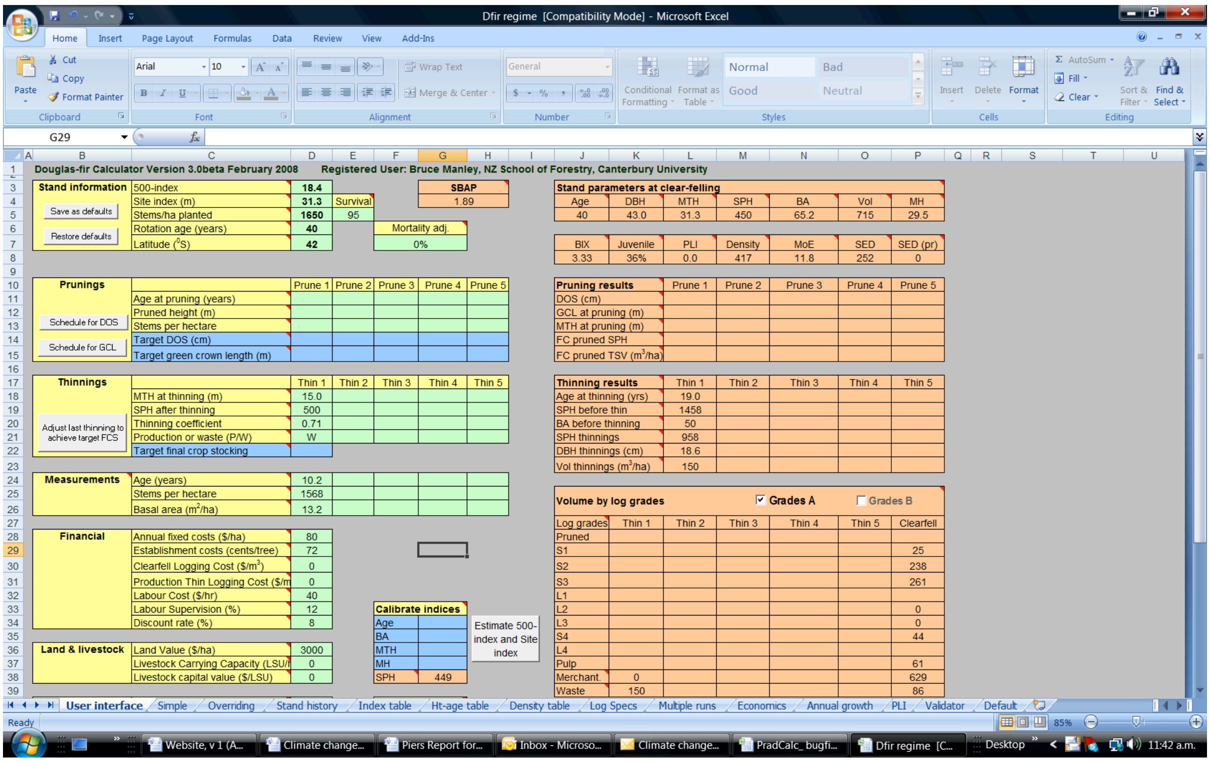
	$0.00			$7.50			$15.00			$30.00		
	6%	8%	10%	6%	8%	10%	6%	8%	10%	6%	8%	10%
Base case	2792	42	-1242	4050	1079	-371	6446	2992	1205	11550	7077	4537
(plant 1150, prune, FCS 375, Thin at 11 m to waste, medium site)												
FCS 600	1659	-634	-1646	3536	907	-387	6627	3365	1619	13317	8660	5897
(plant 1150, prune, FCS 600, Thin at 11 m to waste, medium site)												
Difference	-1133	-676	-404	-514	-172	-16	181	373	414	1767	1583	1360
IS 800	3630	770	-563	4693	1677	167	6949	3435	1615	11773	7246	4671
(plant 800, prune, FCS 375, Thin at 11 m to waste, medium site)												
Difference	838	728	679	643	598	538	503	443	410	223	169	134
Thin at 8 m	2622	-76	-1336	3660	802	-621	5897	2540	804	10725	6338	3836
(plant 1150, prune, FCS 375, Thin at 8 m to waste, medium site)												
Difference	-170	-118	-94	-390	-277	-250	-549	-452	-401	-825	-739	-701
Thin at 14 m	2637	-130	-1444	4002	1020	-431	6490	3045	1246	11805	7302	4753
(plant 1150, prune, FCS 375, Thin at 14 m to waste, medium site)												
Difference	-155	-172	-202	-48	-59	-60	44	53	41	255	225	216
IS 2000	879	-1700	-2888	2413	-392	-1737	5045	1789	90	10656	6347	3890
(plant 2000, prune, FCS 375, Thin at 11 m to waste, medium site)												
Difference	-1913	-1742	-1646	-1637	-1471	-1366	-1401	-1203	-1115	-894	-730	-647
No prune	2196	114	-935	3521	1280	104	6083	3336	1818	11677	7868	5550
(plant 1150, don't prune, FCS 600, Thin at 11 m to waste, medium site)												
Difference	-596	72	307	-529	201	475	-363	344	613	127	791	1013
FCS 250	2863	140	-1141	3726	919	-416	5778	2550	892	10068	5997	3742
(plant 1150, prune, FCS 250, Thin at 11 m to waste, medium site)												
Difference	71	98	101	-324	-160	-45	-668	-442	-313	-1482	-1080	-795
Prod thin	2789	19	-1228	4363	1373	-82	7086	3597	1773	12808	8242	5624
(plant 1150, prune, FCS 600, Thin at 20.5 m for production, medium site)												
Difference	-3	-23	14	313	294	289	640	605	568	1258	1165	1087

Appendix E – the Calculator screens as used

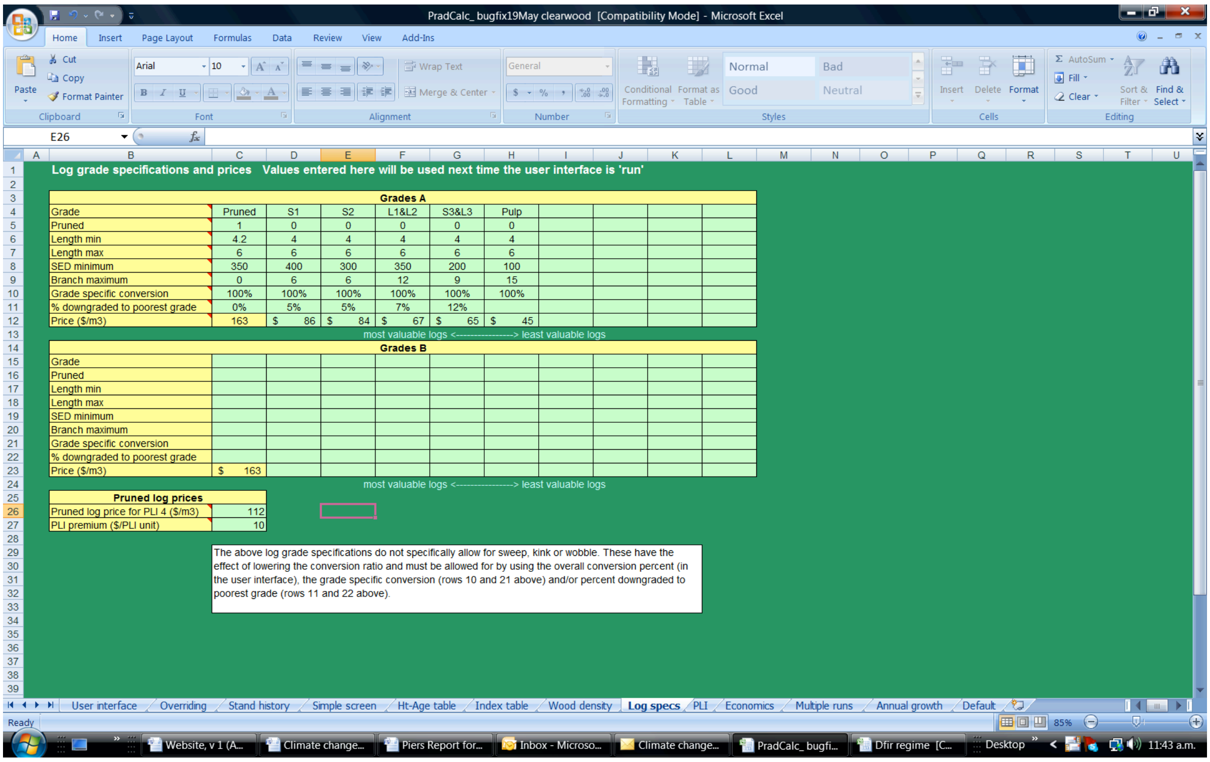
E1 – The radiata pine clearwood regime, user interface



E2 – the Douglas-fir regime, user interface



E3 – the Log Specification screen for the radiata runs



Log grade specifications and prices **Values entered here will be used next time the user interface is 'run'**

Grades A						
Grade	Pruned	S1	S2	L1&L2	S3&L3	Pulp
Pruned	1	0	0	0	0	0
Length min	4.2	4	4	4	4	4
Length max	6	6	6	6	6	6
SED minimum	350	400	300	350	200	100
Branch maximum	0	6	6	12	9	15
Grade specific conversion	100%	100%	100%	100%	100%	100%
% downgraded to poorest grade	0%	5%	5%	7%	12%	
Price ($/m3)	163	$ 86	$ 84	$ 67	$ 65	$ 45

most valuable logs <----------------> least valuable logs

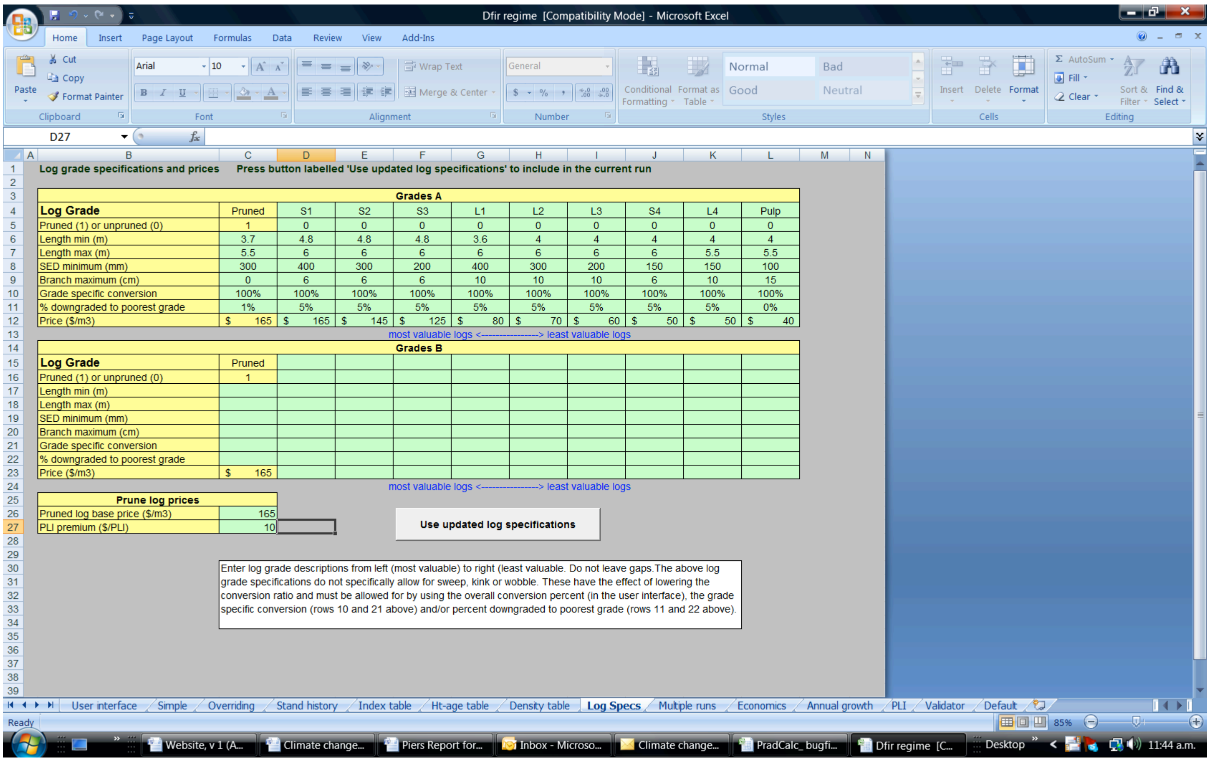
Grades B	
Grade	
Pruned	
Length min	
Length max	
SED minimum	
Branch maximum	
Grade specific conversion	
% downgraded to poorest grade	
Price ($/m3)	$ 163

most valuable logs <----------------> least valuable logs

Pruned log prices	
Pruned log price for PLI 4 ($/m3)	112
PLI premium ($/PLI unit)	10

The above log grade specifications do not specifically allow for sweep, kink or wobble. These have the effect of lowering the conversion ratio and must be allowed for by using the overall conversion percent (in the user interface), the grade specific conversion (rows 10 and 21 above) and/or percent downgraded to poorest grade (rows 11 and 22 above).

E4 – the Log Specification screen for the Douglas-fir run



Log grade specifications and prices **Press button labelled 'Use updated log specifications' to include in the current run**

Grades A										
Log Grade	Pruned	S1	S2	S3	L1	L2	L3	S4	L4	Pulp
Pruned (1) or unpruned (0)	1	0	0	0	0	0	0	0	0	0
Length min (m)	3.7	4.8	4.8	4.8	3.6	4	4	4	4	4
Length max (m)	5.5	6	6	6	6	6	6	6	5.5	5.5
SED minimum (mm)	300	400	300	200	400	300	200	150	150	100
Branch maximum (cm)	0	6	6	6	10	10	10	6	10	15
Grade specific conversion	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% downgraded to poorest grade	1%	5%	5%	5%	5%	5%	5%	5%	5%	0%
Price ($/m3)	$ 165	$ 165	$ 145	$ 125	$ 80	$ 70	$ 60	$ 50	$ 50	$ 40

most valuable logs <----------------> least valuable logs

Grades B	
Log Grade	Pruned
Pruned (1) or unpruned (0)	1
Length min (m)	
Length max (m)	
SED minimum (mm)	
Branch maximum (cm)	
Grade specific conversion	
% downgraded to poorest grade	
Price ($/m3)	$ 165

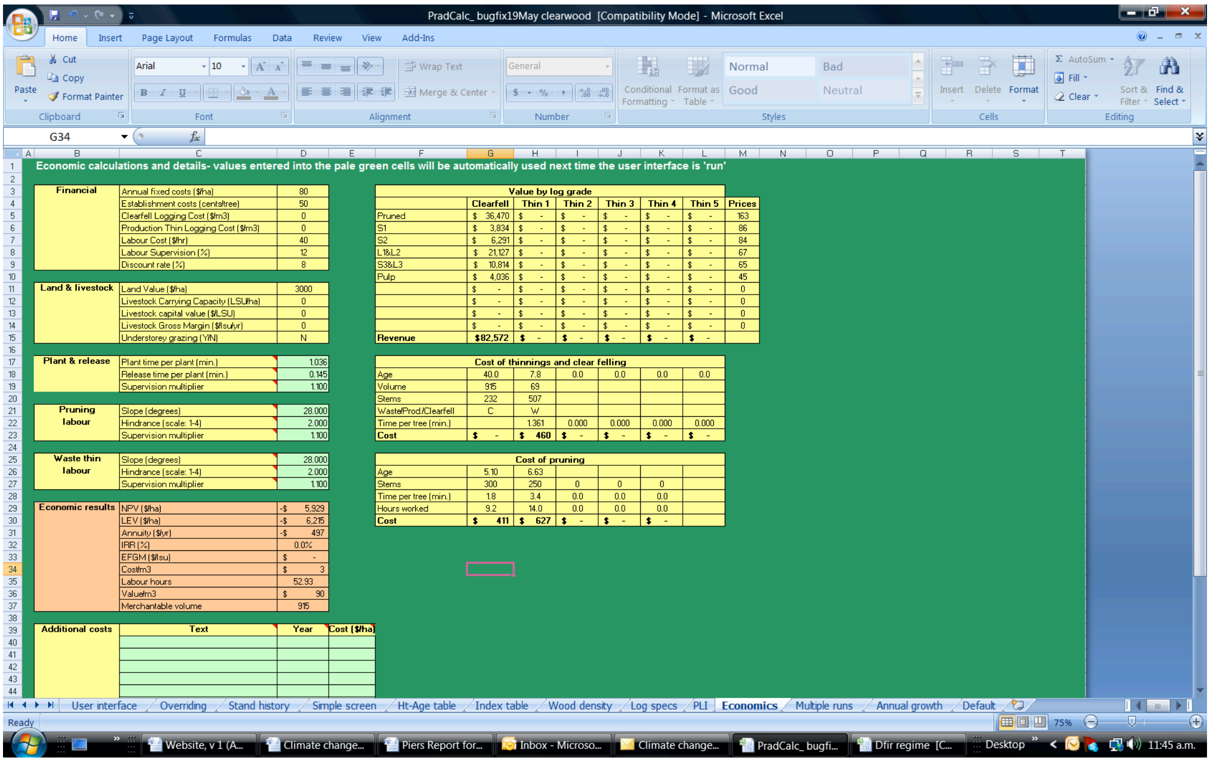
most valuable logs <----------------> least valuable logs

Prune log prices	
Pruned log base price ($/m3)	165
PLI premium ($/PLI)	10

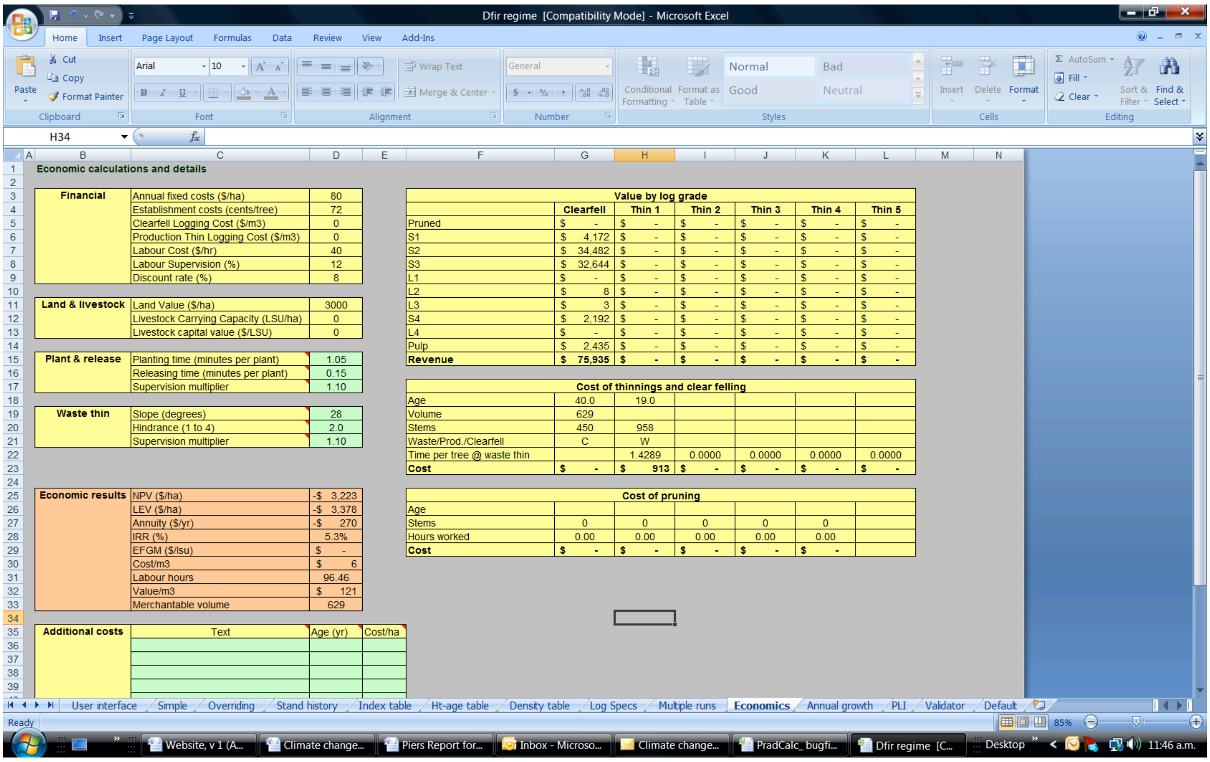
Use updated log specifications

Enter log grade descriptions from left (most valuable) to right (least valuable. Do not leave gaps.The above log grade specifications do not specifically allow for sweep, kink or wobble. These have the effect of lowering the conversion ratio and must be allowed for by using the overall conversion percent (in the user interface), the grade specific conversion (rows 10 and 21 above) and/or percent downgraded to poorest grade (rows 11 and 22 above).

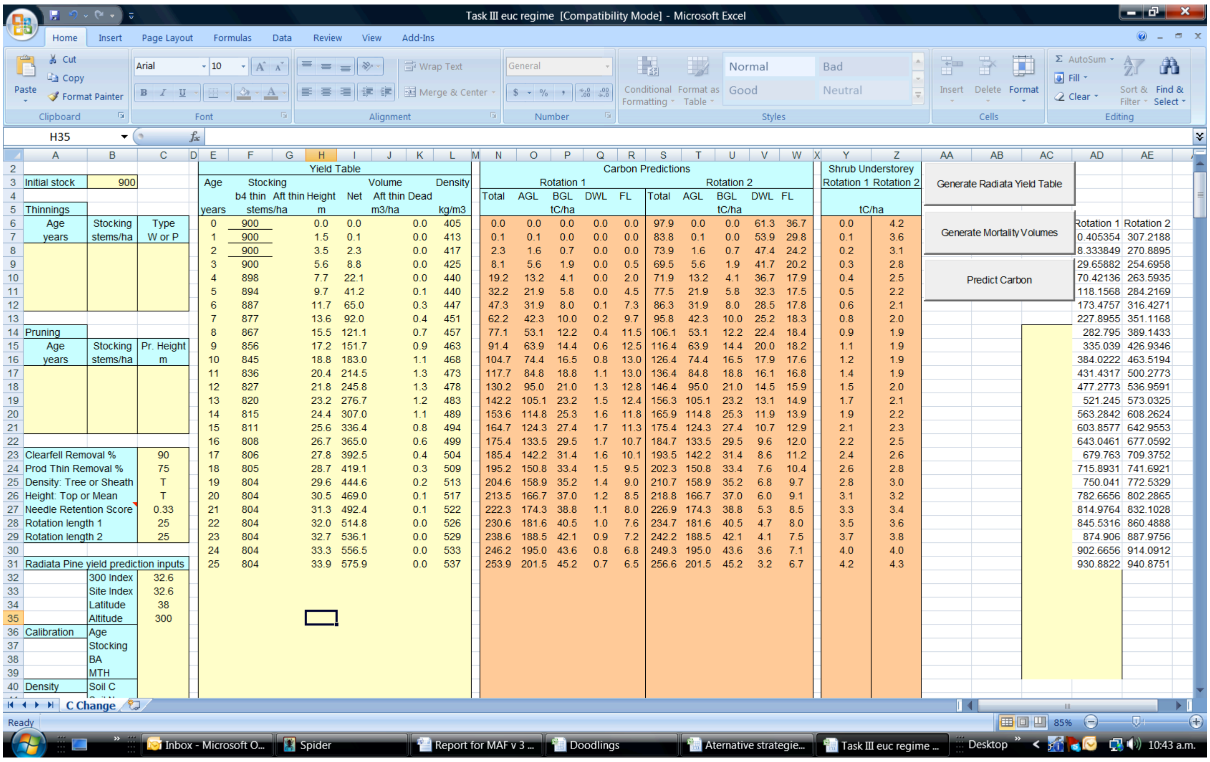
E5 – the Economics screen for the radiata runs



E6 – the Economics screen for the Douglas-fir run



E7 – the Forest Carbon Predictor for prediction of the *E. nitens* carbon sequestration



Initial stock	900	
Thinnings		
Age years	Stocking stems/ha	Type W or P
Pruning		
Age years	Stocking stems/ha	Pr. Height m
Clearfell Removal %		90
Prod Thin Removal %		75
Density: Tree or Sheath		T
Height: Top or Mean		T
Needle Retention Score		0.33
Rotation length 1		25
Rotation length 2		25
Radiata Pine yield prediction inputs		
	300 Index	32.6
	Site Index	32.6
	Latitude	38
	Altitude	300
Calibration	Age	
	Stocking	
	BA	
	MTH	
Density	Soil C	

Yield Table								Carbon Predictions										Shrub Understorey	
Age	Stocking			Volume			Density	Rotation 1					Rotation 2					Rotation 1	Rotation 2
	b4 thin	Aft thin	Height	Net	Aft thin	Dead		Total	AGL	BGL	DWL	FL	Total	AGL	BGL	DWL	FL		
years	stems/ha		m	m3/ha			kg/m3	tC/ha					tC/ha					tC/ha	
0	900		0.0	0.0		0.0	405	0.0	0.0	0.0	0.0	0.0	97.9	0.0	0.0	61.3	36.7	0.0	4.2
1	900		1.5	0.1		0.0	413	0.1	0.1	0.0	0.0	0.0	83.8	0.1	0.0	53.9	29.8	0.1	3.6
2	900		3.5	2.3		0.0	417	2.3	1.6	0.7	0.0	0.0	73.9	1.6	0.7	47.4	24.2	0.2	3.1
3	900		5.6	8.8		0.0	425	8.1	5.6	1.9	0.0	0.5	69.5	5.6	1.9	41.7	20.2	0.3	2.8
4	898		7.7	22.1		0.0	440	19.2	13.2	4.1	0.0	2.0	71.9	13.2	4.1	36.7	17.9	0.4	2.5
5	894		9.7	41.2		0.1	440	32.2	21.9	5.8	0.0	4.5	77.5	21.9	5.8	32.3	17.5	0.5	2.2
6	887		11.7	65.0		0.3	447	47.3	31.9	8.0	0.1	7.3	86.3	31.9	8.0	28.5	17.8	0.6	2.1
7	877		13.6	92.0		0.4	451	62.2	42.3	10.0	0.2	9.7	95.8	42.3	10.0	25.2	18.3	0.8	2.0
8	867		15.5	121.1		0.7	457	77.1	53.1	12.2	0.4	11.5	106.1	53.1	12.2	22.4	18.4	0.9	1.9
9	856		17.2	151.7		0.9	463	91.4	63.9	14.4	0.6	12.5	116.4	63.9	14.4	20.0	18.2	1.1	1.9
10	845		18.8	183.0		1.1	468	104.7	74.4	16.5	0.8	13.0	126.4	74.4	16.5	17.9	17.6	1.2	1.9
11	836		20.4	214.5		1.3	473	117.7	84.8	18.8	1.1	13.0	136.4	84.8	18.8	16.1	16.8	1.4	1.9
12	827		21.8	245.8		1.3	478	130.2	95.0	21.0	1.3	12.8	146.4	95.0	21.0	14.5	15.9	1.5	2.0
13	820		23.2	276.7		1.2	483	142.2	105.1	23.2	1.5	12.4	156.3	105.1	23.2	13.1	14.9	1.7	2.1
14	815		24.4	307.0		1.1	489	153.6	114.8	25.3	1.6	11.8	165.9	114.8	25.3	11.9	13.9	1.9	2.2
15	811		25.6	336.4		0.8	494	164.7	124.3	27.4	1.7	11.3	175.4	124.3	27.4	10.7	12.9	2.1	2.3
16	808		26.7	365.0		0.6	499	175.4	133.5	29.5	1.7	10.7	184.7	133.5	29.5	9.6	12.0	2.2	2.5
17	806		27.8	392.5		0.4	504	185.4	142.2	31.4	1.6	10.1	193.5	142.2	31.4	8.6	11.2	2.4	2.6
18	805		28.7	419.1		0.3	509	195.2	150.8	33.4	1.5	9.5	202.3	150.8	33.4	7.6	10.4	2.6	2.8
19	804		29.6	444.6		0.2	513	204.6	158.9	35.2	1.4	9.0	210.7	158.9	35.2	6.8	9.7	2.8	3.0
20	804		30.5	469.0		0.1	517	213.5	166.7	37.0	1.2	8.5	218.8	166.7	37.0	6.0	9.1	3.1	3.2
21	804		31.3	492.4		0.1	522	222.3	174.3	38.8	1.1	8.0	226.9	174.3	38.8	5.3	8.5	3.3	3.4
22	804		32.0	514.8		0.0	526	230.6	181.6	40.5	1.0	7.6	234.7	181.6	40.5	4.7	8.0	3.5	3.6
23	804		32.7	536.1		0.0	529	238.6	188.5	42.1	0.9	7.2	242.2	188.5	42.1	4.1	7.5	3.7	3.8
24	804		33.3	556.5		0.0	533	246.2	195.0	43.6	0.8	6.8	249.3	195.0	43.6	3.6	7.1	4.0	4.0
25	804		33.9	575.9		0.0	537	253.9	201.5	45.2	0.7	6.5	256.6	201.5	45.2	3.2	6.7	4.2	4.3

Rotation 1	Rotation 2
0.405354	307.2188
8.333849	270.8895
29.65882	254.6958
70.42136	263.5935
118.1568	284.2169
173.4757	316.4271
227.8955	351.1168
282.795	389.1433
335.039	426.9346
384.0222	463.5194
431.4317	500.2773
477.2773	536.9591
521.245	573.0325
563.2842	608.2624
603.8577	642.9553
643.0461	677.0592
679.763	709.3752
715.8931	741.6921
750.041	772.5329
782.6656	802.2865
814.9764	832.1028
845.5316	860.4888
874.906	887.9756
902.6656	914.0912
930.8822	940.8751