The Economics of Intensive Forest Management
A Stand Level Analysis for the Romeo Malette Forest in Ontario[1 2]

A Report Prepared for Tembec Inc., the Ontario Ministry of Natural Resources, and ULERN

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I. Introduction and Summary

Since the signing of the 1999 Ontario Forest Accord by the Ontario Ministry of Natural Resources, representatives of several environmental groups[6] and the forest industry, there has been a renewed interest in the potential for increasing commercial timber yields through intensive forest management (IFM) on Crown lands. The Forest Accord endorsed the increase in parks and protected areas negotiated in the Lands for Life process but also made commitments to mitigate any potential negative effects on the forest industry caused by a reduction in lands available for commercial forestry. Specifically it was promised that long term delivered wood costs and volumes available for industrial use would not be negatively affected by the Accord.

Intensive forest management has been viewed by the parties to the Accord as a means to meet this commitment of maintaining wood supply at no increase in cost in the face of reduced lands available for harvest. The Accord acknowledges that special incentives may be required in relation to "extraordinary expenditures" on IFM.

In light of the Forest Accord it is clear that a detailed assessment of the potential for IFM to increase commercial forest productivity is needed. This report presents the findings of a project examining the economics of IFM at the stand level. Management decisions in Ontario public forests are typically made on a larger scale – i.e., at the forest unit level. However, stand level analysis is an important input into decisions. With stand level analysis, milling and transportation costs are taken as given, whereas an analysis at the forest unit level would need to consider the impact of varying these parameters.

The report presents results for representative stands of jack pine and spruce, in the Romeo Malette forest unit. The representative stands, based on standard forest units, are PJ1 (jack pine), SB1 (black spruce), and SP1 (black spruce, jack pine)[7]. The analysis draws on the work of Margaret Penner (Forest Analysis Ltd., Huntsville, Ontario), who has developed yield curves for different species in the chosen license areas for several different levels of IFM. A description of the yield curve development is contained in a separate report (Penner, 2002). Penner was able to break down net merchantable volume into three categories based on log size. Paul Krabbe of Tembec provided an estimate of the price differential that would be paid by mills for larger versus smaller logs. Thus the economic analysis presented here is more accurate than if a single price had been applied to all merchantable volumes. Cost data was also provided by Tembec staff, Paul Krabbe and Al Stinson.

There is no generally accepted definition in the literature of the term 'intensive forest management'. Typically IFM implies greater spending on silvicultural practices in order to increase wood volume and/or value. Density regulation and genetic improvement are

[6] These groups included the World Wildlife Fund, the Federation of Ontario Naturalists, and the Wildlands League.

[7] The PJ1, SP1, and SB1 classifications, based on Standard Forest Units, are described in Bridge *et al* (2000).

usually involved. Sometimes IFM is defined broadly to include management for multiple objectives rather than just timber. As will be seen in the next section, in this paper we define seven different levels of forest management based on the level of silvicultural expenditures. From lowest to highest expenditure level these regimes are: natural, extensive, basic, intensive 1, intensive 2, intensive 3. A description of these regimes is provided in Table 2 on page 7.

This analysis is solely concerned with revenues and costs associated with the sale of commercial forest products. However, the current motivation to pursue IFM on Ontario crown lands is the hope that a greater volume of lumber can be produced from a smaller land base, which would leave more hectares available as natural habitat. IFM is also viewed as a way of maintaining volumes to existing lumber mills, in order to avoid industry contraction and mill closure (Natural Resources Canada, 2000). A complete economic analysis of IFM would thus need to consider these additional motivations beyond the economics of the increased wood volumes. This broader perspective is beyond the scope of this report. What this report does provide is an analysis of the returns to IFM strictly in terms of commercial forestry. These results are an important building block to addressing the larger questions.

In any economic analysis it is important to define the perspective from which the analysis will be carried out. This report considers the economics of IFM from the perspective of society as a whole as well, as well as from the perspective of a private firm licensed to harvest on public land. These two perspectives give very different views of the economic benefits and costs of IFM. From the public perspective, the goal is to undertake those investments which maximize the net benefits from harvesting a stand of trees, rather than the net benefits to any one stakeholder. The distribution of these net benefits can be viewed as a separate question to be negotiated between the Crown and the lease holder. Hence any payments by the firm to government, such as taxes, are ignored. The value of the wood "on the stump" is estimated by taking a market price entering the mill and deducting transportation and hauling costs back to the stand. Stumpage prices as calculated by provincial authorities are not used.

The public perspective also implies that the costs of IFM must be linked to the revenue that will be received from harvesting the resulting wood volumes once the trees have matured some four to five decades later. This may be likened to accrual accounting procedures. Investments made today to establish a stand and the investments made to manage and maintain that stand over its lifetime are compounded forward to the harvest date and are applied against the revenues realized at that harvest date to determine if the investment was, in an overall sense, economically worth while.

The perspective of a firm is quite different. Revenues for the holder of a Sustainable Forest Management License depend on access to the existing inventory of mature timber within the firm's license area, or the annual allowable cut. One motivation for a firm to undertake IFM would be the hopes that government regulators will agree to an immediate increase in the annual allowable cut, the so-called "Allowable Cut Effect" or ACE. From the firm's perspective the added costs of IFM need only be justified by the anticipated increase in allowable cut.

This report uses two different methods. The first is the Faustmann approach, which is traditional discounted cash flow analysis over multiple forest rotations. The second is the real options approach, which has largely been developed over the past two decades.[8] For investment decisions characterized by significant risk and when management has the flexibility to determine the best time to invest, the real options approach presents a more accurate representation of a project's value. The real options approach assumes that the decision to harvest a stand of trees is based on maximizing economic value, not wood volume, and that the manager has discretion over the harvest date. Lumber prices are assumed to follow a random process and forest managers are presumed to make harvesting decisions in response to volatile prices. The value of a stand of trees using a real options approach is based on the assumption that the forest manager will respond optimally in the future, harvesting when prices are favourable, and delaying the harvest when prices are depressed.

A summary of the results for Jack Pine (Site Class 1) from a public perspective using a 3% discount rate is provided in Table 1 below for both the Faustmann and real options approaches. The natural regime yields the highest return under both approaches. This implies that the value of increased commercial timber yields is insufficient to justify investment in IFM under the assumptions used in this study. From a public perspective, any investment in IFM must be justified by appealing to other values, such as the desire to maintain mill employment. Results for the other species are contained in the body of this report. In general the economics of IFM are worse for the SP1 and SB1 forest units than those presented for PJ1.

The real options approach consistently estimates a larger net present value for all levels of forest management, and gives positive returns for IFM, compared to the negative returns estimated by the Faustmann approach. As is shown later in this report, at higher discount rates, the real options approach also shows negative returns for IFM. The larger return using the real options approach is due to the assumption that the forest manager can act optimally in the face of volatile prices in the future. In reality, there are many constraints placed on forestry firms, such as annual allowable cut requirements, that reduce the anticipated return on investment from that shown below. These returns are not consistent with a policy of maximum sustained yield.

The returns using the real options approach are dependent on the assumption that future lumber prices will be volatile. A reduction in the assumed level of future volatility reduces the predicted ability of a firm to take advantage of periods of relatively high prices and thereby reduces the real options estimate of net present value. The results when the volatility estimate is halved are given in Table 18, on page 36.

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[8] The real options approach is described in Dixit and Pindyck (1994).

Table 1

SUMMARY: PRESENT VALUE OF NET BENEFITS: Jack Pine (PJ1), Site Class 1, 3% real discount rate[9]			
Management Intensity	Faustmann, $/ha	Real Option, $/ha (base case volatility)	Real option minus Faustmann
Natural	$1047	$1864	$817
Extensive	$ 890	$1638	$748
Basic	-$ 305	$ 778	$1083
Intensive 1	-$ 457	$ 427	$504
Intensive 2	-$ 449	$ 460	$909
Intensive 3	-$ 406	$ 540	$906

For a firm holding a long term license to harvest mature trees in the Romeo Malette forest, an important motivation for undertaking IFM is the anticipation that government regulators will increase the firm's annual allowable cut. For such a firm, the benefits of being able to have greater access to mature stands can easily justify the spending required to undertake a program of IFM.

The next section of this report describes the cost and yield data for representative stands in the Romeo Malette forest. Section III explains the Faustmann approach to economic analysis and presents detailed results for a PJ1 representative stand. Section IV describes the real options approach. Section V describes and analyzes the real options results for PJ1. Section VI summarizes the real options results for SB1 and SP1.

II. Cost and Yield Data

1. Management intensities and silvicultural costs

Cost and yield data are estimated for various different levels of management intensity, described in detail in Penner (2002). The different management intensities are defined in terms of desired targets for a stand of trees. A summary of the levels and their targets is given in Table 2, taken from Penner (2002).

[9] All discount rates used in the report are real discount rates. A real discount rate does not include any return that is needed to compensate for inflation. This is appropriate since costs and prices used in the report are not escalated to account for inflation. Roughly speaking the real discount rate equals the nominal interest rate less the expected inflation rate.

Table 2: Definitions of Management Levels

Level of Management Intensity	Target/Focus
Natural	Natural conditions, no intervention
Extensive	Manipulating species composition
Basic	Manipulating species composition Achieving full site occupancy
Intensive	Manipulating species composition Achieving full site occupancy Controlling density to optimize individual tree growing space.

Moving from natural and extensive through to intensive involves progressively greater spending on silvicultural activities. Tables 3, 4, and 5 below provide silvicultural costs for the different intensities applied to PJ1, SB1, and SB1 stands. It will be observed that for PJ1 and SP1 the intensive level has been divided into different subcategories.

Table 3. Silvicultural Costs, PJ1 (Jack Pine)

Cost $/ha.	Natural	Extensive	Basic	Intensive 1	Intensive 2	Intensive 3	Timing
Site Preparation (SIP)			$200	$200	$200	$200	Year 1
Nursery Stock			$360	$360			Year 1
Improved Stock					$390	$420	Year 1
Planting			$360	$360	$360	$360	Year 2
First Tending			$120	$120	$120	$120	Year 5
Second Tending				$120	$120	$120	Year 8
Pre-commercial Thinning (PCT)				$500	$500	$500	Year 20
Data Mgt/Monitoring.	$5	$5	$10	$20	$20	$20	Year 35
Commercial Thinning (CT)				$200	$200	$200	Year 35

Table 4. Silvicultural Costs, SB1 (black spruce)

Cost $/ha.	Natural	Extensive	Basic	Intensive	Timing
Site Preparation (SIP)					Year 1
CLAGG/Fill Planting			$400	$400	Year 1
Nursery Stock					Year 1
Improved Stock					Year 1
Planting					Year 2
First Tending			$120	$120	Year 5
Second Tending					Year 8
Pre-commercial Thinning (PCT)					Year 20
Data Mgt/Monitoring.	$5	$5	$10	$20	Year 35
Commercial Thinning (CT)				$200	Year 35

Table 5. Silvicultural Costs, SP1 (black spruce, jack pine)

Cost $/ha.	Natural/ Extensive	Basic	Intensive Sw	Intensive 1	Intensive 2	Intensive 3	Timing
Site Preparation (SIP)		$200	$200	$200	$200	$200	Year 1
CLAGG/Fill planting		$400					Year 1
Nursery Stock			$360	$360			Year 1
Improved Stock				$390	$420		Year 1
Planting			$360	$360	$360	$360	Year 2
First Tending		$120	$120	$120	$120	$120	Year 7
Second Tending			$120	$120	$120	$120	Year 10
Pre-commercial Thinning (PCT)							Year 20
Data Mgt/Monitoring.	$5	$10	$20	$20	$20	$20	Year 35
Commercial Thinning (CT)			$200	$200	$200	$200	Year 35

2. Volumes

- Net Merchantable Volume

Net merchantable volumes (NMV) for each level of intensity for PJ1, SB1, and SP1 are shown in Figure 1, Figure 2, and Figure 3 . The more intensive levels of management (basic and intensive levels) have significantly higher volumes by year 50.

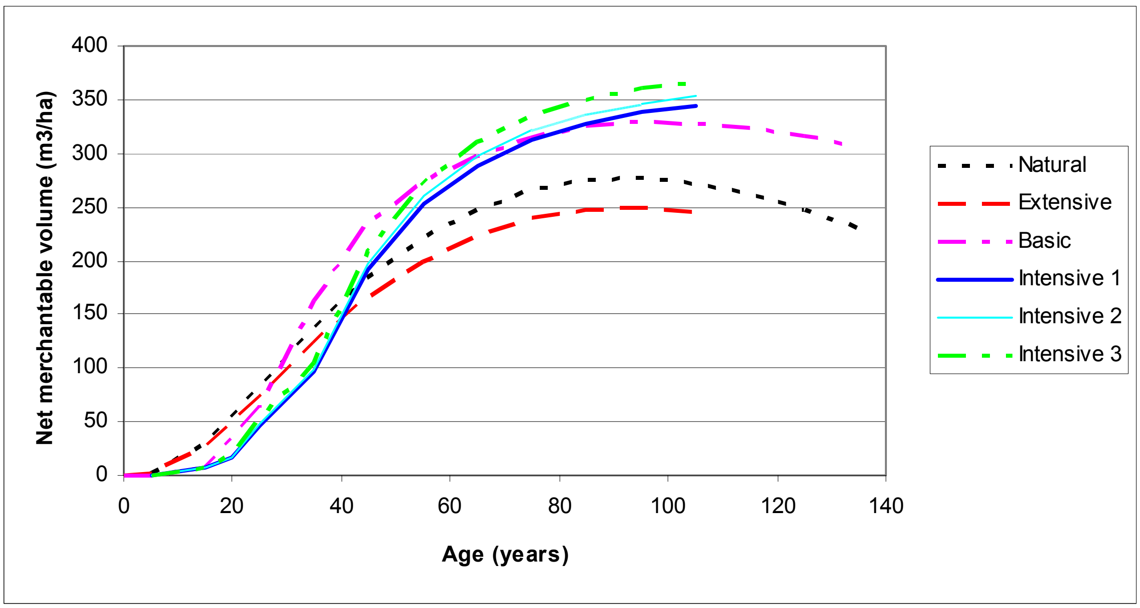

Figure 1: Jack Pine Net Merchantable Volume, Site class 1

Source: Margaret Penner, 2002.

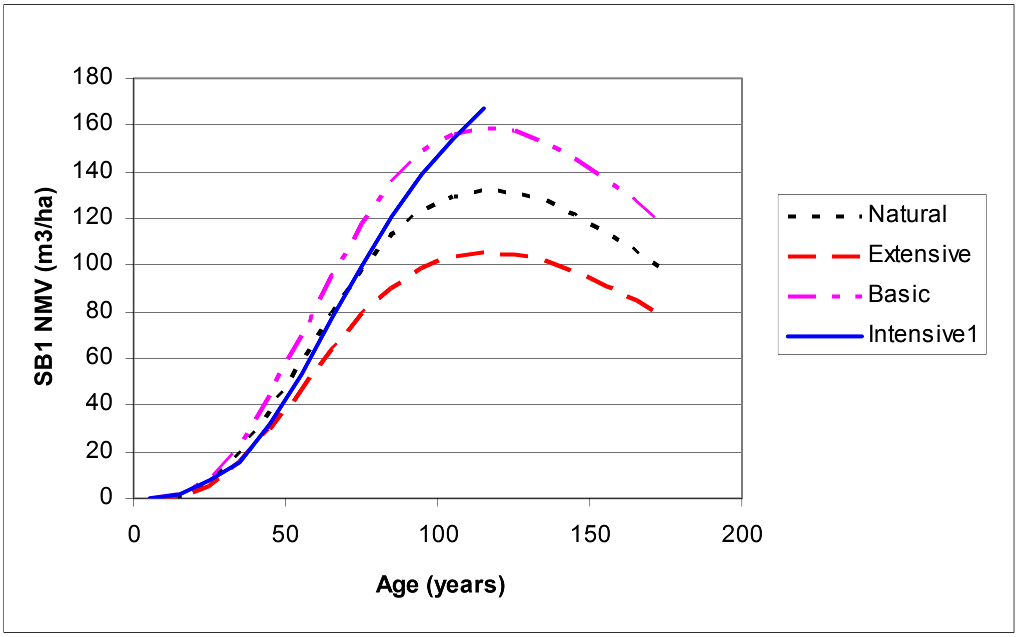

Figure 2 SB1, Net Merchantable Volumes, Site Class 1

Source: Margaret Penner, 2002.

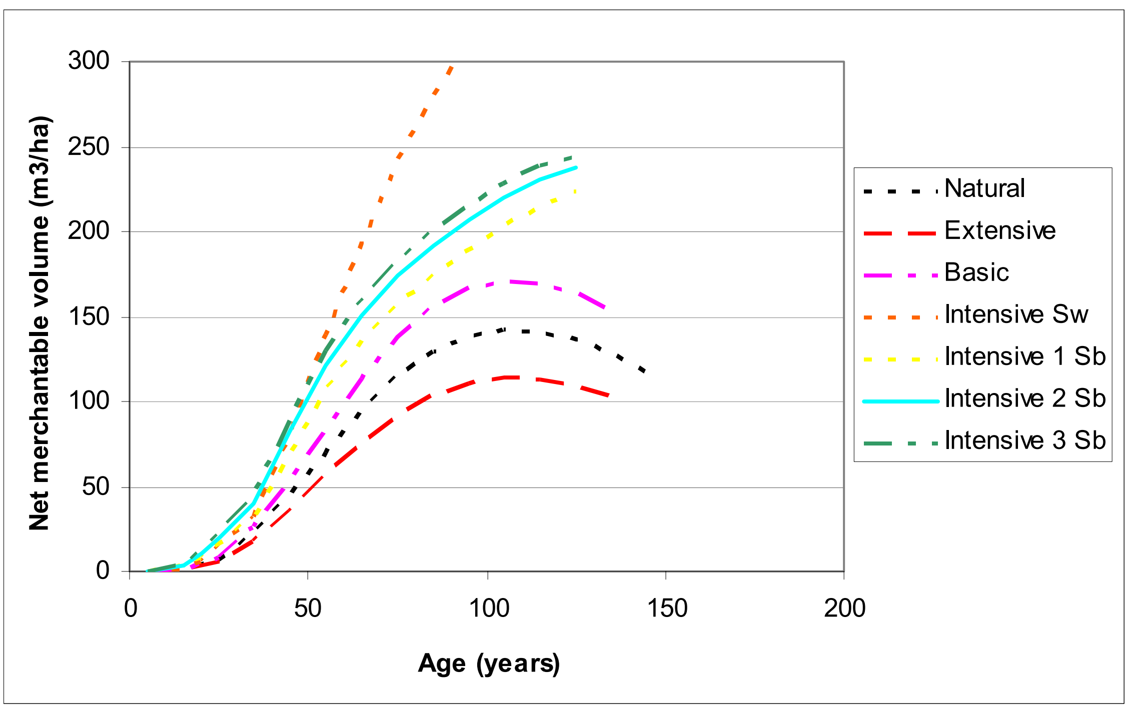

Figure 3: SP1 Net Merchantable Volumes, Site Class 1

Source: Margaret Penner, 2002.

- Products

Of more interest than NMV is the time profile of the different products that will be attained when harvesting a stand at various ages. Harvested volumes by age have been classified according to size and species, with the larger sized logs being the most valuable. The categories of products are as follows:

SPF1	Spruce, pine, fur logs, greater than 16 cm at the small end
SPF2	Spruce, pine, fur, 12 cm to 16 cm class
SPF3	Spruce, pine, fur, 10 cm to12 cm class
PO	Poplar
BW	Birch

Figure 4, Figure 5, and Figure 6 indicate yields for the most valuable products, SPF1 and SPF2, for PJ1, SP1, and SB1 respectively . Under the basic and intensive management regimes, these products appear sooner and are significantly larger in absolute volume than under the natural and extensive regimes.

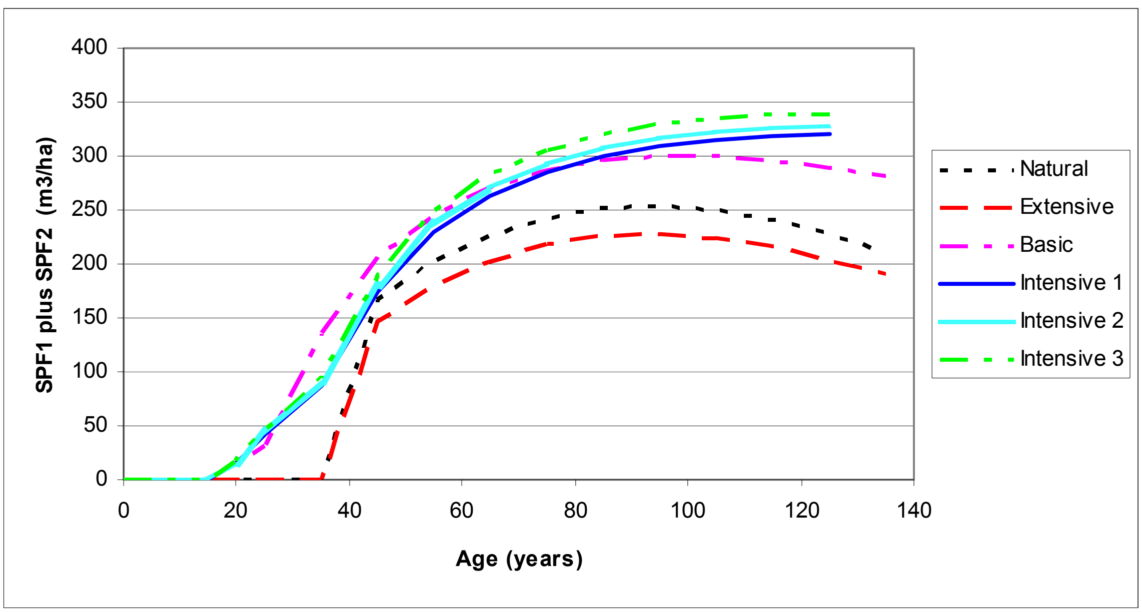

Figure 4 Jack Pine, SPF1 and SPF2 volumes, site class 1

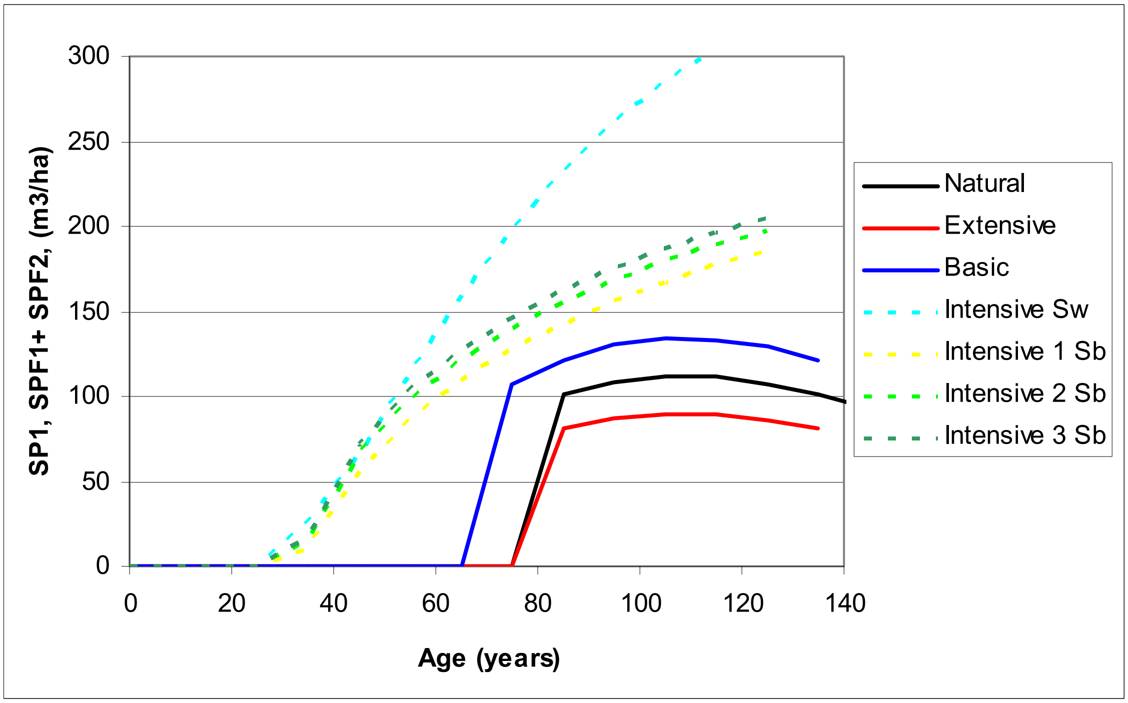

Figure 5 SP1, SPF1 and SPF2 volumes, site class 1

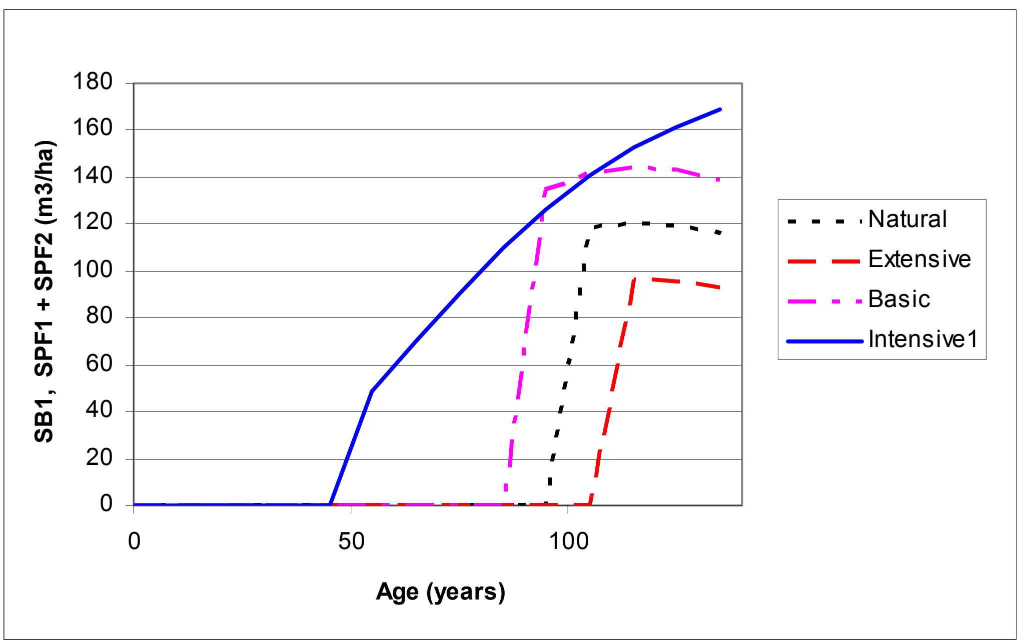

Figure 6. SB1, SPF1 and SPF2 volumes, Site Class 1

A comparison of SPF1 and SPF2 volumes under the Intensive 2 regime for the three species is shown in Figure 7. Clearly the PJ1 volumes are significantly larger than for the other species.

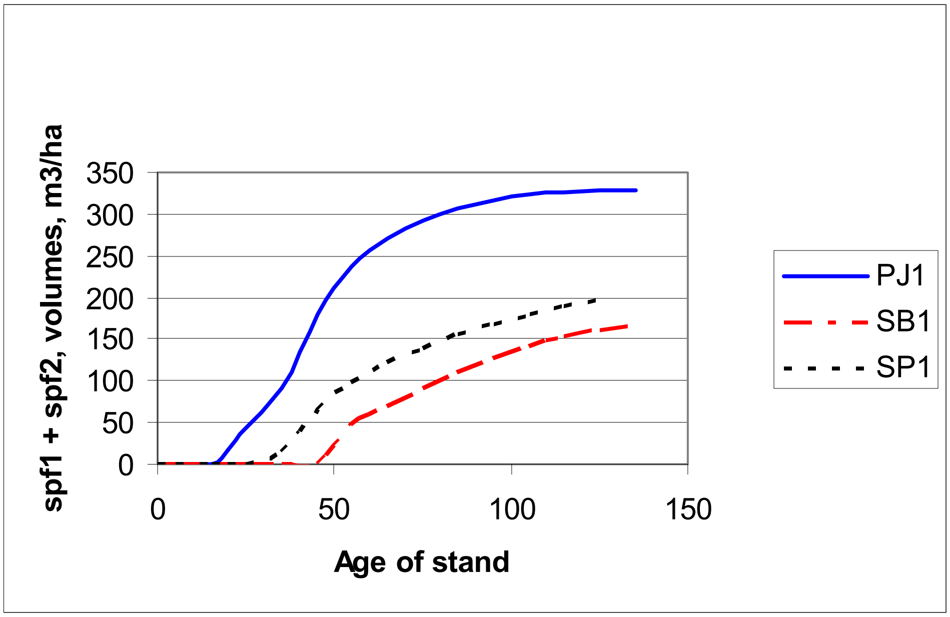

Figure 7. Comparison of PJ1, SB1, and SP1 Volumes, site class 1, intensive 2 regime.

Figure 8 shows the profiles for SPF3 for PJ1. Harvesting SPF3 costs more than its market price. The levels of SPF3 increase rapidly for all regimes in the early years, and then decline sharply. SPF3 volumes are much higher at their peak for the natural and extensive regimes. SPF3 volumes for SP1 and SB1, as well as poplar/birch volumes for all species are shown in Appendix A.

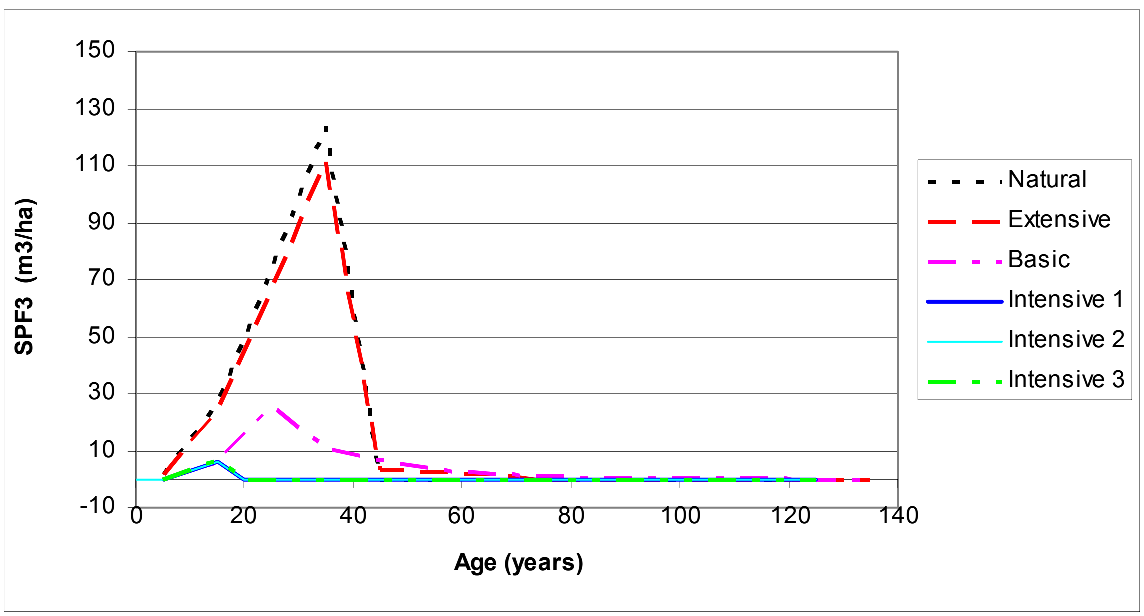

Figure 8. Jack Pine SPF3, Site Class 1

2. Costs and Prices

Confidential price and cost data was provided by Paul Krabbe of Tembec Inc. SPF prices going into the mill are assumed to be approximately $\$50/m^3$. Representative harvesting costs are reported in Rollins *et al* (1995).

III. The Faustmann Approach

1. General Description

The Faustmann approach determines the harvest age that maximizes the present value of net benefits from a stand of trees over an infinite cycle of rotations. In its simplest form, the Faustmann approach presumes that the value of the trees derives from their value to a saw or pulp mill and that the land will always be used for commercial timber harvesting. It is also typically assumed that real prices and costs[10] will be constant over time, although this assumption can be relaxed.

The Faustmann approach takes into account the fact that the optimal rotation length will be different if an infinite sequence of future rotations is considered rather than only a single rotation. In a multi-rotation framework, the timing of the current harvest affects the economics of subsequent harvests. If management costs are fairly low, a multi-rotation analysis will have shorter rotations than would be recommended for a single rotation considered on its own. This is because the sooner the trees are harvested, the sooner a new rotation can be started. However, when forest management costs are high, this conclusion may not hold, since harvesting then triggers major expenditures for planting, thinning, etc. The error in considering only a single rotation will be largest for fast growing species when optimal rotations are quite short or when up-front silvicultural costs are significant.

The Faustmann approach is not consistent with a policy of maximum sustained yield (MSY) which attempts to maximize the yearly flow of wood volume from a management unit. The Faustmann approach assumes that the management goal is to maximize economic returns from a stand of trees, given current prices. The MSY criterion ignores prices and wood values, and hence will usually produce lower economic returns than methods, such as Faustmann, which are concerned with optimum economic yields. The MSY criterion is also difficult to apply when specific products are modeled.

2. Discounting

Discounting is used to compare dollar amounts that accrue in different time periods. The choice of discount rate can have a large impact the economics of a forestry investment since the revenues from harvesting typically accrue many years after planting and

[10] By real prices and cost we mean that price and cost increases due to general inflation have been excluded.

silviculture expenditures are incurred. For this report, results are presented for 3%, 5% and 7% real discount rates.

Two facts justify the need to discount. First, individuals prefer to receive goods and services immediately, rather than wait for some future period – so there is a cost to delaying consumption. This implies that the discount rate should reflect individuals' willingness to trade-off consumption today for consumption next year (the so-called marginal rate of time preference). Secondly, if an individual spends a dollar today rather than investing it, she forgoes the return on investment that could have been earned. This implies that the discount rate should reflect the opportunity cost of capital – i.e. the rate of return that could be earned if $1 were invested rather than spent on consumption goods.

The discount rate is thus related to both the marginal rate of time preference and the opportunity cost of capital[11]. Choosing the appropriate rate depends on the nature of the project under consideration. Some general factors that need to be considered are given below.

(a) Public or private perspective. If the goal is to maximize benefits to society as a whole (a public perspective), it can be argued that a market rate of interest is not an appropriate discount rate. From a public perspective, we would want to choose a discount rate that reflects the willingness of society as a whole to delay current consumption (i.e. make an investment today) for some future return. This rate might be lower than the market rate of interest, because as a society we want to ensure the well-being of future generations. (A high discount rate puts very little value on benefits or costs that accrue a long time into the future.) The determination of the appropriate societal discount rate is discussed in the economics literature, and has been the topic of considerable debate.

(b) Real versus nominal. Interest rates quoted by financial institutions are nominal interest rates because a portion of these rates compensates the investor for inflation. Real interest rates reflect the real return after deducting inflation. For example, if the real interest rate is 5% and inflation is forecast at 2% over the coming year, then a lender would need to charge a nominal rate of 7%, in order to ensure a real return of 5%.

    When a project's costs and revenues in future years have been adjusted to account for inflation, then an economic analysis of that project should use a nominal discount rate. If instead costs and prices have not been adjusted by an inflation factor, then a real discount rate should be used.

(c) Value under certainty. A private firm will maximize shareholders' wealth by undertaking those productive investments with the highest net present value. The net

[11] Under certain strict assumptions (ex. no risk, no taxes) the individual's marginal rate of time preference, the rate of return on private investment, and the market interest rate will all be equal. In reality this does not hold, and the choice of discount rate involves considerable discretion. Boardman *et al*, 1996.

present value of an investment is the present value of future income less the present value of costs, discounted at the opportunity cost of capital, which in a world of certainty is the risk free interest rate. The risk free rate is typically taken to be the rate offered on government bonds. In practice almost no projects would be considered risk free, so that the discount rate must be higher than the risk free rate as described in point (d).

(d) The Risk Adjusted Discount Rate. One way to account for risk is to calculate net present value as in (c) above, but using a discount rate that has been adjusted to reflect the extra return required to compensate for risk. The opportunity cost of capital is then determined as the cost of funds (or the required rate of return demanded by investors) of an all-equity firm engaged exclusively in the same type of business as the project under consideration. The risk-adjusted discount rate is the sum of the risk-free interest rate (typically approximated by the yield of three month Treasury bills), used to discount for the time value of money, and a discount risk premium, used to compensate for the risk associated with the project. In our analysis we have not added a risk premium to the discount rate.

3. Technical Details of the Faustmann Approach

For an infinite series of future rotations, the present value of net revenues received can be expressed as follows:

$$A = [V(t)e^{-rt} - K] + [V(t)e^{-rt} - K]e^{-rt} + [V(t)e^{-rt} - K]e^{-2rt} + \ldots + [V(t)e^{-rt} - K]e^{-nrt}$$

where,

A is the present value of net revenues received on a \$/ha basis when harvesting occurs at age t,

V(t) is the value of the harvest (\$/ha) net of harvesting and transportation costs

K represents any planting and silviculture costs for the current rotation. It is quoted on a \$/ha basis, net of revenue from commercial thinning, discounted to the beginning of the rotation

r is the real discount rate

t is the harvest age or rotation length

n is the number of rotations.

If we let n go to infinity, this equation reduces to

$$A = -K + (V(t) - K)\sum_{i=1}^{\infty} e^{-irt} .$$

It can be shown that:

$$\sum_{i=1}^{\infty} e^{-irt} = \frac{1}{e^{rt} - 1} .$$

The present value of an infinite series of future rotations can then be rewritten as:

$$A = -K + \frac{V(t) - K}{e^{rt} - 1} .$$

For the Faustmann approach, this formula is used to calculate the present value of net benefits for different rotation ages. The optimal rotation age is the harvest age at which net present value is maximized.

4. Sample Calculation for Jack Pine (PJ1) Extensive, Year 45

This section demonstrates the calculation of the net present value of a stand when harvesting occurs at age 45. Volumes of the various products at age 45 are shown below.

Table 6. Volumes (m3/ha), Year 45

SPF1	**SPF2**	**SPF3**	**Poplar/ Birch**	**Net Merchantable Volume**
0	147.2	3.4	15.2	165.8

Table 7 demonstrates the calculation of the net present value of a stand of trees if harvesting occurs at age 45 for an infinite number of rotations into the future. Assuming that real prices and costs remain unchanged in the future, then the net present value of this stand today is shown to be $890/ha. The Faustmann age is the rotation age that maximizes the net present value of the stand under these assumptions. 45 years also turns out to be the Faustmann rotation age.

Table 7. Calculation of stand value for PJ1 when harvesting occurs at age 45 over infinite future rotations

Undiscounted revenue from single harvest:	= (SPF1 vol. X price of SPF1) + (SPF2 vol. X price of SPF2) + (SPF3 vol. X price of SPF3) + (POBW vol. X price of POBW) = $7805/ha
Present value of future revenue over infinite rotations with harvesting at age 45:	= $7805/(e^{rt}-1)$ = $7805/(e^{0.03(45)}-1)$ = $2731/ ha
Harvesting and transportation costs:	= net merchantable volume X harvest cost per m^3 + SPF volume X transportation cost per m^3 = 5255/ha
Present value harvesting and transportation costs over future rotations	= $ $5255/(e^{rt}-1)$ = $1839/ha
Silviculture Costs, Data Management and Monitoring, Year 35	Undiscounted cost, 1 rotation: $5/ha PV beginning of the first rotation = $5 e^{-rt} = 5e^{-0.03(35)}$ = $1.75 Present value from the second rotation onward: $1.75/($e^{rt}$-1) = .61 Present value over all rotations = $1.75 + $0.61 = $2.36/ha
Net present value	$2731 - $1839 - $2 = $890/ha

5. Faustmann results for Jack Pine, Site Class 1

- Extensive

The net present value of the stand of trees over multiple rotations can be calculated in the same manner shown above for other rotation lengths. The year with the maximum net present value is the optimal harvesting age from the Faustmann perspective.

Figure 9 shows the three main components of the net present value calculation for different possible harvesting ages: the present values of revenue, harvesting and trucking costs, and silvicultural expenditures. The present value of harvesting and trucking costs decline steadily, as the impact of discounting is larger than the effect of increased volumes as the stand ages. The sudden increase in the present value of revenues beginning at age 36 reflects SPF2 volumes coming on-stream, whereas prior to that age only SPF3 and POBW are being produced. From age 35 to 45, SPF2 volumes grow extremely rapidly (160% per year); from age 45 to 55 growth in SPF2 settles down to 2% per year. Thus the present value of revenues rises sharply when growth exceeds the discount rate, but falls precipitously after age 45 when growth drops below the discount rate. From age 45 onwards the present value of revenues declines steadily, again because the growth rate in volume is overwhelmed by the discount factor. Until age 38, harvesting and trucking costs exceed revenues. Silvicultural costs are so small as to be barely visible along the horizontal axis.

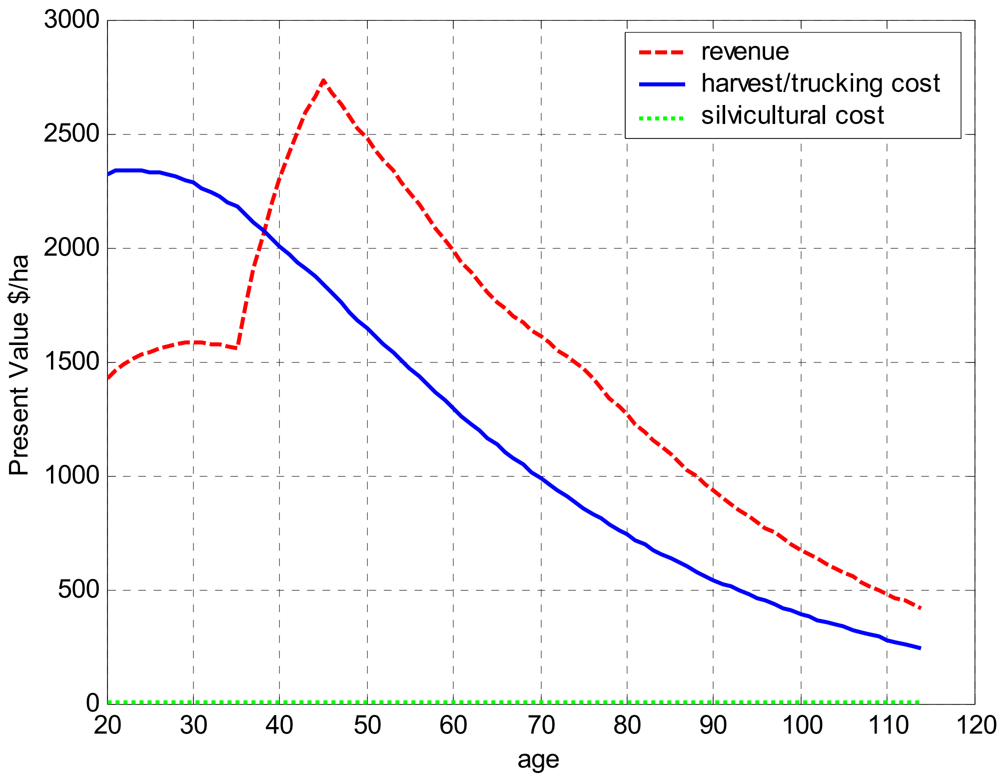

Figure 9. Present Value of Revenues and Costs at Various Harvesting Ages, Extensive Regime, 3% discount rate

Figure 10 shows the sum of the three curves in the previous figure, which is the net present value over time of the Jack Pine stand, site class 1, with extensive treatment. NPV is maximized at $890 per hectare if harvesting takes place in year 45.

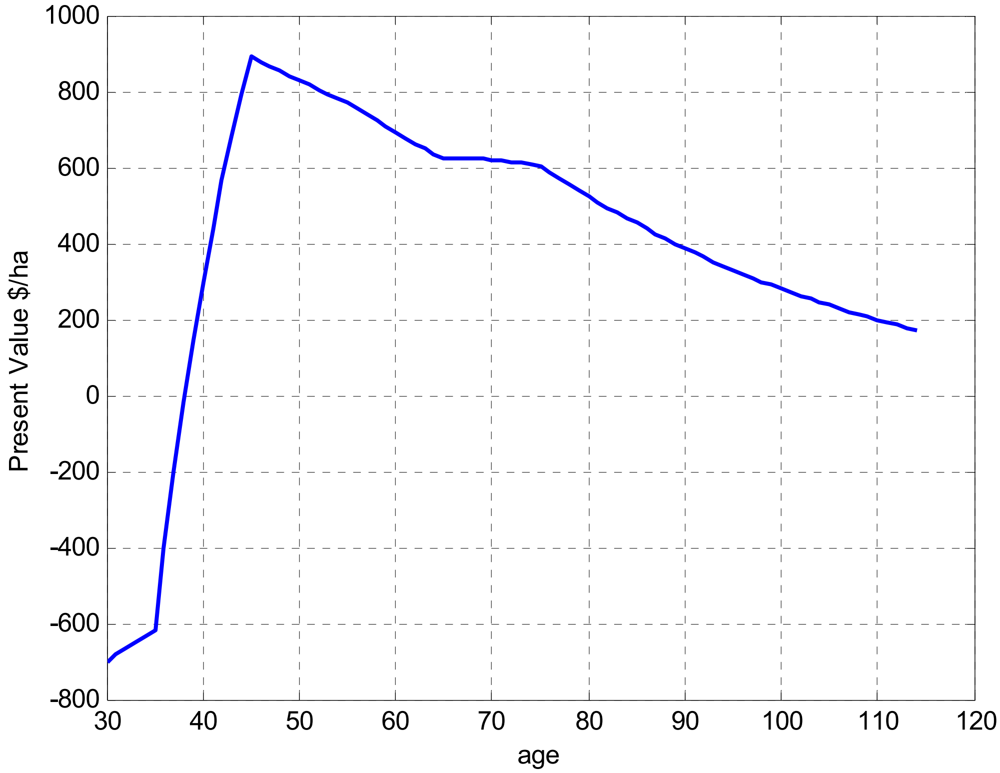

Figure 10. Net present value at various rotation ages, PJ1, extensive, site class 1, 3% discount rate

- Basic

The results for the basic option are shown in the next two figures. In Figure 11 it is clear that revenues are increased when silvicultural treatments at the basic level are applied, and that the present value of revenues exceeds the present value of harvest and transportation costs. However, unlike with the natural regime, there are now major silvicultural costs. The net present value of the basic treatment, shown in Figure 12, is at a maximum at age 45 at $309/ha. This is significantly below the value for the extensive regime at the optimal harvest age.

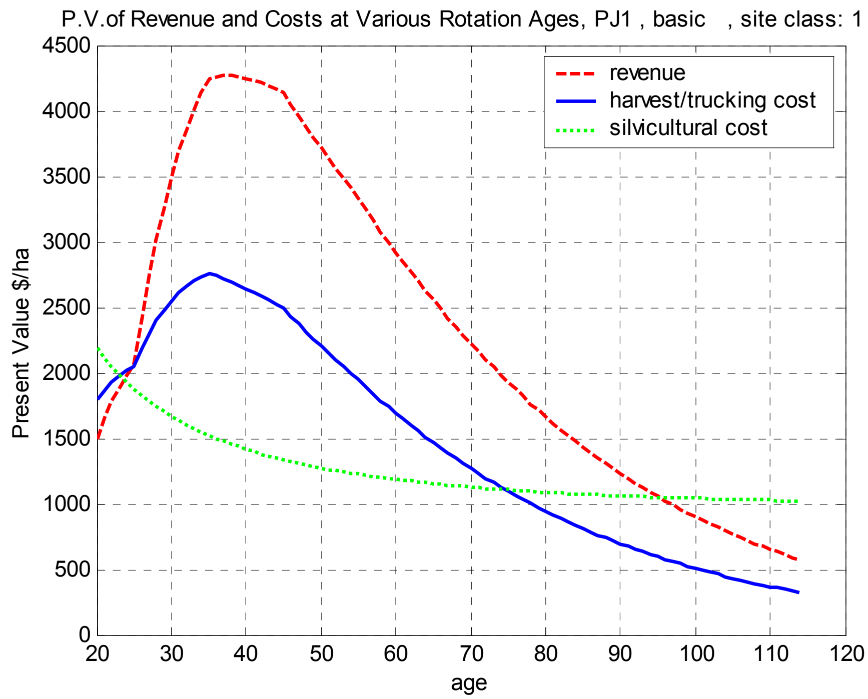

Figure 11. PV revenues and costs at various rotation ages, PJ1, basic regime, 3% discount rate

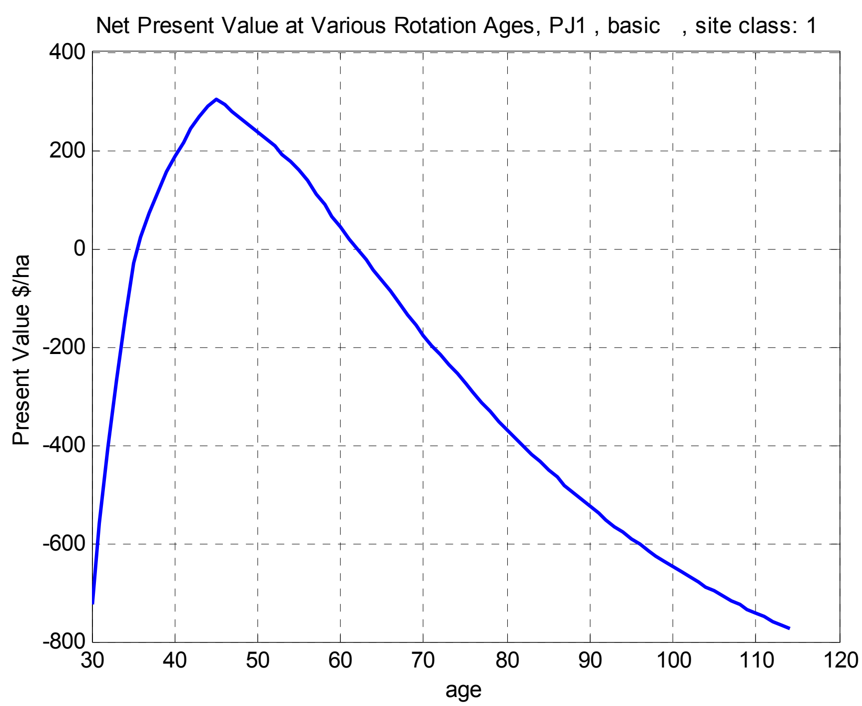

Figure 12. PV at various rotation ages, PJ1, basic regime, 3% discount rate

- Complete Jack Pine Results, Faustmann Analysis

The results for all levels are summarized in the tables below for 3%, 5% and 7% discount rates. The basic and intensive treatments involve major increases in silvicultural expenditures. The resulting increase in merchantable volume is not sufficient to offset these expenditures, resulting in reduced net present values compared to the extensive and basic regimes. For the 3% and 5% discount rates, the optimal rotation ages are significantly about 10 years later for the intensive treatments compared to natural, extensive and basic. For the intensive treatments it is better to delay harvesting, as harvesting triggers the need to spend significant sums on silviculture. A longer rotation period delays these expenditures and thereby minimizes the losses incurred under these regimes.

Table 8 Results of the Faustmann Analysis, PJ1, 3% Discount Rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 5% discount rate
Natural	$ 1.75	45	$ 1047
Extensive	$ 1.75	45	$ 890
Basic	$989	45	$305
Intensive 1	$1432	55	-$457
Intensive 2	$1461	54	-$449
Intensive 3	$1490	54	-$406

Table 9 Results of the Faustmann Analysis, PJ1, 5% discount rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 5% discount rate
Natural	$ 0.9	45	$ 352
Extensive	$0.9	45	$ 299
Basic	$953	45	-$512
Intensive 1	$1254	55	-$928
Intensive 2	$1283	55	-$942
Intensive 3	$1311	53	-$945

Table 10 Results of the Faustmann Analysis, PJ1, 7% discount rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 7% discount rate
Natural	$ 0.43	45	$ 134
Extensive	$ 0.43	45	$ 114
Basic	$ 921	39	-$ 738
Intensive 1	$1131	45	-$1002
Intensive 2	$1158	45	-$1024
Intensive 3	$1186	45	-$1041

6. Faustmann Results for SP1

The next three tables present the Faustman results for SP1. The net return is lower than that shown for PJ1, as SP1 volumes of the valuable products (SPF1 and SPF2) are much lower.

Table 11 Results of the Faustmann Analysis, SP1, 3% Discount Rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 5% discount rate
Natural	$ 2.7	85	$ 118
Extensive	$ 2.7	85	$ 85
Basic	$489	74	-$364
Intensive 1	$1145	73	-$972
Intensive 2	$1175	64	-$962
Intensive 3	$1204	65	-$970
Intensive Sw	$1145	73	-$757

Table 12 Results of the Faustmann Analysis, SP1, 5% discount rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 5% discount rate
Natural	$ 1.8	85	$ 19
Extensive	$ 1.8	85	$ 13
Basic	$467	75	-$441
Intensive 1	$1054	64	-$1009
Intensive 2	$1083	60	-$1026
Intensive 3	$1111	59	-$1048
Intensive Sw	$1054	64	-$ 959

Table 13 Results of the Faustmann Analysis, SP1, 7% discount rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 7% discount rate
Natural	$ 1.23	85	$ 3
Extensive	$ 1.23	85	$ 1
Basic	$447	75	-$ 442
Intensive 1	$987	59	-$973
Intensive 2	$1016	55	-$997
Intensive 3	$1043	55	-$1022
Intensive Sw	$987	58	-$959

7. Faustmann Results for SB1

Results for SB1 are presented in the following three tables.

Table 14 Results of the Faustmann Analysis, SB1, 3% Discount Rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 5% discount rate
Natural	$ 1.75	105	$ 82
Extensive	$ 1.75	114	$ 38
Basic	$495	95	-$390
Intensive	$568	83	-$429

Table 15 Results of the Faustmann Analysis, SB1, 5% discount rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 5% discount rate
Natural	$ 0.9	105	$ 9
Extensive	$ 0.9	114	$ 3
Basic	$476	95	-$461
Intensive	$512	73	-$484

Table 16 Results of the Faustmann Analysis, SB1, 7% discount rate

	PV treatment costs, first rotation, $/ha	Optimal rotation age	Net Present Value, $/ha 7% discount rate
Natural	$ 0.4	105	$ 0.8
Extensive	$ 0.4	114	$ 0.0
Basic	$ 458	95	-$ 456
Intensive	$ 477	66	-$469

IV. The Real Options Approach

1. Introduction

A significant drawback of the Faustmann approach is the assumption that future prices and costs are known with certainty and that management does not have the ability to react optimally to fluctuations in prices. In reality, forest products are traded in world commodity markets and typically exhibit significant volatility. The figure below shows a price index for softwood lumber and ties since the mid-1950's. Volatility appears to have been relatively high in the past decade.

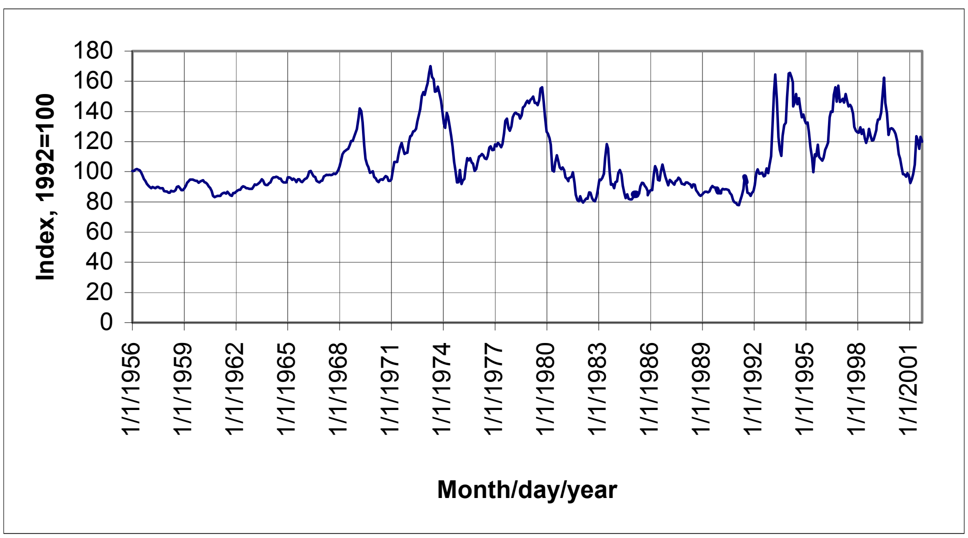

Figure 13 Real Canadian Industrial Price Index, Softwood Lumber and Ties, 1956-2001 (Source: Statistics Canada)

One common approach to dealing with uncertainty is to conduct sensitivity analyses on key variables. Another approach is to calculate the expected net present value of a risky project by multiplying different possible project outcomes (eg. high, medium, and low) by their probability of occurrence and then finding the sum. Net revenues of the different scenarios are discounted using a risk-adjusted discount rate (RADR), which reflects the opportunity cost of capital, or the rate of return demanded by investors on comparable investments (i.e. of similar risk).

The main disadvantage with these traditional approaches to uncertainty is that they cannot properly capture management's flexibility to adapt and revise decisions. In effect the project is valued as if once begun, management cannot deviate from its initial plan, even if markets and prices turn out to be significantly different than originally anticipated. In reality, we know that investment projects are often characterized by significant flexibility to expand, contract, or even shut down if circumstances warrant. Traditional approaches ignore this flexibility and therefore can significantly underestimate the potential value of a risky project.

In contrast, the real options approach can take explicit account of different management options, such as the ability to delay an investment to wait for more favourable circumstances. The real options approach values an investment opportunity, which can often be more valuable that the investment itself. For example the value of the opportunity for a firm to install new technology in a plant some time over the next five years is generally greater than the estimated value of installing the technology next year, since the investment opportunity includes the option of not installing the technology if markets turn out worse than expected. Management flexibility to react to circumstances reduces the downside risk of an investment. The real options approach captures the value of this flexibility.

A simple example will help to clarify these ideas[12]. Consider a firm which must decide whether to invest $1600 in a widget machine. This expenditure is assumed to be completely irreversible – i.e. the machine has little salvage value and cannot be sold if the price of widgets drops precipitously. Today the price of widgets is $200. Next year there is a 50% probability that it will rise to $300 and a 50% probability it will fall to $100. After next year the real price will remain constant forever, and the factory will produce one widget per year forever. The expected price of widgets is therefore $200 (0.5X300 + 0.5X100). We assume a discount rate of 10%.

The traditional approach to valuing this investment would be to calculate the expected NPV as follow:

$$NPV = -1600 + \sum_{t=0}^{\infty} \frac{200}{1.1^t} = -1600 + 2200 = \$600 \ .$$

Because the project has a positive net present value, we would conclude that it should be undertaken. But this conclusion ignores the value of being able to delay the decision to invest.

[12] This example is taken from A. Dixit and R. Pindyck , (1994).

Suppose instead the firm waits one year before investing and invests only if the price goes up. The NPV would now be as follows:

$$NPV = 0.5\left(\frac{-1600}{1.10} + \sum_{t=1}^{\infty}\frac{300}{1.10^t}\right) = 0.5\left(-1454 + \frac{300}{0.1}\right) = \$773.$$

It is more attractive for the firm to wait until next year before deciding whether to make the investment.

This example demonstrates the importance of taking into account the ability to respond to changes in risky variables, such as price. This is the essence of the real option approach. Three key characteristics of this example which make it worthwhile for the firm to delay the decision to invest.

- The future price of widgets is unknown.
- The firm had the ability to delay a decision. If the investment was "now or never" the firm would have undertaken the investment immediately.
- The $1600 expenditure is irreversible. If the firm could recover its total investment if prices dropped in the second period, it would invest immediately. If the investment were partially recoverable, then it may or may not invest immediately. Some degree of irreversibility is necessary for there to be value in delaying the decision.

Uncertainty, irreversibility, and the ability to delay a decision are all necessary for the real options approach to be relevant.

2. Real Options and Forestry

Using a real options approach to forestry, we would ask what is the value of an option to harvest a stand of trees at some time in the future. There are several uncertainties in the future value of this investment opportunity, chief of which would be price and environmental uncertainties including the risk of fire and disease. In this report we consider only price risk. (The complexity of solving a real options problem increases dramatically as the number of uncertain variables is increased.)

There are several irreversible expenditures required when making the investment to turn standing trees into commercial logs, including harvesting and transportation costs, and any silvicultural expenditures required as the stand grows. If the price of wood falls significantly, it is very likely these expenditures would not be recoverable even if the right to harvest the land could be sold.

The third characteristic which creates an option value is the ability to delay an investment. Are forestry firms able to delay harvesting a stand of trees in times of depressed wood prices? If the answer is yes, then commercial forests can act as a natural hedge against price risk. When prices are low, a firm can wait for things to improve, while benefiting from another year's growth in the stand.

In Ontario, recommended harvesting schedule are specified in the Forest Management Plan agreed to by the firm and the Ministry of Natural Resources. The annual allowable cut is determined in an attempt to keep an even flow of wood to local mills. If forestry firms had to adhere strictly to the schedule of annual allowable cuts, then option value would be irrelevant as the firm would no discretion in choosing harvest time. However in reality firms are given some flexibility to deviate from the annual allowable cut in response to market conditions.

3. Characterizing Price Risk

To characterize price risk, we assume that the price of sawlogs follows some known stochastic process. The nature of this process is deduced from statistical analysis of historical data and knowledge about lumber markets. The term stochastic process describes a variable that evolves in a way that is at least in part random. Typically in real options problems, it is assumed that change in the uncertain variable is the sum of a known drift term and a random term that is drawn from a normal distribution ie:

$$Change\ in\ price = [known\ drift\ term] + [draw\ from\ a\ normal\ distibution].$$

If we expect price to drift upwards over time, then we would likely choose a process call geometric Brownian motion, which is often used to model stock market prices. For commodities like lumber and oil, it makes more sense to model price as a mean reverting process in which price can rise or fall for a period of time, but eventually returns to some long run average which reflects both the cost of production and the prices of market substitutes. In the long run, growth in the real price of lumber should be limited by the existence of substitutes for building materials and fiber. Another change in world timber markets which would point to mean reverting prices is the shift from old growth stands to second growth and plantation grown industrial wood. This is documented by Sedjo (1997), among others.

The mean reverting stochastic process used to describe the path of lumber prices in this report is as follows:

$$dP = \eta(\overline{P} - P)dt + \sigma P dz \qquad \textbf{(1)}$$

where,

P= price of sawlogs

dP = change in price over an infinitesimally small time interval (dt)

η = the speed of mean reversion

σ = volatility

dz = increment of a Wiener process, i.e. a draw from a standard normal distribution

$\overline{P}$ = the long run mean price of sawlogs

The choice of η, σ, and $\overline{P}$ has an important impact on the value of the option to harvest. These are generally determined through analysis of historical data, tempered by knowledge of future market trends. The larger the speed of mean reversion, η, the more rapidly the price returns to its long run mean, $\overline{P}$. The higher is volatility, σ, the more likely it is that price will deviate significantly from the mean in the next period. A high σ tends to make it more worthwhile to delay harvesting to wait for a better price.

A discrete time approximation to Equation (1) is:

$$P_t - P_{t-1} = \eta \overline{P} \Delta t - \eta \ \Delta t \, P_{t-1} + \sigma P_{t-1} \sqrt{\Delta t} \varepsilon_t$$

where ε_t is a normally distributed random variable with a mean of zero and a standard deviation of 1. After some algebraic manipulation the parameters can be estimated by ordinary least squares. The data used to estimate the parameters was the Ontario softwood lumber price index (Statistics Canada Cansim II, Series V1575012) over the period January 1981 to May 2002. Regression estimates were as follows: $\eta = 0.3$, $\sigma = 0.2$ and $\overline{P}=69.3$. A value of 0.3 for the speed of mean reversion implies that if price is pushed away from the mean, it will take about 3.3 years to revert to the mean provided no other shocks occur in the meantime. The estimated $\overline{P}$ is for the price index, and this had to be translated into a price at the mill. Because the recent price index values are close to the estimated $\overline{P}$, the current SPF1 price going in to the mill was chosen as the $\overline{P}$ for the analysis. It is assumed in this analysis that the prices of other products will maintain the same relation to SPF1 as is true today.

The accuracy of the parameter estimates is limited by the fairly simple mean reverting price path that has been chosen (Equation 1). It is likely that a more complex process (such as one with stochastic volatility) would be a better description of the data. However, increasing the complexity of the assumed price process complicates the solution of the real options problem, and is beyond the scope of this analysis.

One check on the plausibility of the assumed price process is to simulate numerous different price forecasts using the chosen parameters. Because one of the parameters determining future prices is a draw from a normal distribution, there is an infinite number of future price paths that could be generated from the process of Equation (1) and our chosen parameters. To show what the price paths might look like we have simulated four different realizations of price over a 100 year period. These simulations are shown in Figure 14 and Figure 15 below. With the base case parameters the price remains generally with in the \$20 to \$100 per cubic meter range over the 100 year simulation. With a lower volatility assumption prices ($\sigma = 0.1$) prices generally keep within the \$40 to \$80 range.

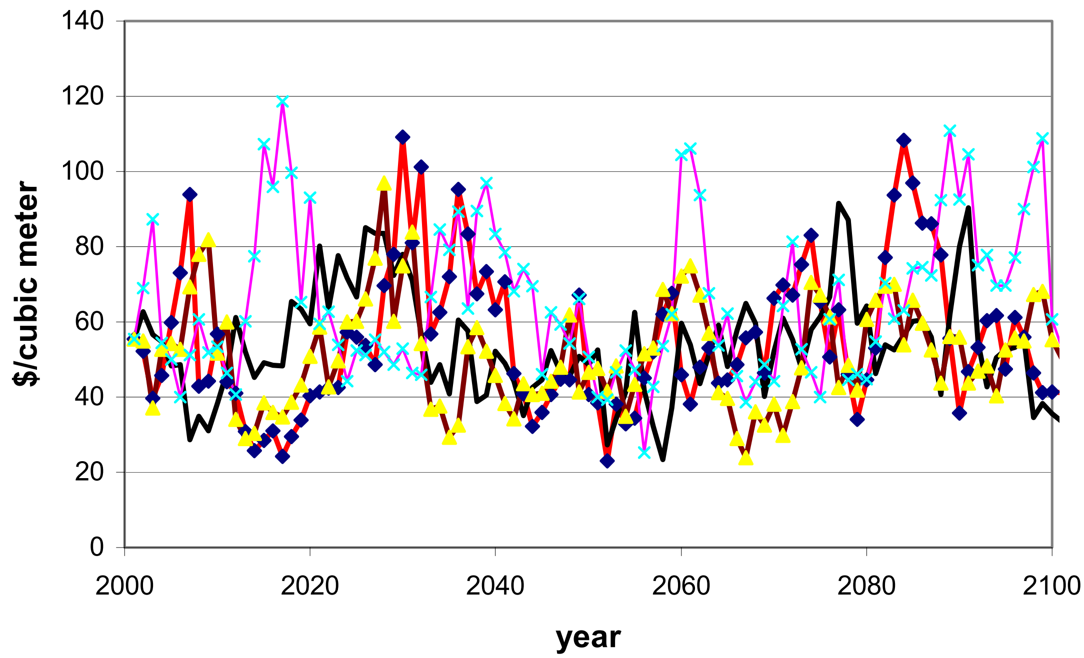

Figure 14 Base case price simulations, η = 0.3, σ=0.2. Each line represents one possible realization of the random mean reverting price process with a speed of mean reversion of 0.3 and instantaneous variance of 0.2.

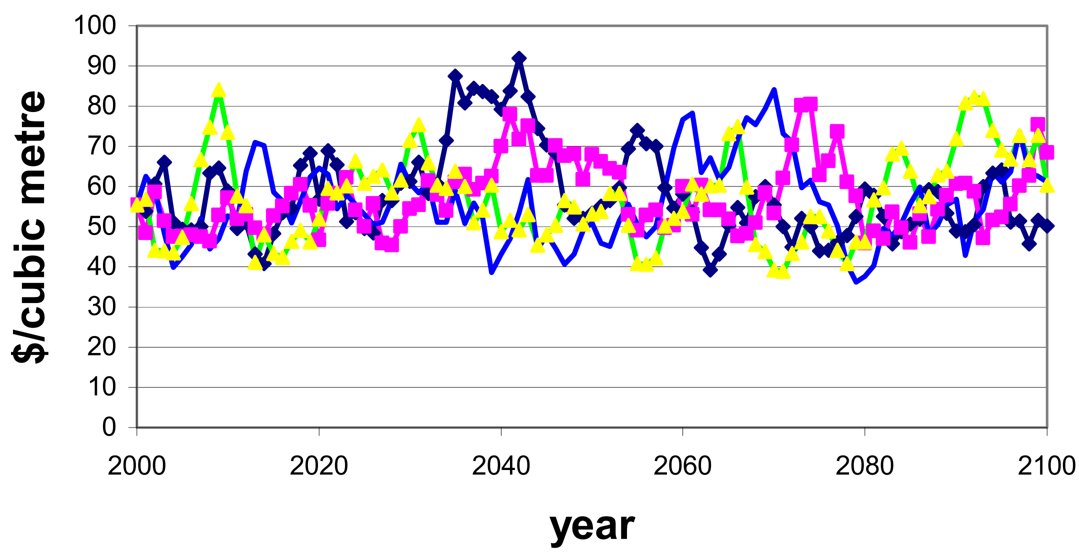

Figure 15. Alternative price simulations, η = 0.3, σ = 0.1. Each line represents one possible realization of the random mean reverting price process with a speed of mean reversion of 0.3 and instantaneous variance of 0.1.

4. Solution of the Real Options Problem

The harvesting decision is characterized by a linear complementarity problem[13] which is solved numerically. Details of the solution are presented in Insley and Rollins (2002).[14]

V. Results using the Real Options Approach for PJ1

1. Public Perspective

Unlike the Faustmann approach, the real options approach does not yield an optimal harvesting time that is known with certainty at the beginning of a rotation. Rather, the optimal harvesting time will depend on prices in a given year, and cannot be known in advance. The results of the real options approach include a critical price estimate for any given year: harvesting should take place if prices meet or exceed that critical price.

Figure 16 shows the value of the options to harvest a stand of trees as a function of the current price for PJ1, site class 1, under intensive 2 treatment, assuming a real discount rate of 3%. Each individual graph in the figure represents a different stand age, and indicates the net merchantable volume per hectare (NMV) achieved by that age, as well as the critical price at which it is worthwhile harvesting. The vertical axis represents the value of the option to harvest as well as the payout from harvesting immediately. The solid curve in each of the graphs represents the value of the opportunity to harvest the stand of trees, *V*, if there are no restrictions on harvesting after the silvicultural treatments are completed, and markets are available for the logs. The dotted line represents the payout from harvesting immediately. The dashed vertical line marks the critical price. When the value of the opportunity to harvest, *V*, is above the payout line, the value of delaying the harvest exceeds the value of harvesting immediately, and it is worthwhile waiting. Once *V* touches the payout line, it is worthwhile harvesting. The point of tangency determines the critical price.

A forest manager will consider both price and volume in deciding when to harvest. If merchantable volumes are low this implies the stand is young and it is worth waiting to gain extra years of growth. If price is low, it may be worthwhile delaying the harvest because with mean reverting prices, in the future we expect price to increase towards a

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[13] Linear complementarity problems are discussed in Wilmott *et al*, 1993.

[14] A similar problem is examined in Insley (2002).

long run average. Thus we observe in Figure 16 that at low prices, the value of the option to harvest the stand is significantly above the payout from harvesting immediately. As the price rises along the horizontal axis, *V* approaches and eventually meets the payout line. When *V* and the payout line coincide, this implies that prices are high enough that it is worthwhile harvesting right away.

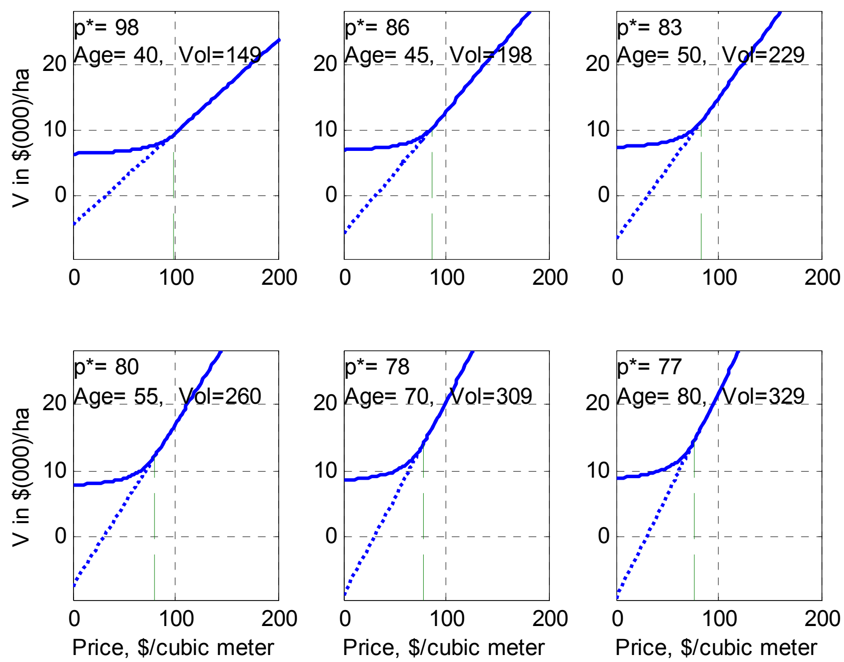

Figure 16: Value of the opportunity to harvest a PJ1 stand at different stand ages, discount rate of 3%, intensive 2 treatment.

If the current price is below the critical price it is optimal to delay harvesting to the next period. If the current price is above the critical price it is optimal to harvest immediately. For a 40 year old stand, according to Figure 16, it would be worth harvesting if the price of SPF1 reached $\$98/m^3$. Although this is a fairly young age by boreal forest standards, with a mean reverting price, it makes sense to harvest early to take advantage of a temporarily high price. By age 45 the critical price has dropped significantly to \$86. As the stand ages the critical price continues to drop because the opportunity cost of delaying the harvest is reduced. The critical price reaches a steady state of about \$76 beyond age 80 when the trees are no longer growing.

It may seem curious that the steady state price of \$76 is above the long run average mean of approximately \$50, which also represents the current price. What the model is telling us is that given historical volatility levels, it is worthwhile delaying harvesting until a price higher than the long run average is achieved. Because this is a stand level analysis, there may costs to delaying the harvest which are being ignored, including costs of reduced capacity utilization at the mill. Including such costs would reduce the critical price at which harvesting is worthwhile. These added costs will be investigated in future research.

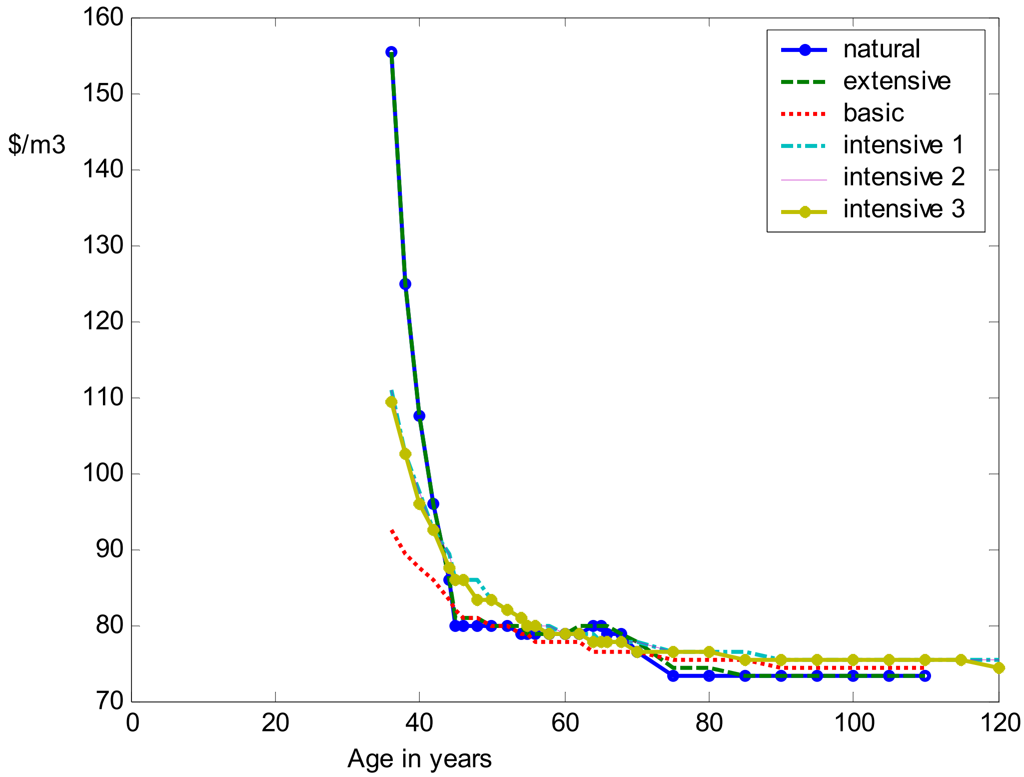

Figure 17. Critical price as a function of stand age for PJ1, for different management intensities, discount rate of 3%.

Figure 17 depicts critical price versus stand age for our representative stand for various management intensities. In the early years we observe that the critical prices for the extensive natural treatments are much higher than for basic or intensive. This is because growth is slower in the natural and extensive regimes, meaning that the opportunity cost of harvesting in these early years is much higher. Recall that the extensive and natural regimes involve natural regeneration with no spending on planting or tending.

We do not have good estimates of the decay that would occur in harvestable volumes for stands older than 100 years. The real options analysis does not use the volume estimates once decline sets in. If we had estimates of the extent of this *cull* we would expect that critical prices would decline after age 100 reflecting the desire to harvest sooner to reduce the amount of cull.

Of significant interest is the value of the opportunity to harvest the stand of trees at the beginning of the first rotation – i.e. on land that has no mature trees. This value represents the maximum amount that a firm would be willing to pay for harvesting rights to the stand, ignoring taxes and other charges, and assuming the firm has complete flexibility as to the timing of the harvest and that markets exist for the logs. A comparison of value over the different management intensities and for three different discount rates is shown in Table 17. Also shown in the table are values computed using the Faustmann formula, assuming a constant price equal to the long-run mean reverting level used in the stochastic model.

Table 17. Land value at the beginning of the first rotation, $/hectare, PJ1.

3% discount rate	**Real options**	**Faustmann**	**Improvement with real options approach** [15]
Natural	$1864	$1047	$817
Extensive	$1638	$890	$748
Basic	$778	$305	$437
Intensive 1	$427	-$457	$884
Intensive 2	$460	-$448	$508
Intensive 3	$539	-$406	$945
5% discount rate			
Natural	$576	$352	$224
Extensive	$504	$299	$205
Basic	-$410	-$512	$102
Intensive 1	-$642	-$928	$286
Intensive 2	-$651	-$943	$292
Intensive 3	-$645	-$945	$300
7% discount rate			
Natural	$209	$134	$75
Extensive	$182	$114	$69
Basic	-$674	-$738	$64
Intensive 1	-$855	-1001	$146
Intensive 2	-$875	-1024	$149
Intensive 3	-$888	-1041	$153

Not surprisingly the value of the opportunity to harvest the stand of trees is much larger than that calculated using the basic Faustmann formula. This is because the option value approach assumes that the forest manager is behaving optimally in the face of volatile prices. When prices are low, harvesting is delayed; when prices increase, harvesting may occur sooner than originally planned. With the Faustmann analysis we have assumed a constant price equal to the long run mean used in the stochastic model; thus the difference between the two approaches reflects the ability to take advantage of price volatility around the mean.

Both the Faustmann and the real options approaches indicate that the extra expenditures incurred in the basic and intensive regimes cannot be justified by the additional revenue that will accrue from harvesting the trees. There may be other reasons to incur these

[15] Real options minus Faustmann.

expenditures, (such as increasing protected natural areas while preventing mill closures) but clearly the added silvicultural costs far outweigh the extra revenues received from achieving SPF1 volumes sooner and in greater quantity.

The analysis is very sensitive to the discount rate chosen, since the costs of IFM occur in the first 35 years, and the benefits, in terms of higher volumes, occur after 35 years. The volumes for intensive management are actually lower than for basic management until about age 65. This is because of thinning operations that remove trees to manage stand density in the intensive regime. The trees that are left take some time to benefit from the more favourable conditions. It is only at a 3% discount rate, using the real options approach, that all three regimes show positive net present value, although the extensive regime still gives the largest return.

The values in Table 17 do not depend on the current price of wood. This contrasts with stands of age 45 and above shown in Figure 16, for which value increases with the current price. This is intuitively reasonable. No matter what the price is at the beginning of a rotation, by the time the stand achieves harvestable volumes, we would expect the price to have reverted toward the long run mean. Thus land values at the beginning of a rotation are relatively insensitive to today's product prices given the parameters we have chosen for our mean reverting process. If we had used a process of geometric Brownian motion, rather than mean reversion, the results would have been different. Under geometric Brownian motion, the expected price rises at a constant rate over time. This implies that land values today would depend on the current price.

2 Firm Perspective

The private firm's perspective on IFM will be very different from that of the government regulator for two main reasons: (i) the firm's revenues come from harvesting an existing inventory of mature timber and (ii) the maximum volume of wood harvested is set by annual allowable cut regulations. Unlike a government regulator, the firm would not consider the marginal benefits of an IFM investment in a given stand to be the extra revenues received from harvesting that stand once it reaches maturity. Rather, for the firm the benefits of today's investment in IFM are the added revenues that will result if the regulator permits an immediate increase in the firm's allowable cut of the mature timber inventory.[16] If an investment in intensive forest management today gives the firm greater access to the existing mature inventory, then the investment may well make sense for the firm.

Suppose a firm is told by a regulator that it will be given the right to harvest a mature stand of trees, if it agrees to begin a program of IFM once the stand is harvested. The value of this investment opportunity is reflected in the value of a 50 year old stand, shown in the third panel of Figure 16 for the intensive 2 level of management. The values shown here are significantly larger than the values at the beginning of the rotation,

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[16] An immediate increase in permitted harvesting levels today in recognition of expected future growth dur to investment in IFM has been termed the Allowable Cut Effect (ACE) in the forest industry. Luckhert and Haley (1995) and Hegan and Luckhert (2000) provide an analysis of the ACE as a policy tool.

reported in Table 3. Even in the limit for very low current prices of SPF lumber, the value of the opportunity to harvest the land for the intensive regime is $7500/ha. It would be worthwhile for the firm to undertake intensive management, if as a result it is given the right to harvest the existing inventory. The firm would, however, make the largest return if it could achieve an increased allowable cut without having to make the investment in intensive management. The economics for the firm would also depend on stumpage and taxes paid to government, neither of which has been included in this analysis.

Although an investment in IFM may make sense for the firm, it is clearly the role of the regulator to compare the marginal costs and benefits of the scheme from society's point of view before embarking on a scheme to encourage firms to make such investments.

3. Sensitivities on key parameters

Sensitivities need to be conducted on key parameters which affect the expected value of the stand at the beginning of a rotation. These sensitivities will be contained in a subsequent report. Two parameters to be considered are volatility and speed of mean reversion.

3.1 Volatility

A lower volatility decreases the value of a stand and also decreases the critical price at which it is optimal to harvest. With less volatile prices there is less opportunity for a forest manager to take advantage of temporarily high prices. A comparison of the results for PJ1 when volatility is halved to 0.2 from 0.1 is shown in Table 18 for a 3% discount rate.

Table 18

Sensitivity on the volatility estimate (σ) for PJ1, Site Class 1		
$/ha - 3% discount rate	Real Option: Volatility = 0.1	Real Option Volatility = 0.2
Natural	$ 1342	$1864
Extensive	$1169	$1638
Basic	$243	$778
Intensive 1	-$143	$427
Intensive 2	-$127	$460
Intensive 3	-$75	$540

3.2 Speed of mean reversion

A slower reversion to the mean price will also increase the value of a stand. For example, decreasing the speed of mean reversion to 0.2 from 0.3 causes the NPV for JP1, basic, to increase from $778/ha for $804/ha, at a 3% discount rate. A 0.2 speed of mean reversion implies that if price is pushed away from the long run mean, it will take about 5 years to return to the mean.

VI. Results for SB1 and SP1

Results for SB1 and SP1 are summarized in the tables below. In general land values are less than for PJ1 due to lower yields as was observed in Figure 7.

Table 19. SB1: Land value at the beginning of the first rotation and optimal Faustmann rotation age.

	Real options	Faustmann	
3% discount rate	**$/hectare**	**$/hectare**	**Rotation age**
Natural	$147	$82	105
Extensive	$ 59	$38	114
Basic	-$277	-$389	95
Intensive 1	-$177	-$432	83
5% discount rate			
Natural	$ 19	$9	105
Extensive	$ 8	$3	114
Basic	-$432	-$461	95
Intensive	-$414	-$484	73
7% discount rate			
Natural	$ 3	$1	105
Extensive	$ 2	$0	114
Basic	-$435	-$463	95
Intensive 1	-$433	-$469	66

Table 20. SP1: Land value at the beginning of the first rotation and optimal Faustmann rotation age.

	Real options	Faustmann	
3% discount rate	**$/hectare**	**$/hectare**	**Rotation age**
Natural	$133	118	85
Extensive	$ 103	85	85
Basic	-$259	-364	75
Intensive 1	-$627	-972	73
Intensive 2	-$606	-962	67
Intensive 3	-$610	-970	65
Intensive Sw	-$615	-757	73
5% discount rate			
Natural	$ 17	19	84
Extensive	$ 13	13	84
Basic	-$384	-441	75
Intensive 1	-$849	-1009	64
Intensive 2	-$860	-1026	60
Intensive 3	-$879	-1048	59
Intensive Sw	-$823	-959	64
7% discount rate			
Natural	$ 3	3	85
Extensive	$ 2	1	84
Basic	-$383	-442	75
Intensive 1	-$848	-974	59
Intensive 2	-$866	-996	55
Intensive 3	-$889	-1022	55
Intensive Sw	-$819	-957	58

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Appendix A: SPF 3 and Poplar/Birch Volumes

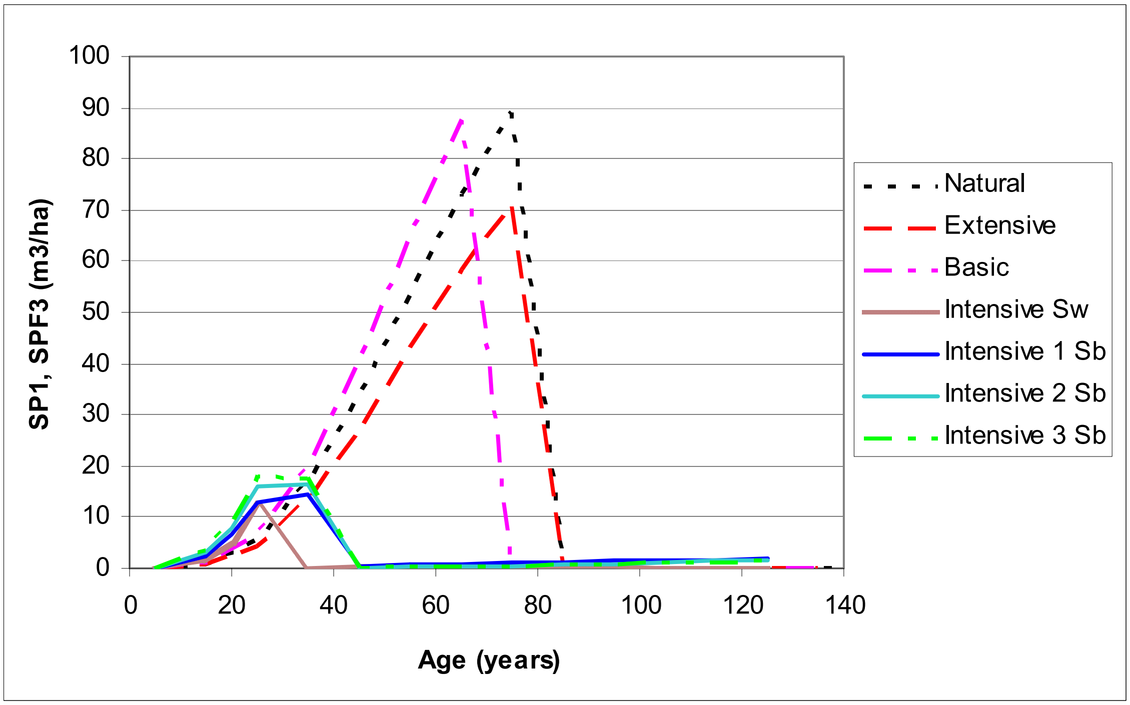

Figure 18. SP1, SPF3 Volumes

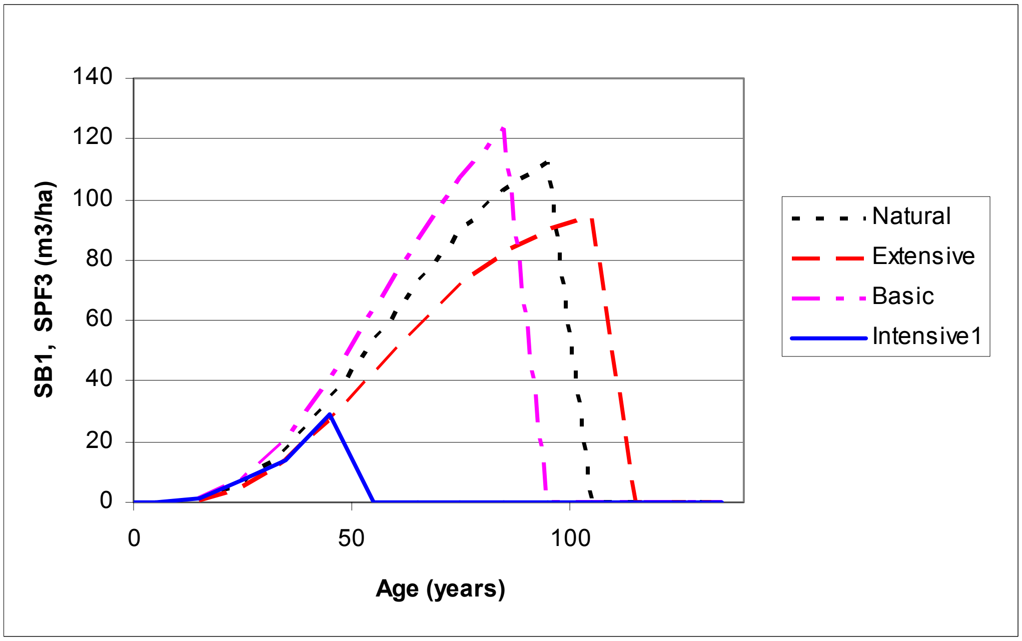

Figure 19. SB1, SPF3 volumes

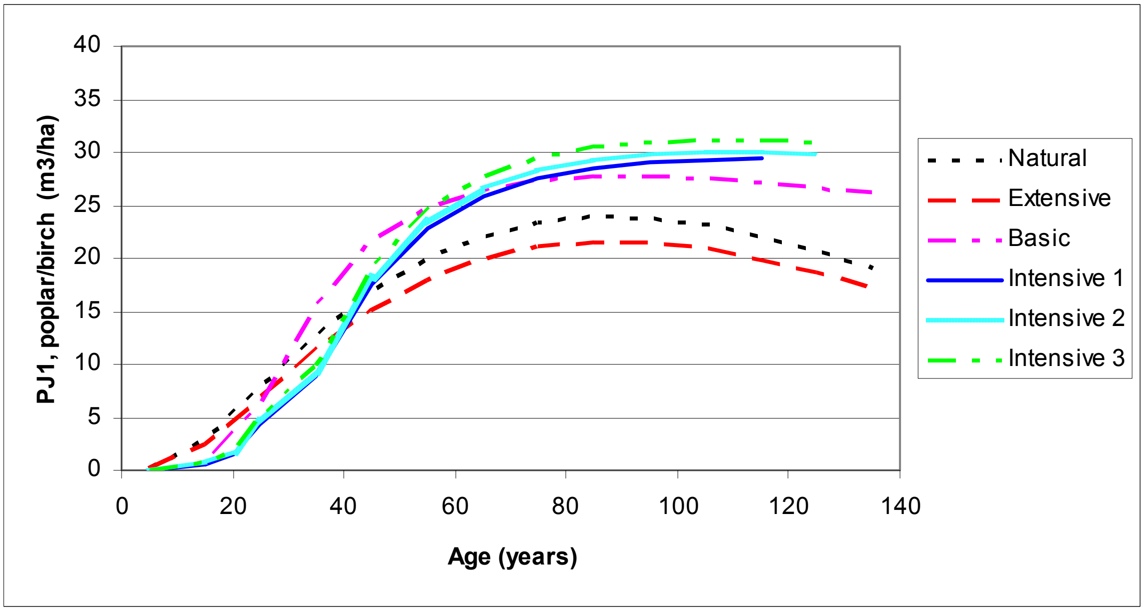

Figure 20. Poplar/Birch Volumes, PJ1, Site Class 1

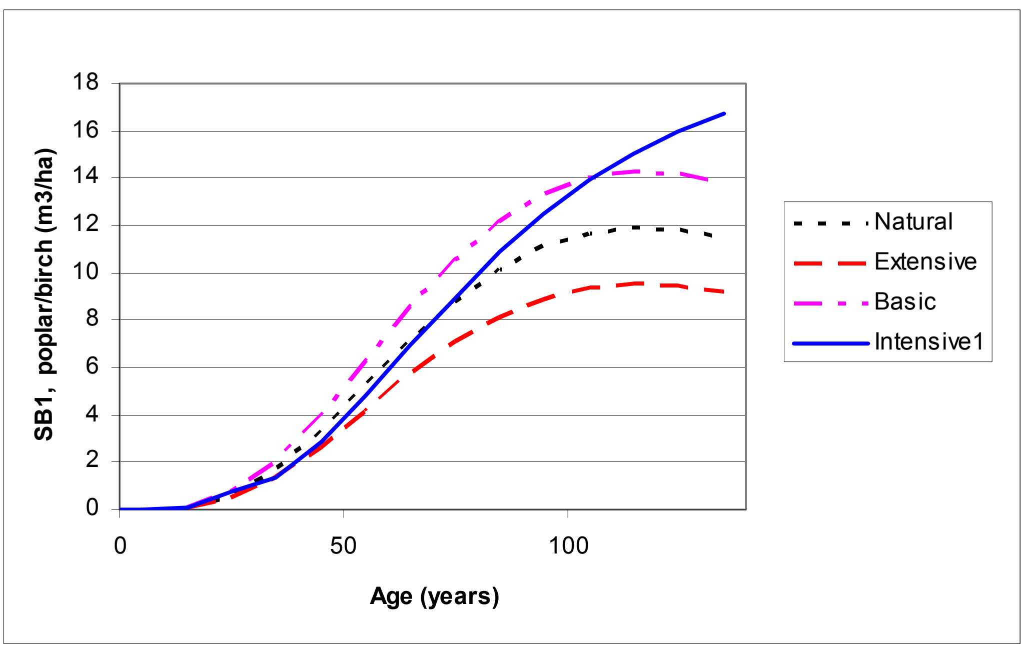

Figure 21. Poplar/birch volumes, SB1, Site Class 1

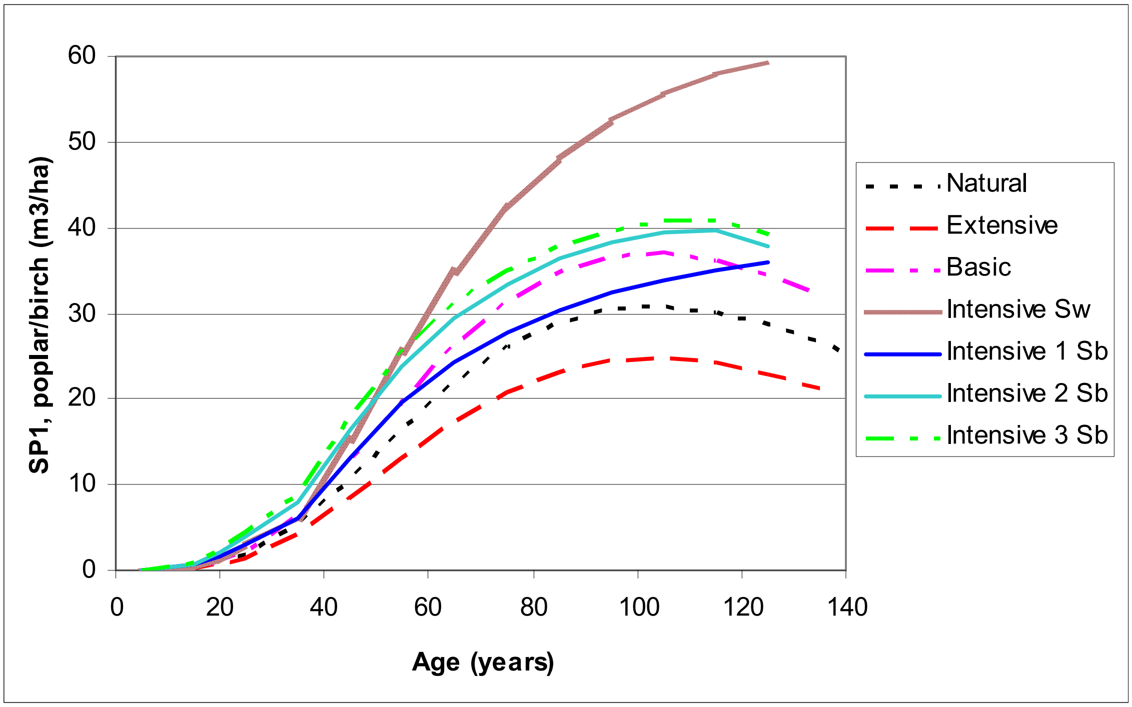

Figure 22. Poplar/birch volumes, SP1, Site Class 1