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DISCUSSION PAPER NO. 284

An Analysis of the Present Value of Stumpage under a Variety of Economic and Management Conditions

by Terry Heaps

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RÉSUMÉ

L'auteur du présent document calcule la valeur actuelle des peuplements d'arbres, ou la valeur prévue des plantations de sapins Douglas dans les régions côtières de la Colombie-Britannique, selon différents degrés de fertilité des terres. Il met à profit les récents progrès réalisés dans le calcul de la croissance des arbres, de la valeur du produit fini et du coût de l'abattage. Les estimations de la croissance des arbres ont été obtenues à l'aide du simulateur DFSIM mis au point par le Service forestier américain pour quatre catégories de terres réparties selon leur degré de fertilité. Dans l'équation pour déterminer la valeur du produit fini, la valeur est assimilée au diamètre moyen du peuplement et les équations déterminant le coût de l'abattage tiennent compte des économies de grosseur (plus les arbres sont gros, plus le coût du mètre cube diminue) et des variations dans les caractéristiques physiques des lieux. L'auteur a utilisé la méthode courante en Colombie-Britannique (la formule Rothery) pour calculer la valeur des peuplements.

Le cycle de reproduction fondé sur le critère économique est celui qui maximise la valeur actuelle d'un peuplement. Ce cycle devrait être choisi pour des raisons d'efficacité économique, de préférence au cycle du volume maximal, celui qui vise à maximiser

le volume moyen d'un peuplement atteint durant le cycle (c'est-à-dire, l'augmentation annuelle moyenne). L'auteur démontre que, contrairement à la croyance populaire, les cycles fondés sur le critère économique dans le cas des peuplements incultes ne sont pas plus courts que les cycles du volume maximal, sauf dans de bonnes terres et dans des conditions favorables d'abattage (au taux d'escompte de 5 %). Il fait remarquer également que les cycles fondés sur le critère économique varient considérablement selon la fertilité du sol et qu'une sylviculture visant à assurer un rendement soutenu ne semble pas économiquement rentable dans le cas de terres basses ou de terres pauvres, si les conditions d'abattage sont également difficiles. Autre point à considérer, le cycle de reproduction fondé sur le critière économique varie considérablement selon les conditions d'abattage et les hypothèses sur le prix futur du produit fini et sur le taux d'escompte utilisé. L'auteur propose d'établir une fourchette de prix pour résoudre l'incertitude relative au prix futur du produit fini.

Les cycles fondés sur le critère économique peuvent être influencés par l'inclusion d'avantages non tangibles dans l'analyse avantages-coûts. Un modèle sommaire de ces avantages intangibles indique que des aires publiques de récréation peuvent être aménagées de façon rentable dans le cas de cycles très longs.

Le simulateur DFSIM conçu pour calculer la croissance des arbres sert à établir des prédictions quant à l'effet sur la croissance de combinaisons de méthodes de sylviculture intensive, telles que le repiquage, l'espacement des jeunes plants, l'arrachage des plants propres à la vente, et la fertilisation. Les cycles de reproduction fondés sur le critère économique et les valeurs prévues des terres sont calculés pour un certain nombre d'exemples de ces pratiques sylvicoles. L'auteur démontre que certaines combinaisons de ces pratiques augmentent la valeur présente des droits de coupe par rapport aux exemples sans aucune culture, sur de bonnes terres ou sur des terres de fertilité moyenne où les conditions d'abattage sont favorables. Le coût et la valeur des jeunes plants vendus sont d'une importance capitale pour déterminer la rentabilité d'une culture intensive. La plantation d'arbres sans aucun autre traitement sylvicole ne semble pas économiquement rentable. Les cycles de reproduction fondés sur le critère économique ne sont pas sensiblement modifiés par rapport aux exemples de reboisement sans autre traitement. Le texte comprend aussi un examen des résultats obtenus par d'autres auteurs qui ont calculé les cycles de reproduction pour divers genres d'applications sylvicoles.

Dans la dernière partie du document, l'auteur traite de l'attitude des secteurs public et privé en Amérique du Nord envers la sylviculture intensive. Ce n'est que récemment, comme il le constate, qu'on a commencé à s'intéresser à cette activité. Il examine et critique les attitudes actuelles envers la sylviculture intensive, s'intéressant spécialement au ministère des forêts de la Colombie-Britannique.

ABSTRACT

This paper estimates the present value of stumpage or soil expectation values for growing Coastal Douglas-fir in British Columbia under a variety of conditions. The calculations make use of recent advances in estimating tree growth and in estimating end product values and logging costs. Tree growth esimates were obtained from the DFSIM tree growth simulator developed by the U.S. Forest Service for four classes of soil fertility. The end product value equation relates value to the average diameter of the stand and the logging cost equations incorporate economies of size (cost per m^3 is less the larger the tree) and allow for variations in the physical characteristics of the site. The B.C. Appraisal method (the Rothery formula) is used to calculate stumpage.

The financial rotation is the rotation which maximizes the present value of stumpage. This rotation should be used on grounds of economic effiency rather than the maximum volume rotation which maximizes stand volume averaged over the rotation period (i.e. mean annual increment). It is shown that contrary to popular belief, financial rotations for untreated stands are not shorter than maximum volume rotations except on good sites under good logging conditions (at a 5% discount rate). It is also shown that financial rotations vary substantially with soil fertility and that basic sustained yield forestry does not appear to be economically viable on low sites or on poor sites if logging conditions are also poor. A further point is that financial rotations vary substantially depending on logging conditions and on assumptions one makes about future end product prices and on the discount rate used. A minimax strategy is suggested for resolving uncertainity about future end product prices.

Financial rotations may be affected by including non-timber values in the cost-benefit calculation. A crude model of these non-timber values shows that popular recreation areas may justifiably be managed on very long rotations.

The DFSIM tree growth simulator makes predictions about the effect on growth of combinations of intensive silvicultural methods such as planting, juvenile spacing, commercial thinning and fertilization. Financial rotations and soil expectation values are calculated for a number of examples of these treatments. Some combinations of these treatments are shown to increase the present value of stumpage over the no treatment examples on good sites or on medium sites where logging conditions are good. The costs and values of the early commercial thinnings are critical in determining the economic viability of intensive management. Planting without further treatment does not appear to be economically viable. Financial rotations are not changed very much over the no treatment examples. The results of other authors who have estimated rotations for various types of stand treatments are also reviewed.

A final section reviews the attitudes of both the public and private sectors in North America towards intensive management. It is shown that interest in the subject has arisen only recently. Current attitudes towards intensive silviculture are reviewed and critiqued with special attention paid to the B.C. Ministry of Forests.

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I. Introduction

Many different criteria have been proposed for determining the age at which a stand of trees should be harvested. These criteria are discussed in detail in any forest management textbook, for example Brasnett (1953) or Davis (1966). The criteria can be broadly classified into two groups. Some criteria emphasize physical objectives, i.e. technical rotations where trees are cut when they are large enough to produce a desired product, silvicultural rotations where trees are allowed to grow until their vigour of growth starts to fall, or maximum volume rotations where the rotation maximizes the average volume of wood (MAI = mean annual increment) harvested over a cutting cycle. On the other hand, there are criteria which maximize economic objectives. These objectives may be forest rent (FR) - the net value of the crop when harvested, averaged over the cutting cycle; present net worth (PNW) - the net present value of the revenues and costs associated with a single harvest; financial rotations which maximize the soil expectation value (SE) defined as the net present value of the revenues and costs associated with repeated harvests from the same site; and finally rotations which maximize the internal rate of return on net revenues from the repeated cropping operation.

Economists are now generally agreed, for reasons discussed in Samuelson (1976), that maximizing SE is the correct economic objective if the aim of the forest land owner is to obtain the highest possible return on his assets. However, the use of this criterion is generally believed to result in much shorter rotations than the use of physical or maximum FR criteria. For example, Goundrey (1960) works out an example of coniferous stands in Quebec where the financial rotation is 52 years, while the maximum forest rent rotation is 72 years and the maximum volume rotation is 80 years.[1]

This example is based on a 5% interest rate. A higher interest rate would substantially increase the difference.

These differences in rotations have caused economic rotations to be the subject of much criticism in the forestry literature. Some of these criticisms will be reviewed in Section 3. However, examples like the one above, have been worked out using very rudimentary biological and economic models. Much more sophisticated models, both of the growth of managed stands and of the revenues and costs associated with harvesting such stands, are gradually becoming available particularly for the more valuable species. Since most of the future harvest will come from managed stands, it is clear that the rotations to be used in the future should be based on our best knowledge of the growth of these stands, rather than on volume against age (VAC) curves derived from observations of old growth stands. Moreover, the economic rotations should be based on the best economic data available. The revenue and cost functions now available estimate these values as functions of stand characteristics such as average diameter at breast height (DBH), average height, volume per hectare, trees per hectare and various physical characteristics of the site. There are important economies of size in logging and larger logs command a quality premium (i.e. are more valuable per unit volume, see p. 7). These factors tend to lengthen economic rotations, reducing the commonly supposed significant difference between economic and physical rotations. In many examples below, these factors actually cause the economic rotation to be no less than the physical rotation.

Another factor that may tend to lengthen economic rotations is the use of stand tending techniques to increase forest growth rates and to improve the quality of the wood. Intuitively, putting a stand under intensive management may increase the growth rate of its value and hence make growing trees seem like a better investment, relative to other types of investment, over a longer growing cycle. Fortunately, the tree growth simulators predict the effects on yield of such intensive management techniques as juvenile spacing, commercial thinnings and fertilization so that the impact on rotations of using these techniques can be estimated. Moreover, it will be possible to consider the important question as to whether intensive management is a profitable activity.

This report will use the data mentioned above to calculate various economic rotation periods for Pacific Coast Douglas-fir under a variety of conditions The first set of examples are of stands that are managed in the sense that care is taken to ensure prompt natural regeneration after harvesting. However, these stands are then subjected to no further treatment during the growing cycle. The financial rotations in these examples turn out to be significantly shorter than maximum volume rotations <u>only</u> under good growing conditions and good logging conditions. It is also interesting to note that even in these cases, the tree growth simulators predict that the use of the (shorter) financial rotations would not reduce substantially the average annual amount of wood harvested (i.e., the MAI).

The second set of examples will consider stands subjected to some form of treatment in addition to site preparation, i.e., stands which are managed intensively. One treatment considered is replanting the site immediately after harvesting. The replanting examples usually have the same financial rotations as the natural regeneration examples. Replanting results in larger volumes being harvested than under natural regeneration. However, the cost of replanting is always greatly above the increase in the economic benefits of the harvests. The other treatments involve combinations of thinnings, juvenile spacing and fertilization. In these examples, the financial rotations tend to be longer than the natural regeneration-no treatment examples. However, the difference is not substantial. It would probably be more dramatic if it had been possible to prescribe the treatments in an economically optimal manner (see, for example, the results of Riiter, Brodie and Kao (1982) discussed on p. 40). One example, involving all three types of treatment, substantially increases the values that can be derived from forestry <u>on the better growing sites</u>.

The calculations and analyses of economic rotations for non-intensively managed stands are described in the fourth section of this report. The second section describes the data used and establishes notation. The third section then gives some details on the calculation of PNW and financial rotations. An outline and critique of the key assumptions on which these calculations are based is also given.

A number of examples of intensive management are analysed in the fifth section. This section also discusses the results of other authors who have calculated rotations for various types of stand treatment.

Both forest companies and Forest Services in North America have shown an increasing interest in the practice of intensive management on their lands at least since the 1950's. This historical process is described in a sixth section with the purposes of throwing some light on why the attitudes of both the private and public sectors towards devoting resources to this type of activity have changed. Current methods of evaluating and financing silvicultural investments are reviewed and critiqued. Special attention is given to the B.C. Ministry of Forests which has plans to greatly expand the practice of intensive silviculture in its domain of jurisdiction.

The final section of this report will summarize the conclusions of this and the other studies.

II. Description of Data

The growth data for coastal Douglas-fir used in this study are estimates developed by the United States DFSIM tree growth simulator.[2] Douglas-fir is the most valuable species growing on Vancouver Island and the lower coastal area of British Columbia. The productive forest area in this region is distributed by soil fertility class -- 4% good, 38% medium, 49% poor and 9% low (B.C. Ministry of Forests, 1980a, 593). DFSIM gives growth estimates for each of these classes. The discussion below will focus on the most important site class -- the medium site characterized by site index 125.[3] Data on site indices 145 (good) and 105 (poor) are also provided in appendices A and B and sometimes discussed in the text. Table 1 gives the biological characteristics of the medium site with variable definitions being given below the table. It is assumed that the stand is grown using natural regeneration. The site is however prepared for the establishment of each new crop by debris removal, scarification, etc. It will be assumed that fully stocked new stands are established immediately after clear cutting. The data is thus representative of undisturbed second growth stands rather than the virgin stands that have been harvested in the past. Thus there are many more trees per hectare and the trees are of much smaller diameter than in virgin stands.

It may be noted that as the stand ages, many of the trees die. If the stand was thinned periodically, some of this mortality could be harvested which might add to the value of the stand if the thinning could be done profitably.[4] The MAI is based here on the potential log volume the stand can produce as defined explicitly under the table. In this example, it is at a maximum at 75 years. However, it is fairly constant for a range of ages being within 5% of its maximum between the ages of 55 and 100. A rotation anywhere in this range would generate essentially the same average annual fibre supply.

TABLE 1

BIOLOGICAL CHARACTERISTICS OF NATURAL, NO TREATMENT, MANAGED

COASTAL DOUGLAS FIR STAND, SITE INDEX 125

Age (yrs.)	DBH (cms.)	HT (m)	STEMS (#/ha.)	MAI (m^3/ha/yr.)
25	13.2	14.0	2391	-
30	16.3	17.7	1902	5.6
35	19.3	21.2	1512	8.1
40	22.0	24.3	1233	9.8
45	24.7	27.2	1037	10.8
50	27.2	29.8	894	11.5
55	29.6	32.3	785	11.8
60	32.0	34.5	701	12.0
65	34.2	36.6	632	12.2
70	36.3	38.5	578	12.2
75	38.4	40.2	531	12.2
80	40.3	41.8	492	12.2
85	42.3	43.3	459	12.2
90	44.1	44.7	430	12.2
95	45.9	45.9	405	12.0
100	47.7	47.1	383	11.9

Source: Curtis et al. (1982, Table 1C)

Variable definitions:

DBH: diameter at breast height (1.3m)

HT: height of tree of average volume

STEMS: number of live trees per hectare

MAI: mean annual increment = merchantable volume per hectare to close utilization standards divided by stand age. This volume consists of the volume between the stump and a 10cm top diameter in all stems having a DBH of at least 19.3 cm.

The DFSIM model was calibrated with data on the volumes of second growth stands scattered throughout the Pacific Northwest and British Columbia. Observations on natural, no treatment, stands were plentiful up to an age of 80 years so that the growth estimates in these cases can readily be believed to be "good regional averages" as claimed by the model's builders.

The revenue function REV used in this study is taken from Dobie, Kasper and Wright (1975) who estimated relationships between lumber and chip values per cunit and DBH for various types of stands. A low risk coastal Douglas-fir case was used and the values inflated to 1979 dollars.[5] REV denotes lumber and chip values from harvesting a hectare of the stand. The formulation here recognizes that some stand volume will be lost during the logging process. Thus REV = REV(DBH,V,C) = AREV(DBH) · (1-C/100) · V where V is merchantable volume (on the stump) per hectare and C is the waste and breakage percentage (10% in the base case). Some of the values of AREV are listed in Column 2, Table 2. AREV increases with DBH because there are larger lumber recovery factors for larger logs and because and because larger dimensional lumber and hence more valuable lumber can be cut from larger logs.

The cost function COST (per unit hectare) is developed from cost and productivity estimates made by Cooney (1981) and Cooney and Haley (1982). The function COST has the form COST (DBH, V, H, N, X) where H is the average height of the stand, N the number of trees per hectare and X is a vector of parameters describing the physical characteristics of the stand. COST is increasing in the stand variables and ACOST = COST/(1-C/100)V

TABLE 2

ECONOMIC CHARACTERISTICS OF NATURAL, NO TREATMENT, MANAGED COASTAL DOUGLAS FIR STAND, SITE INDEX 125

AGE (yrs.)	AREV ($/m^3)	ACOST ($/m^3)	ASTUMP ($/m^3)	MINSTUMP ($/m^3)	APROFIT ($/m^3)
35	53.73	63.61	-16.90	1.97	7.01
40	54.63	59.91	-12.41	2.04	7.13
45	55.53	57.50	- 9.22	2.10	7.24
50	56.73	52.07	- 2.75	2.19	7.40
55	57.93	49.78	0.59	2.28	7.53
60	58.83	48.03	3.12	2.34	7.67
65	58.83	46.65	4.50	2.34	7.67
70	59.73	45.63	6.30	2.41	7.79
75	60.63	44.82	7.90	2.47	7.91
80	61.53	44.15	9.35	2.54	8.03
85	62.58	43.59	10.82	2.61	8.16
90	62.58	43.14	11.28	2.61	8.16
95	63.63	42.76	12.57	2.69	8.30
100	64.53	42.44	13.67	2.75	8.42

Variable definitions:

AREV: See page 7.

ACOST: = COST (.9V). See page 7 for COST. It is assumed that 10% of stand volume is lost in waste and breakage during the logging operation. ACOST is thus average cost per cubic meter recovered.

ASTUMP: = $(1 + t)^{-1}$ AREV - ACOST = STUMP/(.9V). See page 12.

MINSTUMP: = (.08)AREV. See page 13.

APROFIT: = AREV - ACOST - ASTUMP = t (ACOST + ASTUMP). See page 12.

t: profit and risk percentage, here taken to be 15%.

decreasing in the stand variables reflecting the economies of size involved in logging larger trees (see Column 3, Table 2). These economies of size occur because productivity (m^3 per turn) increases in yarding and loading with the size of the logs and because more wood can be loaded on logging trucks with larger logs. ACOST is the average over the recovered volume to make it comparable to AREV.

Logging costs are the sum of the costs of each phase of the processing operation from road construction to milling. The different phases are listed in Table 3. The table also lists the exogenous parameters in X in the calculation of COST and the values used in the base case. The base case is intended to represent relatively good logging conditions. The falling and bucking component of COST includes the cost of handling the breakage. The other components of COST are based only on recovered volumes, however.

The difference AREV - ACOST is usually called the conversion return and is available to be divided into a return on the capital employed in the harvesting operation and a return to the forest owner.

Costs called the site treatment costs (STC) are also incurred when the site is cleared up after harvesting to ensure prompt regeneration. This cost component is taken below to be \$.03 per m^3 of harvest plus \$15.20 per ha. based again on the estimates of Cooney (1981).

TABLE 3

COMPONENTS OF COST CALCULATIONS

1. Processing Phases

- road construction and maintenance
- falling and bucking
- yarding
- loading
- hauling
- unloading, sorting, booming
- crew transportation
- engineering
- scaling
- administration and overhead
- milling[6]

2. Exogenous Parameters in Cost Calculations and Base Case Value[7]

parameter	description	base value	interpretation
T	terrain index	1	even
O	obstacle index	1	small
B	brush density index	1	light
S	ground slope	20%	moderate
EX	exposed bedrock index	1	low
C	waste and breakage percentage	10%	low
MULT	round trip hauling time	3 hrs.	
TD	round trip crew transportation distance	30 km.	
M	milling cost	$\$20.59/m^3$	

III. The Theory of Financial Rotations

The maximum economic benefit that an owner of forest land can obtain from having a crop of trees harvested is the value of the products made from the trees minus the opportunity costs of the factors of production used in the harvesting and milling process. These opportunity costs are the minimum compensation these factors must receive in order to induce them to engage in this process rather than in some other activity. Normally, the difference of values and opportunity costs is called economic rent. Financial rotations then seek to maximize the present value of economic rents obtainable from repeated harvesting of forest land.

One means the owner has of receiving the economic rent is to offer the harvesting rights to his stand for sale. If there are a sufficient number of independent operators interested in the sale, then some should be willing to pay close to the economic rent by definition. In British Columbia, however, harvesting rights on Crown lands are now rarely offered for competitive sale.[8] The Forest Service is, however, charged in legislation with ensuring that "the financial interest of the Crown in its forest and range resources [is asserted] in a systematic and equitable manner."[9] Thus a complex appraisal procedure has evolved which tries directly to estimate the economic rent and sale prices are usually equal to these appraised rents. (British Columbia Ministry of Forests, 1980b).

Obviously, there are numerous practical difficulties associated with estimating opportunity costs. Operating costs are estimated from observation of operating costs in similar operations in the near past, and are supposed to be the costs incurred by an operator of average efficiency. A profit and risk allowance is then made to represent the opportunity cost of the operator. This is "an allowance on the investment in plant, facilities and working capital sufficient to induce an operator to undertake the risks involved."[10] An estimate is also made of REV, the value of the products obtainable from the tree and then STUMP, the stumpage payments due to the Crown are the residual after deducting from REV the estimated operating costs and the profit and risk allowance.

The Crown owns 95% of the productive forest land in British Columbia, so the calculations of SE presented here will follow as closely as possible the procedures used by the province's principal forest land owner. The REV and COST functions mentioned in the last section will be used as estimates of values and operating costs.

Thus,

$$\text{STUMP} = \text{REV} - \text{COST} - \text{PROFIT}$$

The profit and risk allowance is made in British Columbia according to the Rothery formula (Rothery (1944)). Rothery felt that there were severe practical difficulties "in calculating the investments, particularly if plants are old , and also in determining an appropriate rate of return on them."[11] To avoid these difficulties, he proposed that the profit and risk allowance be some percentage (t) of operating costs plus stumpage.

That is,

$$\text{PROFIT} = t\ (\text{COST} + \text{STUMP})$$

The percentage t that was to be allowed could be determined by looking at what this percentage was for market sales of similar properties.

This paper will also follow the Rothery formulation. However, some further comments are made on the formula in Appendix D. It is easily seen now that

$$\text{STUMP} = (1 + t)^{-1}\text{REV} - \text{COST}$$

The base case uses a profit and risk percentage of 15%. The values of ASTUMP = STUMP/(1-C/100)V are shown in Column 4 of Table 2. For comparison, the average stumpage price received by the Crown for Douglas Fir in the Vancouver Region in 1979 was $10.49/m^3$ (British Columbia Ministry of Forests 1980c, 62). British Columbia also has minimum stumpage rates which are 8% of the value of the logs. These are recorded in Column 5 of Table 2 as MINSTUMP. These rates would be charged if the stand was logged at age 55 or less. However, the rates do not usually have an impact on the calculations reported below so it will be assumed that the normal stumpage formula applies at all ages. The last column in Table 2 APROFIT reports the return above operating costs to the logging and milling operation.

Table 4 gives the values of STUMP in dollars per hectare in Column 2. The next column gives the FR (forest rent) which is STUMP divided by the number of years in the rotation. It can be seen that the maximum FR rotation is at least 100 years, much longer than the maximum volume rotation of 75 years. Over the extra 25 years, the economic gains from having larger trees to harvest outweighs the losses in MAI.

The PNW (present net worth) of growing one crop of trees is

$$PNW = STUMP \cdot EXP(-R \cdot A) - STC$$

where R is the discount rate, A is the rotation and STC is site treatment costs. Column 4 of Table 4 gives the values of PNW for the base case.

The SE (soil expectation) or bare land value of using the site to grow trees in perpetuity with crops being harvested every A years is

$$SE = \frac{STUMP - STC}{EXP(R \cdot A) - 1} - STC$$

This is calculated in Column 5 of Table 4 and it is a maximum at a rotation of 75 years, the same age as the PNW rotation and the same age as the maximum volume rotation.[12]

TABLE 4

FINANCIAL VALUES OF NATURAL, NO TREATMENT, MANAGED
COASTAL DOUGLAS FIR STAND
SITE INDEX 125

AGE (yrs.)	STUMP ($ '000/ha.)	FR ($/ha/yr.)	PNW ($/ha.)	SE ($/ha.)
35	-4.32	-123.4	-774.2	-937.0
40	-4.37	-109.4	-619.0	-715.9
45	-4.05	-90.0	-456.5	-510.3
50	-1.42	-28.4	-148.8	-162.1
55	.35	6.3	-12.5	-13.4
60	2.03	33.8	64.2	67.6
65	3.21	49.3	85.4	88.8
70	4.86	69.4	105.9	109.2
75	6.53	87.1	110.8	113.5
80	8.24	103.0	106.4	108.4
85	10.14	119.3	98.2	99.6
90	11.12	123.6	75.5	76.3
95	12.93	136.1	62.4	62.9
100	14.63	146.3	47.2	48.0

Source and definitions: see text.

The discount rate is 5% (see Appendix E).

This example thus contradicts the commonly held belief that financial rotations must necessarily be much shorter than maximum volume rotations. Waiting for the benefits that accrue from harvesting larger logs has offset the impatience associated with discounting. The equivalence here of the two rotations will not however hold in many of the other examples examined below.

Financial rotations are calculated on the assumption that repeated crops of trees can be grown on a site without affecting the site productivity. Perhaps the first example of the use of financial rotations was the replacement of mixed stands in Saxony by pure stands of short rotation spruce in the Nineteenth Century. Within two rotations, yields had fallen dramatically. This was partly due to soil deterioration due to frequent exposure and also to the choice of unsuitable habitats for spruce [see Brasnett (1953,30)]. In the Nineteenth Century in Europe it was also a major forestry problem to devise management regimes under which forests would regenerate naturally. This objective also impinged on the choice of rotation. These two problems may help explain the poor reputation of financial rotations. In any case, they show that the biological assumptions underlying the calculation of financial rotation do not hold automatically. Of course, these days these problems are less prevalent because better site treatment techniques are known and artificial regeneration is possible (see, however, Swift (1983) for a more pessimistic view.)

Another set of deficiencies in the calculations above center around externalities as admitted by Samuelson (1976). Forests produce many products, not just wood. Examples are watershed protection, wildlife habitat,grazing, recreation and aesthetic values. These products are mainly non-marketable and difficult to place social values on. Nevertheless, social welfare maximization should be based on the net present value of all these products plus the wood values. This objective, however, need not require rotations that are very much longer than financial rotations as shown by Calish et.al. (1978).[14] Indeed, some forest products such as water yields, which could be used for irrigation or hydro-electricity generation, are enhanced by very short rotations. Other products such as wildlife production can be enhanced by the provision of a variety of habitats such as more open areas to provide grazing and nesting material and older timber areas to provide shelter. Fisheries, watersheds can be protected by leaving uncut strips along stream edges. On the other hand, production of wilderness is completely incompatible with timber production and requires infinitely long rotations. Visual aesthetic values are also usually believed to be best provided by mature forests. These values might best be provided for by reserving particularly valuable areas from timber production completely. This issue is examined empirically in the next section. In general, however, much multiple use production is probably best provided for by modification of logging and silvicultural practice than by modification of the rotation period.

Financial rotations are also calculated on the assumption that real revenues and costs will be constant far into the future. This assumption is made for the sake of tractibility of the SE maximization problem. Except for a few special cases (Bare and Waggener (1980)), calculation of rotation periods under other expected real price paths requires the use of complicated numerical simulation methods. However, revenues today reflect today's timber supply conditions where stands of old-growth mature timber are still being logged. As the harvest shifts more and more to second growth timber the supply of larger logs will diminish. This will tend to increase the quality premium on large logs over smaller logs. Consequently, financial rotations calculated on today's economic conditions will be too short in the future.

One other point should be made about future prices. It has been forecast [Adams *et al*. (1982)] that there will, over the next several decades, be a large expansion in the use of silvicultural techniques such as thinning. The long-run prospects are thus for a substantial increase in the supply of wood products.

Another key parameter in the calculation of the rotation is the choice of the discount rate (5% real is used in the base case) as will be seen in the next section. It is usually suggested that this rate should be either the social rate of time preference or the marginal social opportunity cost of capital in the private sector.[15] The latter is advocated here on the grounds that social preferences about future consumption are better treated by explicit constraints on the planning process rather than by a very subjective manipulation of a single parameter.

British Columbia (on MSOCK grounds) has adopted a discount rate of 10% (with 8% and 12% to be used for sensitivity analysis) for the purposes of Benefit-Cost Analysis (Loose, 1977). A rationale for the use of a lower rate in the context of forestry investments is given in Appendix E.

Finally, one may question the objective ascribed to a forest owner by financial rotation theory (Duerr *et al*. (1979, 174-175)). Large industrial owners are concerned with the profitability of their total operation, both milling and forestry. Considerations of the type of timber required by the mill and the necessity of keeping the mill running continuously may determine the rotation used.[16] Firms may also have different objectives than the maximization of profits as has been discussed in the economics literature. The actions of small woodlot owners may be determined more by financial exigencies (such as payment of property tax) and current market conditions than by present value calculations.[17] On the other hand, public agencies often stress economic growth and community stability. Thus they choose rotations which maximize the sustainable flow of fibre from their forests. The alternative of financial rotations means shorter rotations, lower annual yields and employment. It should be noted,however, that financial rotations offer greater income to the landowner if the returns from earlier harvesting are invested in businesses (perhaps in other regions) which offer higher rates of return than long forest rotations. This income could be used to stimulate the growth of other sectors of the economy as a compensation for a smaller forest sector.

IV. Financial Rotations for Coastal Douglas-fir

The first variable considered here which affects the rotation is soil fertility as measured by site index. Table 5 gives rotations and values for four different site indices for naturally regenerated managed stands. Heaps (1981) shows that there should be longer rotations for the poorer sites and this property of rotations is confirmed here. Indeed, except for the good site , the financial rotation is at least as long as the maximum volume rotation. The table also shows how the bare land values fall with site fertility with the poorest site seeming to have no value for sustained yield forestry at all. It may be said that short financial rotations occur when the site is especially valuable for forestry.

Table 6 looks at the sensitivity of the rotation to change in wood product prices. An increase in prices relative to costs increases marginal revenues associated with harvesting but also increases the marginal opportunity costs associated with not harvesting. Thus the impact of an increase in prices on the financial rotation is not immediately obvious. It can be shown, however, that the results in Heaps (1981) imply that financial rotations should be shorter because of the quality premiums and economies of size associated with large logs. This result is confirmed by the calculations shown here and it is seen that the financial rotation does seem to be quite sensitive to the price level used. The price level used in the base case is the average price over the period 1978-1980 as this was the period over which the cost data was collected. Real coastal Douglas-fir prices were 14% higher over this period, than the average real price for 1972-1981 whose coefficient of variation was 13.3%.[18]

It would seem that one could have little confidence in calculated financial rotations when they are apparently so sensitive to the price of wood products and this price tends to be so variable. The numbers in Table 7

TABLE 5

ROTATIONS AND VALUES FOR DIFFERENT SITE INDICES

SITE INDEX	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAIROT (yrs.)
145	65	325	65	312	75
125	75	113	75	110	75
105	90	9	90	9	75
85*	100	-37	100	-37	90

Definitions:

SEROT: The age of the stand which maximizes SE.

PNWROT: The age of the stand which maximizes PNW.

MAIROT: The age of the stand which maximizes MAI.

* The biological data ends at age 100 so that SEROT may actually be longer than 100 and SE may be higher than -37. However, since the change in SE from age 95 to age 100 is very small, these figures are likely to be almost correct. All cases where the rotation is 100 years or more will be reported as 100 years.

TABLE 6

EFFECT ON ROTATIONS AND VALUES OF CHANGES IN WOOD PRODUCT PRICES

NATURAL STAND, NO TREATMENT, SITE INDEX 125

θ	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
.8	100	-33	100	-33
.9	85	26	85	25
1.0	75	114	75	111
1.1	60	242	60	230
1.2	60	416	60	395

Explanation: SE and PNW have been recalculated with REV multiplied by the scaling factor θ.

may restore confidence somewhat, however. Here the SE values for different rotations are calculated as a percentage of their maximum value for three different relative price levels. A rotation of 75 years would lead to substantial financial losses if the relative price level given by $\theta = .9$ accurately represents the future. Therefore, a rotation of 80 years might be preferred as being safer in the sense of minimizing the maximum loss from misestimating future wood prices. The use of $\theta = .9$ as a lower bound seems justified since perpetual forestry would not be profitable at lower prices.

Table 8 gives the financial rotations and bare land values for different values of the discount rate. Again, it may be seen that the financial rotation is quite sensitive to the discount rate used and multiple harvest forestry of this type is not economically viable at discount rates at 8% or more. This lack of viability is true also for good sites for discount rates of 10% or more. Thus, if 10% is the correct discount rate, it appears that tree farming may only be a profitable activity when intensive management techniques are used. The effects of a variety of different operating conditions are shown in Table 9. The case of a high risk allowance of 25% may be seen (by looking at the formula for SE) to be equivalent to reducing prices to $\theta = 1.15/1.25 = .92$ and so there is a 10 year increase in the rotation as in the case $\theta = .9$ (Table 7). The other cases, not involving a change in the breakage percentage, have the effect of changing costs (nonuniformly) relative to prices and the magnitude of the impact on the rotation depends on the magnitude of the impact on costs. A closer examination of the calculations shows cost changes of the order of 3-7% (at 75 years) change the rotation by 5 years, a 15% increase (long haul, Case 6) increases the rotation by 10 years and a 20% increase (long haul, steep slope, Case 10) increases the rotation to at least 100 years. These magnitudes correspond to the results obtained by changing the price level by equivalent amounts (Table 7). Finally, increases in the breakage percentage

TABLE 7

SE AS A PERCENTAGE OF ITS MAXIMUM VALUE

SITE INDEX 125

θ	ROTATION					
	60	65	70	75	80	85
.9	-	-	-	33	79	100
1.0	60	78	96	100	95	88
1.1	100	98	97	90	81	72
1.2	100	92	86	78	68	59

Explanation: SE is expressed as a percentage of the maximum value it achieves for the same value of θ.

TABLE 8

EFFECT ON ROTATIONS AND VALUES OF CHANGES IN DISCOUNT RATE,

NATURAL STAND, NO TREATMENT, SITE INDEX 125

R	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
.02	100	2231	100	1929
.04	80	304	85	292
.05	75	114	75	111
.06	70	32	70	32
.08	60	-20	60	-20
.10	60	-32	60	-32
.12	55	-34	55	-34

TABLE 9

EFFECT ON ROTATIONS AND VALUE OF EXTREME PHYSICAL CONDITIONS

NATURAL STAND, NO TREATMENT, SITE INDEX 125

	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
1. Level (S=0%)	70	133	70	129
2. Steep Slope (S=90%)	80	75	80	74
3. Rock bluff or cliffs (EX=4)	80	90	80	89
4. High risk allowance (t=.25)	85	41	85	40
5. Short haul (MULT=1)	70	163	70	158
6. Long haul (MULT=9)	85	9	85	9
7. No breakage (C=0%)	75	133	75	130
8. High breakage (C=20%)	75	93	75	91
9. Level, short haul (S=0%, MULT=1)	70	187	70	181
10. Steep Slope, long haul (S=60%, MULT=9)	100	-12	100	-12
11. Level, short haul, no breakage (S=0%,MULT=1,C=0%)	60	222	60	211
12. Steep Slope, long haul high breakage (S=60%,MULT=9,C=20%)	100	-16	95	-16
13. Many Conditions Bad (S=40%,MULT=9,C=20% EX=4,t=.25)	100	-47	100	-47

reduces the value of the harvest but also reduce harvesting costs as the broken material does not have to be handled. These changes offset each other, for example in Case 8, C=20%, the value of the harvest is reduced by 11.1% and the cost of harvesting is reduced by 10.8%. Thus there is little impact on the rotation.

An attempt was also made to say something about how non-timber values might affect the financial rotations. Maximization of the net present value of all timber values might lead to long rotations (or no harvesting at all) provided the non-timber values are heavily weighted towards older stands. Two very simple ways to model such a weighting scheme are

(1) $V(T) = 0 \quad \text{for} \quad T < 50$

$V(T) = b \quad \text{for} \quad T \geq 50$

(2) $V(T) = bT$

where V(T) is the social value per hectare of all non-timber products of a T year old stand. For each weighting scheme, a least b (roughly) was found such that the maximization of the net present value of timber and non-timber values required a rotation of at least 100 years. The results were b=$400/yr./ha. in Case 1 and b=$4/yr/ha. in Case 2. Both cases thus give a non-timber value of $400/yr./ha. for a 100 year old stand.

The question is then whether such a number could possibly be reasonable to forest areas with apparently high non-timber values. To examine the question, some data is presented in Table 10 below on a few popular provincial parks in south-western British Columbia.

Alice Lake and Cultus Lake rate highly for water-based recreation, picnicing, hiking and natural beauty. Mount Seymour and Cypress Bowl are popular skiing and hiking areas. The logging of key areas in these parks would undoubtedly destroy their recreational capacity so at least some of their forest areas must be viewed as producing recreation values at least

TABLE 10

RECREATION IN B.C. PROVINCIAL PARKS

PARK	AREA (ha.)	VISITS IN 1980	VISITS PER HA.
Alice Lake	397	99,393	250
Cultus Lake	656	190,567	290
Mount Seymour	3508	192,900	55
Cypress Bowl	2104	264,106	125

Source: British Columbia. Parks and Outdoor Recreation Division, 1981, Park Data Handbook 1980 (Victoria, B.C.).

those of the average number of recreation days per hectare calculated in Table 10. Griffen (1984) estimated recreation-day demand curves for various parks including three of the above. From these he estimates a mean social value of a user day of roughly \$4 (\$1979). Using this estimate, the social values of recreation per hectare per year for the parks would be: Alice Lake \$1000, Cultus Lake \$1160, Mount Seymour \$220 and Cypress Bowl \$600. These numbers suggest that Alice Lake, Cultus Lake and Cypress Bowl are best kept as parks. If one added visual aesthetic values to the figure for Mount Seymour, one would undoubtedly come to the same conclusion.

One other experiment with the sensitivity of the financial rotation was carried. The REV function was modified to make larger and older trees more valuable relative to smaller and younger trees. This modification took the form of multiplying REV by a scaling factor $\theta(A)$ where A is the age of the stand. The scaling factor had the property that $\theta(A)<1$ for $A<A_o$ and $\theta(A)>1$ for $A>A_o$ for some A_o. The calculations showed that the financial rotations could be significantly lengthened by such a relative price change, particularly when $A_o>85$. These examples serve to emphasize a point made in the previous section. If society wishes large trees in the future and is willing to pay for them, then financial rotations will adjust accordingly.

V. The Effect of Intensive Management on Rotations

A number of silvicultural techniques are available for greatly increasing the yields of the second growth crops of trees that will increasingly be the source of the timber supply in the future. These techniques include juvenile spacing (also called precommercial thinning), artificial regeneration using genetically improved seedlings, commercial thinnings and fertilization. It appears to be widely recognized in industry that some combinations of these techniques are now economically viable. In British Columbia, the major forest firms are moving to apply these intensive management techniques on the forest lands that they manage. For example, MacMillan Bloedel is implementing the "Designed Forest System." The company estimates that yields can be increased 55 to 100 percent by regular thinning (where the thinnings are included in the yield.) Further increases of perhaps 15% can be achieved by tree breeding and 10-20 percent by fertilization.[19] Industry and government attitudes towards intensive management are discussed in more detail in the next section.

The tree growth simulator DFSIM allows one to predict the effects of various stand treatments. Several examples involving combinations of some of planting, commercial thinning, precommercial thinning and fertilization will be examined here for a medium site. The specific treatments are given in Table 11 as Cases 2-5. The biological characteristics of each case are listed in Appendix C. Compared to the no treatment case, Case 2 -- planting only -- increases maximum MAI by 11%, Case 3 -- commercial thinning only -- by 8%, Case 4 -- precommercial thinning plus commercial thinning -- by 23% and Case 5 -- the above plus fertilization -- by 43%.

TABLE 11

ROTATIONS AND VALUES FOR DIFFERENT STAND TREATMENTS

SITE INDEX 125

SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAIROT (yrs.)	MAIVAL ($/ha.)
1. Natural regeneration, no treatment					
75	113	75	111	75	113
2. Planted to 988 trees per hectare, planting cost $250 per hectare					
70	-50	70	-56	75	-77
3. Natural regeneration, commercial thinnings at ages 39,48,60,83					
85	-32	85	-32	90	-43
4. Natural regeneration, precommercial thinning at age 11 to 988 trees per hectare, commercial thinnings at ages 28,36,49,66,84					
75	-124	75	-121	90	-153
5. Natural regeneration, precommercially thinned at age 11 to 741 trees per hectare, commercial thinnings at ages 29,36,50,63,77,91, fertilizations at ages 20,35,50, fertilization cost $153 per hectare.					
70	75	70	73	85	27

Definition: MAIVAL is the SE value at MAIROT.

It should be noted that the DFSIM estimates here are less firmly based than those for the no treatment cases examined earlier. For example, no observations on planted stands of age greater than 40 years or on stands subjected to repeated fertilizations were available to the simulator's authors. The yield estimates in these cases are informed guesstimates and probably hold a slightly below average position in the spectrum of opinion about responses to intensive management.

Table 11 gives the financial rotations and bare land values for each of the examples.[21] Looking at Column 2, one sees that at the price level assumed here none of the treatments are profitable on financial criteria. The reasons for this result are as follows. In Case 2, planting alone, the value of the growth response (11%) is simply too small to compensate for the cost of planting.[22] Case 3 involves 4 commercial thinnings. The problem here is the small diameter (25.4 cm) and large number of stems to be felled (254 per ha.) during the first thinning, resulting in very high falling and bucking costs per m^3. The conversion return for this thinning is \$1.40 per m^3 (which corresponds to the observations of Smith (1978,4-12) that trees need to be at least 20 cm. in diameter for there to be a positive conversion return.) Since the stumpage formula gives operators a profit and risk allowance of over \$7 per m^3, this means the Crown would have to pay over \$5.50 per m^3 to have this thinning carried out. The bare land value decomposes as

$$SE = 65.33 - 103.26 - 14.25 + 7.39 + 12.99 = -32.30$$

The 65.33 is due to the final clearcut. This amount is less than the value of the clearcut in the no treatment case because a smaller final volume is harvested. The increase in MAI is in fact harvested in the form of thinnings. The net present values associated with the thinnings (last four terms above) are thus critical to the economic viability of this example. If the gross value of these thinnings were sufficiently high, then this treatment would be economically viable.

The bare land value for the fourth example decomposes into

$$SE = 175.69 - 131.34 - 155.60 - 61.90 + 12.66 + 36.16 = - 124.33$$

The growth response to precommercial thinning is enough to increase the net present value of the clearcut over the no treatment case but these gains are negated by the present value of the cost of precommercial thinning, the second term above. The same remarks apply to the thinnings as in Case 3.

Finally, the last case involving fertilization as well has

$$SE = 330.15 - 98.49 - 132.45 - 131.56 - 19.47 + 57.74 + 69.26$$

The second term is the present value of fertilization cost and the third term is the present value of the cost of the precommercial thinning. These two terms together with the net present value of the final harvest add up to 99.21 so again the gains due to the growth response are less than the present value of costs of fertilization and precommercial thinnings.

The results above have been subjected to sensitivity analyses with respect to the price level used. Table 12 and Table 13 give the financial rotations and bare land values for an increase in wood values of 10 and 20 percent respectively (Douglas-fir prices were in 1979 at least 15% higher than the level used here). If prices are 10% higher than the base case, then the full treatment of Case 5 does 90% better on its SE value than the no treatment case, while the other cases are still less profitable than the no treatment case but less than in the base case. If prices are increased by 20%, the Case 5 bare land value is more than double the no treatment case. Cases 3 and 4 involving thinning but no fertilization are also now more profitable than the no treatment case. What has happened can be illustrated by looking at the decomposition of SE for Case 4:

$$SE = 482.15 - 133.43 - 36.34 + 63.58 + 117.33 = 493.29$$

The net present value associated with the three thinnings (the last three terms) now more than compensate for the present value of precommercial thinning costs (the second term). There is thus a net gain in SE over the no treatment case because of the larger volumes harvested at the rotation age.

Similar calculations have been made for a good site and are shown below in Tables 14-16. Table 14 (base level prices) shows that in contrast to a medium site, Case 5 full treatment is now profitable with an SE value 18% higher than the no treatment case. Case 5 did, however, look very good on a medium site at the higher price levels and Table 15 and 16 confirm that this conclusion is also true for good sites. It is also interesting that Case 4 without fertilization is profitable on a good site with prices raised 10% contrary to the same case on a medium site.

The conclusion from these calculations then is that intensive manage-

TABLE 12

ROTATIONS AND VALUES FOR DIFFERENT STAND TREATMENTS

PRICE LEVEL RAISED BY TEN PERCENT*

SITE INDEX 125

SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAIROT (yrs.)	MAIVAL ($/ha.)
1. Natural regeneration, no treatment					
60	242	60	230	75	218
2. Planted to 988 trees per hectare, planting cost $250 per hectare					
65	108	65	94	75	43
3. Natural regeneration, commercial thinnings at ages 39,48,60,83					
75	188	75	184	90	159
4. Natural regeneration, precommercial thinning at age 11 to 988 trees per hectare, commercial thinnings at ages 28,36,49,66,84					
65	176	65	169	90	108
5. Natural regeneration, precommercially thinned at age 11 to 741 trees per hectare, commercial thinnings at ages 29,36,50,63,77,91, fertilizations at ages 20,35,50, fertilization cost $153 per hectare					
65	460	65	441	85	361

* REV has been multiplied by 1.1

TABLE 13

ROTATIONS AND VALUES FOR DIFFERENT STAND TREATMENTS

PRICE LEVEL RAISED BY TWENTY PERCENT*

SITE INDEX 125

	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAIROT (yrs.)	MAIVAL ($/ha.)
1. Natural regeneration, no treatment						
	60	416	60	395	75	323
2. Planted to 988 trees per hectare, planting cost $250 per hectare						
	60	299	60	271	75	163
3. Natural regeneration, commercial thinnings at ages 39,48,60,83						
	70	422	70	409	90	361
4. Natural regeneration, precommercial thinning at age 11 to 988 trees per hectare, commercial thinnings at ages 28,36,49,66,84						
	65	493	65	474	90	369
5. Natural regeneration, precommercially thinned at age 11 to 741 trees per hectare, commercial thinnings at ages 29,36,50,63,77,91, fertilizations at ages 20,35,50, fertilization cost $153 per hectare						
	65	854	65	821	85	694

Definition: MAIVAL is the SE value at MAIROT.

*REV has been multiplied by 1.2

TABLE 14

ROTATIONS AND VALUES FOR DIFFERENT STAND TREATMENTS

SITE INDEX 145

SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAITOR (yrs.)	MAIVAL ($/ha.)
1. Natural regeneration, no treatment					
65	325	65	312	75	263
2. Planted to 988 trees per hectare, planting cost $250 per hectare					
60	203	60	181	65	193
3. Natural regeneration, commercial thinnings at ages 33,40,50,75,99					
70	74	70	71	85	55
4. Natural regeneration, precommercial thinning at age 10 to 988 trees per hectare, commercial thinnings at ages 24,31,42,57,74,91					
65	107	65	103	25	29
5. Natural regeneration, precommercially thinned at age 10 to 741 trees per hectare, commercial thinnings at ages 25,32,42,54,67,80,94, fertilizations at ages 17,32,47, fertilization cost $153 per hectare.					
60	382	60	362	85	244

Definition: MAIVAL is the SE value at MAIROT.

TABLE 15

ROTATIONS AND VALUES FOR DIFFERENT STAND TREATMENTS

PRICE LEVEL RAISED BY TEN PERCENT*

SITE INDEX 145

	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAIROT (yrs.)	MAIVAL ($/ha.)
1. Natural regeneration, no treatment	55	556	60	525	75	404
2. Planted to 988 trees per hectare, planting cost $250 per hectare	55	483	55	436	65	418
3. Natural regeneration, commercial thinnings at ages 33,40,50,75,99	65	432	65	415	85	369
4. Natural regeneration, precommercial thinning at age 10 to 988 trees per hectare, commercial thinnings at ages 24,31,42,57,74,91	60	573	65	546	85	420
5. Natural regeneration, precommercially thinned at age 10 to 741 trees per hectare, commercial thinnings at ages 25,32,42,54,67,80,94, fertilizations at ages 17,32,47, fertilization cost $153 per hectare	60	956	60	908	85	677

* REV has been multiplied by 1.1

TABLE 16

ROTATIONS AND VALUES FOR DIFFERENT STAND TREATMENTS

PRICE LEVEL RAISED BY TWENTY PERCENT*

SITE INDEX 145

SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAIROT (yrs.)	MAIVAL ($/ha.)
1. Natural regeneration, no treatment					
50	814	55	772	75	544
2. Planted to 988 trees per hectare, planting cost $250 per hectare					
50	789	55	722	65	644
3. Natural regeneration, commercial thinnings at ages 33,40,50,75,99					
60	805	65	773	85	683
4. Natural regeneration, precommercial thinning at age 10 to 988 trees per hectare, commercial thinnings at ages 24,31,42,57,74,91					
55	1060	60	1003	85	811
5. Natural regeneration, precommercially thinned at age 10 to 741 trees per hectare, commercial thinnings at ages 25,32,42,54,67,80,94, fertilizations at ages 17,32,47, fertilization cost $153 per hectare					
60	1530	60	1454	85	1142

*REV has been multiplied by 1.2

ment which includes fertilization appears to be a good investment under good growing conditions or provided on a medium site a good price can be obtained for the small diameter thinnings. On the latter point, it should be noted that the values and costs used for thinnings here have largely been extrapolations of observations of values and costs for larger logs and are thus suspect. Further research into the economics of thinnings is clearly needed as this information is critical in determining the viability of intensive management (some research in this area is discussed later in this section). The development of markets for thinnings and cost-effective methods of conducting these operations will also be important.

One other point is that the above calculations understate the value of intensive management because the treatments discussed here were not themselves chosen to optimize the base land value (some research in this area is also discussed below). Clearly, delaying the first costly thinning in these examples would make intensive managements look better.

The effect of these intensive management examples on the financial rotation does not appear from the tables to be very significant (more than ±5 years) except in Case 3 where only commercial thinning is used. Intensive management increases growth rates. However, if there is no juvenile spacing this response is delayed and hence the rotation is delayed to capture this later response. For the same reason, treatments which were economically optimal would probably delay the first thinning and hence tend to have longer financial rotations than the examples examined here.

The different treatments were also subjected to some sensitivity analysis with respect to the discount rate. Table 14 lists the financial rotations for the high price case and an 8% discount rate. Cases 2 and 4 fare poorly here because of the cost of planting or juvenile spacing occurs

TABLE 17

ROTATIONS AND VALUES FOR DIFFERENT STAND TREATMENTS

HIGH PRICES AND DISCOUNT RATE*

SITE INDEX 125

	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAIROT (yrs.)	MAIVAL ($/ha.)
1. Natural regeneration, no treatment	55	42	55	42	75	-5
2. Planted to 988 trees per hectare, planting cost $250 per hectare	55	-184	55	-185	75	-248
3. Natural regeneration, commercial thinnings at ages 39,48,60,83	65	47	65	47	90	21
4. Natural regeneration, precommercial thinning at age 11 to 988 trees per hectare, commercial thinnings at ages 28,36,49,66,84	55	-14	55	-14	90	-68
5. Natural regeneration, precommercially thinned at age 11 to 741 trees per hectare, commercial thinnings at ages 29,36,50,63,77,91, fertilizations at ages 20,35,50, fertilization cost $153 per hectare.	55	50	55	49	85	-31

*REV has been multiplied by 1.2 and the discount rate raised to .08

TABLE 18

ROTATIONS AND VALUES FOR DIFFERENT STAND TREATMENTS

HIGH PRICES AND DISCOUNT RATE*

SITE INDEX 145

	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)	MAIROT (yrs.)	MAIVAL ($/ha.)
1. Natural regeneration, no treatment						
	50	140	50	137	75	10
2. Planted to 988 trees per hectare, planting cost $250 per hectare						
	45	-54	45	-60	65	-169
3. Natural regeneration, commercial thinnings at ages 33,40,50,75,99						
	55	145	55	143	85	82
4. Natural regeneration, precommercial thinning at age 10 to 988 trees per hectare, commercial thinnings at ages 24,31,42,57,74,91						
	50	121	50	119	85	7
5. Natural regeneration, precommercially thinned at age 10 to 741 trees per hectare, commercial thinnings at ages 25,32,42,54,67,80,94, fertilizations at ages 17,32,47, fertilization cost $153 per hectare.						
	50	204	50	200	85	38

*REV has been multiplied by 1.2 and the discount rate raised to .08

in the harvest cycle. Cases 3 and 4 still give higher bare land values than the no treatment cases. However, the impressive gain given by the full treatment case is no longer so impressive basically because the difference in the net present value of the clearcuts has been dampened. Financial rotations are slightly shortened by the higher discount rate. The case of a good site is also examined in Table 18. The results are qualitatively similar to the medium site except that the full treatment case continues to show an impressive gain (46%) over the no treatment case.

A number of other authors have recently examined models of forest growth which incorporate the effects of intensive management. Dynamic programming methods are used to determine optimal treatments and optimal rotations. These models are becoming more and more sophisticated as better biological models and better economic information are incorporated into them. This section reviews some of the more recent work on these models, particularly the work of Brodie, Kao and associates of Oregon State University who have been using a model of Douglas-fir growth, DFIT, which is the predecessor of DFSIM used in this study.

Clark and De Pree (1975) analyse thinning policies for Scots Pine using data developed by Kilkki and Vaisanen (1969). The model assumes the main determinents of volume growth per ha. are volume per ha. and age of the stand. Economically, the net value of thinning increases with age and may be less than the net value of clearcuts. The objective is to maximize the present net value of all future thinnings and clearcuts. The empirical results are that the financial rotation is very sensitive to the choice of discount rate R, for example being 100 years at R = .01, 75 at R = .04 and 50 at R = .08 assuming that the net value of thinning equals the net value of clear cuts. If, however, the net value of thinning is less than the net value of clearcuts, then the amount of thinning is reduced and so is the financial rotation, by significant amounts at low discount rates.

Another approach to optimal thinning is that of Chen, Rose and Leary (1980, 1981). They use dynamic programming to calculate thinning regimes and rotations for red pine in the Lake States which maximize the annual volume produced rather than an economic objective. Their approach is of interest because a biological model is used which is more typical of the modern approach to forest growth. The key variable in their model is stand basal area per unit area rather than volume per unit area. The growth rate of basal area is related to basal area, basal area removed by thinning and age via a modified Richards function. Average height is related separately to age and then volume is calculated from height and basal area. The maximum volume rotation is 90 years for a low initial basal area and 70 years for a high initial basal area. In the latter case average volume is increased by 19.4 percent over the no thinning case. Unfortunately, the rotation for the no thinning cases is not given but it is presumably less than 70 years.

The series of papers by Brodie and Kao and associates by contrast focus on choosing thinning regimes to maximize economic criteria, usually the SE value. The biological and economic modelling becomes increasingly more sophisticated. The first paper, Brodie, Adams and Kao (1978), focuses on the sensitivity of financial rotations for coastal Douglas-fir to changes in economic and biological parameters. The biological model is rather crude, the key growth variables being volume per unit area and a normality factor. It is fitted to empirical growth data for the Pacific Northwest. Cost and revenue functions for thinning and final harvest were fitted to empirical data and incorporated a quality premium for larger trees and a cost penalty for low volume thinnings. Optimal thinnings and rotations are calculated via a forward recursive dynamic programming algorithm. The base case is a medium site and a discount rate of 3%. The financial rotation is 70 years.

This is not compared to the no thinning financial rotation but is presumably longer. An interesting result is that if only the first harvest is considered, i.e. the PNW criterion is used, the optimal rotation becomes 90 years. Higher fertility sites are shown to have longer rotationswhich is contrary to the no thinning case. Increasing the discount rate again dramatically reduces the rotation, for example at 6% to 50 years on the medium site. At 9%, the SE values are negative indicating that sustained yield management is not profitable at the product values used.[23] Finally, it is shown that rotation periods are increased by increased regeneration costs or reduced initial stocking levels which is the conventional wisdom.

Brodie and Kao (1979) construct a much improved version of their model by basing it on the stand simulation model DFIT developed by Bruce et al. (1977). The key state variables in DFIT are number of trees per acre and basal area of the stand. Once the rates of growth of these variables are described, equations are given for calculating other stand characteristics of interest such as volume per acre, height and average diameter from which the economic characteristics of the stand can be more accurately calculated.

Moreover, the model allows for the prediction of the effects of intensive management activities, not only thinning but fertilization and genetic improvement. Brodie and Kao extend the dynamic programming algorithm to find optimal treatments within this more complex biological model. The model is used to illustrate the effect of a quality premium which increases with tree diameter. The financial rotation is 60 years (for medium sites) with no quality premium, 80 years with a premium increasing up to 20 inch diameters and 100 years if the premium increase continues (linearly) above 20 inches. This illustrates the important point that financial and maximum MAI rotations may not be so different when the quality premium is taken into account.

This point is investigated in more detail in Riiters, Brodie and Kao (1982) using the same model. First, maximum volume rotations are calculated for different site indices with and without thinning. Thinning extends optimal rotations under this criterion from 50 to 70 years on medium to good sites and increases average yields by 17 to 21 percent. Secondly, the optimal thinning regime and rotation which maximize SE are calculated. For the medium site, the financial rotation is 80 years and at all ages (because of the quality premium) the stand is managed so that there are fewer larger trees than under the maximum volume criterion. It is interesting that the financial rotation yields an average volume 96% of the maximum possible with thinning while its SE value is 33% higher.

Another improvement on the model discussed above has been presented in LeDoux and Brodie (1983). LeDoux and Butler (1981) have presented a careful analysis of the costs of harvesting small trees, particularly during thinning.[24] This analysis involved selecting appropriate yarding machinery which could feasibly be used to yard given diameter classes of trees at the least cost. The optimal economic rotations have then been recalculated with this improved cost data. For the optimal commercial thinning regime the rotation is still 80 years.

Allowing precommercial thinning at age 10 doesn't change the financial rotation but increases commercial volume over a rotation by 2.2% and since tree sizes are substantially increased, it increases the SE value by 93 percent. Finally, if optimal fertilization treatments are added to pre-commercial thinnings, then the rotation is reduced to 70 years, annual yield is increased by 31.9 percent and SE is increased 201 percent over the commercial thinning only case.[25] These results suggest that the examples computed in this paper may significantly understate the potential economic benefits of intensive management because the treatments prescribed in the examples could not be manipulated in search of the highest economic gain.

VI. Forest Management in North America

This section deals with the attitudes of the public and private sectors in North America towards intensive forest management. Some historical background is provided why interest in this subject was insubstantial until the last few decades. Current attitudes towards intensive silviculture are also described and critiqued with special attention paid to the B.C. Ministry of Forests. The beneficial effects of spacing, thinning and other treatments have been known for a long time. It was necessary in Europe and Japan in the 18th Century and earlier to husband carefully the limited local supplies of wood available to their villages and towns. In contrast, the early settlers in North America faced a vast forest stretching across the continents. Thus forest was initially regarded as a hindrance to agricultural settlement and was attacked carelessly with fire and axe. Then, as demand grew in the eastern States and the eastern forests were depleted, further growth required the opening up of the Midwestern hinterland. Canals and railroads were built into this hinterland and this transportation network also allowed the focus of the lumber industry to shift into the Great Lakes areas. The Lake states and the Ontario lumber industry expanded rapidly but peaked by the end of the 19th century as the pineries in these areas were depleted.[27] The expanding transcontinental railway network then allowed the industry to migrate further on to the American South and eventually to the Pacific Coast. By the late 1920's, hundreds of sawmills in the South had either liquidated or moved West leaving behind "ghost towns" and vast areas of unproductive cutover lands.[28] The prevailing mode of timber exploitation was "cut out and get out". It was not profitable to manage the cutover lands to grow a second crop of trees while there were still other areas of virgin timber to move to.

Public concern with the rate of depletion of the forests in the older exploited areas arose in the second half of the 19th century as part of the Conservation movement. This concern led governments to take some preliminary steps toward ensuring the protection and conservation of their forests. Fire protection systems began to be organized in cooperation with industry who had often suffered great losses from forest fires. The Eastern States, Quebec and Ontario established forest reserves where settlement would be discouraged and logging regulated. These reserves were intended to protect nontimber values such as watershed protection and to eventually provide a permanent timber supply by regulating logging methods to promote regeneration and protection of young stands. The types of regulation envisioned were minimum diameter limits for the harvested trees and the disposal of logging slash to minimize the risk of fire on cutover lands.[29]

The turn of the century saw a growing interest in the application of scientific forestry on timber lands. The first attempts to apply classical European forestry principles to the management of private forest lands appear to have included the 7000 acre Vanderbilt estate in North Carolina by G. Pinchot, 1892, and the Lotbinière seignury in Quebec by E.G. Joly, 1896. The first forestry schools in universities were established including one at the University of Toronto in 1907. A Division of Forestry was established in the United States Department of Agriculture in 1881. This division grew rapidly after Pinchot was appointed Head in 1898. In 1905, it became the Forest Service and was given responsibility for managing (for multiple use) the National Forest System.[30] A few companies sought the Division's advice on the preparation of management plans for successive timber crops. The Forest Service also began to prepare such management plans for its own lands.[31]

In Canada, the federal government appointed a Chief Inspector of

Timber and Forestry in 1899. This led to efforts to improve the methods of timber harvesting being used on Dominion Lands (the Prairies plus the Railway Belt in B.C.) in order to get better regeneration , the establishment of timber reserves with fire protection staff (1906), the beginnings of a systematic forest survey (1906), and the establishment of nurseries (1904,1912).[32] Ontario and Quebec established nursery-research stations in 1908. Large scale seeding or replanting of denuded areas was viewed, however, as being too expensive relative to its benefits. Thus the nurseries concentrated on providing seedlings for shelterbelts to protect farm lands and on research.[33]

A pulp and paper industry now began to arise in Eastern Canada to utilize the small diameter spruce left behind by the lumbermen. These operations required a much larger fixed investment than the sawmills and hence were much less mobile. Thus some progressive companies, influenced by the developing forestry profession, became interested in growing trees on their limits in order to ensure the continuity of their operations. Wilson (1929) provides a number of such examples. He was Chief Forester of the Laurentide Company of Grand'Mère Que. which began reforestation experiments in 1908. By the late 1920's this company was planting 3-4 million seedlings a year. A number of large companies in the American South and Pacific North West also began reforestation experiments and planning for sustained yield in the 1920's (Brandstrom (1957), Heyward (1958)). This activity was stimulated by the Clarke-McNary Act of 1924 which provided federal aid for setting up cooperative fire protection agencies for public and private lands. Such protection was essential before any forest management could be undertaken. Another important act was the Knutson-Vandenberg Act of 1930. This Act authorized appropriations for the operations of nurseries and the establishment and maintenance of plantations by the Forest Service. It also permitted the

Forest Service to require timber sale purchasers to make deposits for tree planting, seed sowing or stand improvement on cutover areas. This Act continues to provide a major source of funds for reforestation work in National Forests today.[34] Public agencies in Canada also expanded their activities in the 1920's, establishing more research stations, undertaking improved forest surveys and expanding replanting and direct seeding activities. Replanting was attempted in Northern Ontario for the first time (8263 acres).[35]

The financial exigencies of the Depression led to the collapse of many private reforestation projects. Public forest activities in Canada and the United States were also starved for funds. However, forestry activity in the United States was stimulated by the New Deal Recovery Program. The Civilian Conservation Corps created in 1933 engaged in large scale protection and replanting activities on both private and public lands. There was also increasing concern that private logging practices were severely damaging the reproductive capacity of the land. Thus, some circles were advocating massive expropriations of lands not being managed for sustained yield. The NRA act of 1934 contained a lumber code which imposed minimum forestry practices standards for private lands which were intended to ensure that cutover lands were left in a good condition to produce another crop. Although the Act was disallowed, a number of trade association were formed whose members voluntarily followed many of the practices prescribed in the Act (Recknazel, 1939). This was done no doubt partly to ward off the threat of nationalization.[36]

The movement to put industrial and non-farm timber lands under sustained yield management grew rapidly. In 1941, Weyerhaeusen Co. called one of its reforestation projects in Washington a "Tree Farm". The idea proved popular and the next year the American Forest Products Institute was formed, to register and publicize tree farms certified by various trade associations.

By 1950, there were almost 3000 tree farms registered, comprising almost 23 million acres of timberland. The basic criteria for certification were protection from fire and pests and harvesting practices that would ensure prompt restocking with desirable species.[37]

Public agencies also moved towards sustained yield management on their own lands during the 1940's. Certain reverted railway lands in Oregon (O & C lands) were required by legislation to be managed on a sustained yield basis in 1937. Congress passed in 1944 a Sustained-Yield Forest Management Act authorizing the establishment of either cooperative sustained-yield units combining federal and private lands or consisting of federal forest land only. In 1946 further legislation established the Bureau of Land Management in the Department of the Interior and the Bureau delineated in more detail sustained yield policies for the O & C lands and other master units.[38]

In British Columbia, the Forest Service (established 1912) had been mainly concerned with fire protection and had made only minor expenditures on research and replanting during the 1930's. Publicly owned timber was harvested under tenures where the land reverted to the Crown after harvesting. Thus licensees had no incentive to use conservative logging methods although Bloedel-Stewart and Welch began to reforest some of its privately held land in 1938.[39] A Royal Commission was held in 1945 to investigate the state of the timber supply. The Commission recommended new forms of tenure for the province which would be managed on a sustained yield basis. These tenures, implemented in 1947, included Forest Management Licenses (later called Tree Farm Licenses) where a licensee has assigned for his own permanent use a combination of Crown Lands and other tenures that he held. The Licensee was required to manage these lands on a sustained yield basis under management plans prepared by himself and approved by the Chief Forester. Public working circles also began to be be established where the Forest Service was responsible for the management plans, the cutting being done under contract. Sustained yield was also to be the principle here although progress towards this goal was slow due to lack of information. Tree Farms on private land were provided for in 1951 by giving special taxation treatments to lands managed for sustained yield.[40]

Ontario had included in its agreements with timber limit holders a requirement that they submit for Departmental approval management plans particularly relating to cutting methods. However, this requirement was usually just a formality. By 1948, however, enforcement had been beefed up and agreement holders were preparing inventory reports and long-run management plans for submission for Departmental analysis and approval. A Royal Commission in 1947 recommended achieving sustained yield and measures to insure a continuous fibre flow were proclaimed in the Crown Timber Act of 1953.[41] The goal of forest policy in many jurisdictions, both public and private, had thus become by the 1950's sustained yield. Silviculture systems were designed to promote reasonably prompt regeneration. Harvesting levels began to be governed by AAC's (annual allowable cuts) which were levels calculated from inventory data that were believed would ensure a continuous flow of fibre throughout the future.

Together with the commitment to sustained yield went an increasing interest in reforestation. Restoring unproductive lands to a productive condition was the most direct means of increasing the AAC's. This interest was apparent in the United States where the area being planted or direct seeded each year doubled in all ownership classes from 1951 to 1960.[42] The belief that growing trees was good business practice grew. In part, this belief was fortified by rising stumpage and forest land prices which made corporations more dependent on their own lands for future company growth. However, it also reflected the growing influence of professional foresters on corporation policy and the growing conservationist tendency of the Forest Service which was under increasing pressure to produce nontimber values in the National Forests. In 1960, the Forest Service was given a new mandate, the Multiple Use Sustained Yield Act, which directed it to harmonize and coordinate the production of both nontimber and timber values in its lands without impairing the productivity of these lands.[43]

Interest also grew in this decade in the use of intensive methods of increasing timber growth. The Forest Service expanded its research activities into stand improvement practices and some corporations with large land holdings followed suit. The same trends of increased planting and experimentation with stand improvement practices was evident in Canada, particularly in B.C. Private companies in B.C. had planted 11,916 acres up to 1949. In the next 10 years 60,188 acres were reported as planted.[44] The security of tenure embodied in Tree Farm Licenses undoubtedly encouraged this expansion of planting activity. As well, the costs were partly borne by the Crown as licensees were allowed to include approved forestry costs with their logging costs in the calculation of stumpage rates. The allowable cut effect (ACE) provided an additional inducement in that higher growth rates in the TFL could lead to a higher AAC.[45] A modified form of these incentives for more intensive management continues to exist in B.C. today. The Forest Service had the responsibility to ensure regeneration in PSYU's. It also increased its planting efforts for a while but suffered a setback in the late 50's when adverse weather conditions killed many seedlings in the nurseries.[46]

In Ontario, responsibility for regeneration lay with the limit holders under the management plans they submitted to the Ministry of Natural

Resources. However, this regulation does not seem to have been enforced effectively and due to the short-term of the tenures and the fact that the licensees had to bear the cost , regeneration efforts lagged. The Ministry, however, stepped up its own effort beginning with "Project Regeneration" in 1956. In 1962, the Ministry took over complete responsibility for regeneration.[47]

Other provinces seem to have relied at this time mainly on natural regeneration. Some private companies were, however, engaging in planting and fertilization experiments (Snyder, 1960).

During the early 60's annual cuts in Canada were believed to be still well below AAC's at the regional level. Thus growth of the forest industry could still be accommodated by expanding logging operations into new areas.[48] There was thus not a great need to increase growth rates through intensive management and thus activity in this area largely remained at the experimental level. Silvicultural efforts in planting and site preparation, however, continued to expand rapidly. At the same time, some companies began to get interested in intensive forestry. Macmillan-Bloedel inaugurated an Intensive Forestry Program in 1963 with a budget of $5 million. The program involved planting, juvenile spacing to 988 trees per hectare and site rehabilitation.[49] Pacific Logging Co. in B.C. which owned the majority of its lands began fertilization trials in the late 60's.[50]

In the United States, timber stand improvement activities now began to be applied on a large scale, spurred no doubt by a steady increase in the demand for wood products. During the period 1968-71, an average of 570,000 hectares were subject to species conversion or juvenile spacing. This area represented 15% of the average area cut and was largely in the National Forests or in industrial holdings.[51] A survey of large landowners in the American South revealed that improvement cuts had been carried out on 350,000 hectares of a land holding of 17 million hectares. These owners had also carried out some form of site preparation on half of the area harvested and had replanted two-thirds of this area (Guttenberg, 1969). The pulp industry was prominent in using the most advanced techniques. No doubt the 30 year rotation planned for pulpwood made these investments seem more attractive than elsewhere.

The tree farms in the Pacific North West were also introducing new intensive methods in a large way. Juvenile spacing and fertilization began in a substantial way in 1968. Commercial thinnings rose rapidly from 1955 until 1962 as markets for small logs improved. It has since continued at a fairly stable level.[52]

Weyerhauser Co. has always been a leader in the adoption of advanced forestry practices. Since 1966, its operations have been aimed at creating the Target Forest. This forest would be planted with genetically superior seedlings, juvenile spaced at age 10, fertilized at age 15 and every 5 years thereafter, thinned at age 20 and every 5 years thereafter and finally, clearcut at age 45.[53]

An interesting development in the late 60's was the appearance of estimates of the economically feasible opportunities for reforestation and stand improvement measures. Marty and Newman (1969) estimated that stand improvement opportunities existed on 3.75 million hectares of the National Forests of which 3.23 million hectares would yield an internal rate of return of at least 3%. An additional 1.82 million hectares were available for reforestation. This type of analysis was later extended to include privately owned forest land by the Forest Service (USDA Forest Service, 1974). It should be noted that the economic evaluation done in these studies differs from the single stand cost-benefit analysis employed in this paper. The returns to a project were valued in terms of the increase in AAC in the relevant management unit that the project would permit. In reality, the decisions to increase harvesting rates and to practice intensive management are separable. If harvesting rates are constrained by AAC's, it is being assumed that there is a high cost associated with loss of continuity of operations. This type of analysis is then associating with intensive management as a benefit, the avoidance of this high cost and thus makes intensive management look much more profitable than a single stand analysis. There is a question here which deserves further research -- whether there really are high costs associated with not following sustained yield policies.

The approach of valuing the allowable cut effect (ACE) as a benefit is also very popular with industry up to today (Burch, 1980, 65). The calculations of the previous section show that intensive management can be profitable or nearly profitable on its own on the better growing sites. It is not surprising then that the use of intensive management techniques has expanded markedly in the last 15 years as intensive management would in many cases appear to be extremely profitable when the additional benefits of the ACE are added in.

The Forest Service updated its estimates of stand improvement opportunities as required by law in 1980 (USDA Forest Service, 1980). Their study identifies 68 million hectares or 35% of U.S. commercial timber land as being economically treatable. With these treatments, net annual timber growth is expected to increase by 60%. 27.8% of the above area was recommended for juvenile spacing or commercial thinning. The rest was recommended for reforestation or species conversion. These opportunities are 74% in private non-industrial holdings. No National Forest land is included as the Forest Service believes that it has already scheduled or planned all economic opportunities on its own land. Non-industrial owners have been eligible for some public assistance with their lands since at least 1936. In 1973, this assistance was increased with the passage of the Forestry Incentives Program which provided financial assistance for reforestation and stand improvement work. The Forest Service reported that from 1973-82, this program was responsible for the treatment of 0.93 million hectares. The Forest Service itself accomplished about 25% of Timber Stand Improvement Work in the United States in 1982, an area of about 146,000 hectares being treated. The average cost of $370 per hectare was funded partly from its own appropriation and partly from funds generated by the Knutson-Vandenberg Act of 1930.[54] Finally, large industrial owners expect to greatly expand their activities in such a way that AAC's in 1985 will be 14% higher than in 1970 (DeBell et al, 1977).

Intensive forestry has not spread as rapidly in Canada as in the United States. Government and industry attention continues to be absorbed by the problems of regeneration and the reforestation of the considerable areas of unsatisfactorily stocked forest lands. However, during the 1970's there has been considerable changes in provincial forest policies that include arrangements whereby stand tending activity can be funded in the future. In Nova Scotia, Nova Scotia Forest Industries has been using intensive management techniques on its leases. The benefits to the company are judged on their impact on the AAC. The cost is partly offset by a stumpage rebate of $\$0.79/m^3$ of healthy wood harvested.[55] North West Pulp and Paper in Alberta is also engaged in extensive spacing operation. The company bears the cost but is rewarded by not having to pay stumpage on increases in the AAC due to intensive management.[56]

Ontario has carried out some improvement cutting, mainly in the southern part of the province. 125,000 hectares were subjected to regeneration or tending activity in 1976.[57] The province has been revising its tenure arrangements and signing Forest Management Agreements with large users. These agreements shift the responsibility for regeneration back to industry. The cost is subsidized at rates equal to the government's cost of carrying out this work. Other silvicultural treatments can be carried out at Company expense. In this case, the Company pays only 10% of the going stumpage rates on any increase in the AAC attributable to the treatment.[58]

Quebec and New Brunswick have been moving to take over responsibility for regeneration on Crown Lands. Little stand tending has yet been carried out on these lands. A few large companies in New Brunswick have engaged in intensive silvicultures on their privately owned lands.[59]

The B.C. Ministry of Forests is demonstrating an increasing commitment to spend funds on intensive forest management. Current Ministry plans to call for increasing expenditures on intensive silviculture from $23.7 million in 1982-83 to $68.1 million in 1986-87. Over the same period the annual amount of treatment is planned to increase from 30,400 hectares to 108,400 hectares.[60] The Ministry's Research Branch is on the forefront of developing computer models (called TASS) which will predict the yields resulting from various types of silvicultural treatments. Alternative treatments can then be analyzed by an advanced timber-supply programming model such as MUSYC to determine the most profitable treatment, subject to multiple use and sustained yield constraints. Such an analysis was carried out for the Okanagan Timber Supply Area in 1981, an area in which it had been felt that the annual allowable cut (AAC) would eventually have to be reduced. A plan was found involving a large increase in the rate of planting, juvenile spacing and rehabilitation of decadent cedar-hemlock stands which would allow the AAC on Crown lands to be increased by 35% in the future. This plan would pay for itself in the form of increased stumpage revenue.[61]

Finally, it should be noted that the Canadian government has also committed itself to increasing support to silvicultural practices. Under the 1982 Framework for Forest Renewal federal funds are to "be directed to the costs of intensive treatment such as spacing young stands and rehabilitation of the large backlog of neglected land [and to] incentives to small private woodlot owners."[62] The funds are to be spent under agreements to be negotiated with the provinces which have long-term forest renewal plans and are to be accompanied by increased provincial and industrial commitments. Agreements have been signed with Nova Scotia and PEI and negotiations are continuing with the other provinces.[63]

The program has been rationalized as being necessary to meet future supply targets and also in terms of social goals such as reducing unemployment. It is recognized that these rationalizations need to be supplemented with a quantification of the costs and benefits associated with these projects. It is hoped that the calculations in this paper will contribute to making such a quantification possible.

The attitude of the B.C. Ministry of Forests towards intensive forest management merits some further discussion here. The objective of the Ministry is to maintain the present level of harvest in the province indefinitely. The recent Resource Analysis indicated, however, that there would be "fall-downs" in the annual allowable cut in many Timber Supply Areas several decades hence if current harvesting and silvicultural practices were continued. The Ministry views intensive silviculture as one means by which these falldowns can be avoided -- the other means being improved utilization standards and the harvesting of more remote stands.[64]

The results reported here suggest a different reason for pursuing intensive forest management. For good sites, it may be a very profitable investment opportunity, although of course there are problems financing investments which will not yield financial returns for several decades. The Ministry has set itself the laudable task in its next Resource Analysis of estimating the economically recoverable timber supply as a function of prices and costs.[65] Presumably, annual allowable cut calculations will in future be based on the economically recoverable supply and if falldowns are to be avoided, means must be found of increasing this recoverable supply. Intensive management is really the only means by which the Ministry can influence the recoverable supply. Improved utilization and the harvesting of more remote stands will only increase the recoverable supply in the future if there are price increases or technical improvements in harvesting technique.

The Ministry talks of comparing the cost of moving into remote stands with the cost of supplying the same volume of timber from intensive silviculture. It is not clear, however, what is meant by the cost of moving into remote stands. If these stands are in the recoverable supply there is no cost to the government in having them harvested. If they are not in the recoverable supply, then the cost is the subsidy the government will have to pay to the firms that log these stands. The benefits of maintaining harvest rates in this way should be compared to the benefits of giving subsidies to firms in other sectors of the economy.

The Ministry currently finances intensive management either directly from its own funds or by offering incentives to licensees to carry out forest management techniques. These incentives consist of credits against stumpage payments of approved forestry costs on Crown Land and in the case of Tree Farm Licences, the annual allowable cut may be increased to reflect the increases in forest productivity due to silvicultural treatments.[66] Incentives are given at the discretion of the regional forest managers, so, unlike the funding of the Ministry's own activities, are not subject to legislative scrutiny. Thus the Ministry is freed from its own budgetary and professional constraints concerning how much intensive management it can get carried out. In 1980, the Forest Service carried out stand tending activities on 21,373 hectares while licensees treated 17,881 hectares.[67]

Under these programs, the Province pays most of the cost of silvicultural activity on the forest land that it owns. However, under the Rothery method of calculating stumpage, the Province does not receive all the benefit. According to the formulas in Appendix D, if treatment results in higher quality trees and equal increments ΔR to the values obtained by the operator and the value estimates by the assessors then stumpage increases by $(1 + t)^{-1} \Delta R$ and operator's profits by $t(1 + t)^{-1} \Delta R$. The additional profit to a licensee might be regarded as a return on his investment on equipment and working capital needed to carry out silvicultural treatments. This presumes, however, that the licensee was also the agent carrying out the treatments and that the reimbursement he received initially did not include a return to capital. A more systematic and equitable treatment of licensees would result if the capital costs of carrying out silviculture were reimbursed at the time the treatment was carried while the profit and risk allowance on treated second growth stands was reduced a little. For example, if the value of the stand was enhanced by 10% a profit and risk percentage of 20% could be reduced to 18% without reducing operator's profits.[68]

As noted above, Tree Farm Licensees may be allowed to increase their annual allowable cut to reflect increases in the productivity of their land base resulting from intensive silvicultural practice. The financial implications of this incentive should be reviewed. Do the increased stumpage payments to the Crown cover the credits against stumpage for silvicultural costs? If not, the economic benefits to the Crown will only accrue in the future when better quality trees begin to be harvested. The costs of obtaining these benefits should also be charged against the future, i.e., any loss in current stumpage payments might be made up by borrowing against the increased stumpage payments in the future.

VII. Conclusions

The examples worked out in this study indicate that for second growth Douglas-fir at least, financial rotations are quite sensitive to factors such as soil fertility, the real price of wood products, discount rates and topographical conditions. This sensitivity is disappointing because it makes it difficult to use the financial rotation as an operational criterion in designing forest management plans. However, it was also shown that on good and medium sites there was a possibility of choosing a compromise financial rotation which might result in obtaining close to the maximum economic benefits for a range of possible price outcomes.

The examples here also show that financial rotations are not significantly shorter than maximum volume rotations except on good growing sites under nonadverse logging conditions. In most cases, the impact of discounting the value of the future harvest is offset by the economies of size and quality premiums associated with growing larger trees. On good sites, the use of maximum volume rotations would result in substantial economic losses. For example, under base case prices, the bare land value is reduced by 19% by using the maximum volume rotation of 75 years (Table 23, p.71). On the other hand, using the financial rotation of 65 years reduces MAI by only 1.6% over the maximum volume rotation (Table 20, p.68).

Another conclusion of this study is that sustained yield forestry is not economically viable (at a discount rate of 5%) on medium sites where logging conditions are very poor (Table 9, p.25) and on poor sites unless logging conditions are quite good (Table 27, p.75). Wood values alone do not justify the treatment of these sites to ensure natural regeneration of Douglas-fir. This conclusion suggests that forestry efforts should be concentrated on the more fertile and the easier to log sites.

The B.C. Ministry of Forests has in fact excluded low sites (but not poor sites) from AAC calculations since 1974 on the grounds that the sites are unsuitable for reforestation (Pearse, 1976, p.D9). In addition, the most recent Forest and Range Analysis recognizes that "the returns on forest management investments [on poor and low sites] are expected to be minimal or nil".[69] The analysis here supports these views but suggests that they do not go far enough. Determination of the returns on forest management depends not only on site quality but on accessibility and other factors influencing logging costs.

The question of whether nontimber values can significantly lengthen the financial rotation has been examined in this study. Some examples were worked out where the forest area had a relatively high nontimber value relative to other areas and where this value depended on the presence of older stands in the area. It appeared that the social value of these uses of the forest could be high enough to outweigh the timber values and to make no logging at all the harvest level yielding the highest net social benefits. Such sites are, however, only a very small proportion of the forest land base.

The biological data has also permitted a look at the economics of intensive management. Financial rotations were not changed much by the examples of intensive management worked out here. One case, involving juvenile spacing, several commercial thinnings and several fertilizations looks very profitable compared to the no treatment case on good sites. This case also looks good on medium sites under optimistic price assumptions. These examples would probably look better if the treatments had also been chosen to maximize the bare land values and the financial rotations would be longer in this case. These conclusions are supported by the work of Brodie, Kao <u>et</u>. <u>al</u>. who were able to compute economically optimal treatments. The examples here indicate that delaying the first commercial thinning would probably increase SE.

Finally, the historical review has shown that interest in sustained yield let alone intensive management is a relatively recent phenomenum in North America. Nevertheless, many large progressive companies are now engaged in the large scale application of these techiques and the trend is clearly towards more and more intensive silviculture. These programs are usually justified in terms of the allowable cut effect rather than the single stand benefit - cost analysis used here and hence make intensive silviculture appear to have much greater economic benefits than obtained here. The economic rationale for the trend is thus clear. It has been contended here, however, that this type of analysis is deficient in that it evades a proper accounting of the costs of not following a sustained yield policy.

A. SENSITIVITY ANALYSIS OF THE PRESENT VALUE OF STUMPAGE FOR A GOOD SITE

TABLE 19

BIOLOGICAL CHARACTERISTICS OF NATURAL, NO TREATMENT, MANAGED

COASTAL DOUGLAS FIR STAND, SITE INDEX 145

Age (yrs.)	DBH (cms.)	HT. (m)	STEMS (#/ha.)	MAI (m^3/ha/yr.
25	15.8	17.25	1981	6.1
30	19.4	21.58	1497	9.8
35	22.8	25.57	1173	12.2
40	26.0	29.29	958	13.6
45	29.0	32.74	810	14.5
50	31.9	35.91	701	15.0
55	34.6	38.83	620	15.3
60	37.1	41.51	556	15.5
65	39.6	44.04	504	15.7
70	42.0	46.36	462	15.8
75	44.2	48.52	425	15.9
80	46.5	50.50	395	15.8
85	48.6	52.40	370	15.6
90	50.6	54.13	348	15.4
95	52.7	55.75	329	15.2
100	54.6	57.24	309	15.0

Source: Curtis *et al*. (1982, Table 1D)

Variable definitions:

DBH: diameter at breast height (1.3m)

HT: height of tree of average volume

STEMS: number of live trees per hectare

MAI: mean annual increment = merchantable volume per hectare to close utilization standards divided by stand age.

TABLE 20

ECONOMIC CHARACTERISTICS OF NATURAL, NO TREATMENT, MANAGED COASTAL DOUGLAS FIR STAND, SITE INDEX 145

AGE (yrs.)	AREV ($\$/m^3$)	ACOST ($\$/m^3$)	ASTUMP ($\$/m^3$)	MINSTUMP ($\$/m^3$)	APROFIT ($\$/m^3$)
25	51.92	71.85	-26.70	1.84	-21.77
30	53.73	63.09	-16.37	1.97	-11.33
35	54.63	58.81	-11.30	2.04	- 6.55
40	55.53	52.72	- 4.43	2.10	0.71
45	56.73	49.48	- 0.15	2.19	5.06
50	58.83	47.20	3.96	2.34	7.67
55	59.73	45.57	6.37	2.41	7.79
60	60.63	44.39	8.33	2.47	7.91
65	61.53	43.47	10.04	2.54	8.03
70	62.58	42.77	11.65	2.61	8.16
75	62.58	42.19	12.22	2.61	8.16
80	63.63	41.75	13.58	2.69	8.26
85	64.53	41.38	14.73	2.75	8.42
90	65.43	41.07	15.83	2.82	8.53
95	66.33	40.81	16.87	2.88	8.65
100	66.33	40.58	17.10	2.88	8.65

Source and definitions: see text.

TABLE 21

FINANCIAL VALUES OF NATURAL, NO TREATMENT, MANAGED
COASTAL DOUGLAS FIR STAND
SITE INDEX 145

AGE (yrs.)	STUMP ($ '000/ha.)	FR ($/ha/yr.)	PNW ($/ha.)	SE ($/ha.)
25	-3.66	-146.2	-1067.2	-1495.8
30	-4.33	-144.3	- 989.8	-1274.1
35	-4.36	-124.5	- 785.5	- 950.8
40	-2.18	- 54.4	- 326.1	- 377.2
45	-0.88	- 1.9	- 44.0	- 49.2
50	2.67	53.3	181.2	197.4
55	4.83	87.8	268.2	286.6
60	6.99	116.4	304.7	320.7
65	9.24	142.2	312.4	325.0
70	11.60	165.8	302.0	311.4
75	13.10	174.7	257.1	263.3
80	15.46	193.3	230.0	234.3
85	17.58	206.8	195.8	198.6
90	19.72	219.1	162.4	164.2
95	21.89	230.4	130.9	132.1
100	23.03	230.3	95.1	95.7

Source and definitions: see text.

TABLE 22

EFFECT ON ROTATIONS AND VALUES OF CHANGES IN WOOD PRODUCT PRICES

NATURAL STAND, NO TREATMENT, SITE INDEX 145

θ	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
.8	85	5	90	5
.9	70	143	70	138
1.0	65	325	65	312
1.1	55	556	60	525
1.2	55	824	55	771

Explanation: SE and PNW have been recalculated with REV multiplied by the scaling factor θ.

TABLE 23

SE AS A PERCENTAGE OF ITS MAXIMUM VALUE

SITE INDEX 145

θ	ROTATION						
	55	60	65	70	75	80	85
.9	12	62	89	100	86	82	71
1.0	88	99	100	96	81	72	61
1.1	100	99	94	86	73	63	53
1.2	100	95	88	79	66	57	48

Explanation: SE is expressed as a percentage of the maximum value it achieves for the same value of θ.

TABLE 24

EFFECT ON ROTATIONS AND VALUES OF CHANGES IN DISCOUNT RATE,

NATURAL STAND, NO TREATMENT, SITE INDEX 145

R	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
.02	85	3862	95	3216
.04	70	700	70	657
.05	65	325	65	312
.06	60	152	60	148
.08	55	19	55	19
.10	50	-20	50	-20
* .12	50	-31	50	-31

* In this case, Crown could reduce its losses by going to a 45-year rotation and charging minimum stumpage.

TABLE 25

EFFECT ON ROTATIONS AND VALUE OF EXTREME PHYSICAL CONDITIONS

NATURAL STAND, NO TREATMENT, SITE INDEX 145

		SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
1.	Level (S=0%)	60	358	60	341
2.	Steep Slope (S=90%)	70	222	75	214
3.	Rock bluff or cliffs (EX=4)	65	289	65	278
4.	High risk allowance (t=.25)	70	176	70	171
5.	Short haul (MULT=1)	60	419	60	398
6.	Long haul (MULT=9)	70	104	70	101
7.	No breakage (C=0%)	65	369	65	355
8.	High breakage (C=20%)	65	280	65	269
9.	Level, short haul (S=0%, MULT=1)	60	456	60	434
10.	Steep Slope, long haul (S=60%, MULT=9)	80	64	80	63
11.	Level, short haul, no breakage (S=0%,MULT=1,C=0%)	55	519	60	493
12.	Steep Slope, long haul high breakage (S=60%,MULT=9,C=20%)	80	51	80	50
13.	Many Conditions Bad (S=40%,MULT=9,C=20% EX=4,t=.25)	95	-15	95	-15

B. SENSITIVITY ANALYSIS OF PRESENT VALUE OF STUMPAGE FOR A POOR SITE

TABLE 26

BIOLOGICAL CHARACTERISTICS OF NATURAL, NO TREATMENT, MANAGED

COASTAL DOUGLAS FIR STAND, SITE INDEX 105

Age (yrs.)	DBH (cms.)	HT. (m)	STEMS (#/ha.)	MAI (m^3/ha./yr.)
25	10.8	11.09	2786	-
30	13.4	14.20	2359	-
35	15.8	17.04	1966	4.3
40	18.2	19.63	1633	5.9
45	20.5	22.01	1373	7.1
50	22.7	24.20	1178	8.0
55	24.8	26.18	1032	8.5
60	26.8	27.98	916	8.9
65	28.8	29.66	823	9.1
70	30.6	31.15	748	9.2
75	32.5	32.55	687	9.2
80	34.2	33.83	632	9.2
85	35.9	34.99	588	9.2
90	37.6	36.06	548	9.1
95	39.3	37.06	516	9.1
100	40.8	37.98	487	9.0

Source: Curtis *et al*. (1982, Table 1B)

Variable definitions:

DBH: diameter at breast height (1.3m)

HT: height of tree of average volume

STEMS: number of live trees per hectare

MAI: mean annual increment = merchantable volume per hectare to close utilization standards divided by stand age.

TABLE 27

ECONOMIC CHARACTERISTICS OF NATURAL, NO TREATMENT, MANAGED COASTAL DOUGLAS FIR STAND, SITE INDEX 105

AGE (yrs.)	AREV ($/m^3)	ACOST ($/m^3)	ASTUMP ($/m^3)	MINSTUMP ($/m^3)	APROFIT ($/m^3)
40	52.82	66.04	-20.10	1.91	-15.13
45	53.73	62.35	-15.63	1.97	-10.59
50	54.63	59.90	-12.40	2.04	-7.31
55	55.53	58.16	-9.88	2.10	-4.73
60	56.73	53.95	-4.63	2.19	.59
65	56.73	52.11	-2.78	2.19	2.43
70	57.93	50.62	-0.25	2.28	5.03
75	58.83	49.33	1.83	2.34	7.16
80	58.83	48.33	2.82	2.34	7.69
85	59.73	47.47	4.47	2.41	7.79
90	60.63	46.77	5.95	2.47	7.91
95	60.63	46.13	6.59	2.47	7.91
100	61.53	45.63	7.88	2.54	8.03

Source and definitions: see text.

TABLE 28

FINANCIAL VALUES OF NATURAL, NO TREATMENT, MANAGED
COASTAL DOUGLAS FIR STAND
SITE INDEX 105

AGE (yrs.)	STUMP ($ '000/ha.)	FR ($/ha/yr.)	PNW ($/ha.)	SE ($/ha.)
40	-4.25	-106.3	-597.7	-691.2
45	-4.52	-100.4	-500.8	-559.8
50	-4.45	-89.0	-392.5	-427.6
55	-4.17	-75.9	-296.0	-316.2
60	-2.22	-37.0	-141.7	-149.1
65	-1.48	-22.8	-90.3	-94.0
70	-0.14	-2.0	-38.7	-39.9
75	1.14	15.2	-9.2	-9.9
80	1.86	23.3	-3.1	-3.2
85	3.13	36.9	6.2	6.2
90	4.39	48.7	9.0	9.1
95	5.12	53.9	3.2	3.3
100	6.40	64.0	0.8	0.8

Source and definitions: see text.

TABLE 29

EFFECT ON ROTATIONS AND VALUES OF CHANGES IN WOOD PRODUCT PRICES

NATURAL STAND, NO TREATMENT, SITE INDEX 105

θ	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
.8	100	-58	100	-58
.9	100	-29	100	-28
1.0	90	9	90	9
1.1	75	67	75	65
1.2	75	144	75	141

Explanation: SE and PNW have been recalculated with REV multiplied by the scaling factor θ.

TABLE 30

EFFECT ON ROTATIONS AND VALUES OF CHANGES IN DISCOUNT RATE,

NATURAL STAND, NO TREATMENT, SITE INDEX 105

R	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
.02	100	952	100	823
.04	90	82	90	80
.05	90	9	90	9
.06	85	-20	85	-19
.08	75	-33	75	-33
.10	70	-35	70	-35
.12	60	-33	60	-33

TABLE 31

EFFECT ON ROTATIONS AND VALUE OF EXTREME PHYSICAL CONDITIONS

NATURAL STAND, NO TREATMENT, SITE INDEX 105

	SEROT (yrs.)	SE ($/ha.)	PNWROT (yrs.)	PNW ($/ha.)
1. Level (S=0%)	85	19	90	18
2. Steep Slope (S=90%)	100	-24	100	-24
3. Rock bluff or cliffs (EX=4)	90	-4	90	-4
4. High risk allowance (t=.25)	100	-23	100	-23
5. Short haul (MULT=1)	85	29	85	28
6. Long haul (MULT=9)	100	-36	100	-36
7. No breakage (C=0%)	90	16	90	16
8. High breakage (C=20%)	90	2	90	2
9. Level, short haul (S=0%, MULT=1)	75	45	75	44
10. Steep Slope, long haul (S=60%, MULT=9)	100	-50	100	-49
11. Level, short haul, no breakage (S=0%,MULT=1,C=0%)	75	60	75	58
12. Steep Slope, long haul high breakage (S=60%,MULT=9,C=20%)	100	-49	100	-49
13. Many Conditions Bad (S=40%,MULT=9,C=20% EX=4,t=.25)	100	-73	100	-72

C. BIOLOGICAL DATA FOR VARIOUS EXAMPLES OF INTENSIVE MANAGEMENT ON A MEDIUM SITE

TABLE 32

BIOLOGICAL CHARACTERISTICS OF COASTAL DOUGLAS FIR STAND,

SITE INDEX 125, PLANTED TO 988 TREES PER HECTARE

AGE (yrs.)	DBH (cms.)	HT. (m)	STEMS (#/ha.)	MAI (m^3/ha./yr.)
25	17.4	15.5	973	2.9
30	20.8	19.2	914	6.2
35	24.0	22.5	832	8.5
40	27.1	25.5	753	10.2
45	29.9	28.3	684	11.4
50	32.7	30.9	625	12.2
55	35.3	33.3	576	12.8
60	37.8	35.5	534	13.2
65	40.1	37.6	494	13.4
70	42.3	39.4	459	13.6
75	44.4	41.2	430	13.6
80	46.5	42.8	403	13.5
85	48.5	44.2	378	13.3
90	50.4	45.6	358	13.2
95	52.3	46.9	341	12.9
100	54.1	48.0	324	12.7

TABLE 33

BIOLOGICAL CHARACTERISTICS OF NATURAL, COMMERCIALLY THINNED*

COASTAL DOUGLAS FIR STAND, SITE INDEX 125

AGE (yrs.)	DBH (cms.)	HT. (m)	STEMS (#/ha.)	MAI+ (m^3/ha./yr.)
35	19.3	21.2	1529	8.2
40	21.9	24.3	865	9.9
45	24.6	27.3	788	11.0
50	27.8	30.1	548	11.8
55	30.2	32.6	524	12.2
60	32.5	34.8	494	12.5
65	36.7	37.2	348	12.8
70	38.9	39.1	338	13.0
75	41.1	40.9	329	13.1
80	43.2	42.6	316	13.2
85	47.3	44.3	245	13.2
90	49.4	45.7	240	13.2
95	51.5	47.0	235	13.2
100	53.5	48.3	230	13.1
39	25.4	23.7	254	122.5
48	26.4	28.9	136	87.3
60	29.0	34.8	116	104.1
83	36.1	43.5	64	110.9

* The last four lines of the tables describe the thinnings with the entry under STEMS being the number of trees cut and the entry under MAI the volume cut.
+ Includes the volume of the thinnings conducted prior to the age.

TABLE 34

BIOLOGICAL CHARACTERISTICS OF NATURAL, PRECOMMERCIALLY THINNED AND COMMERCIALLY THINNED* COASTAL DOUGLAS FIR STAND, SITE INDEX 125

AGE (yrs.)	DBH (cms.)	HT. (m)	STEMS (#/ha.)	MAI* (m^3/ha./yr.)
25	18.7	15.8	971	4.3
30	22.6	19.5	672	7.6
35	26.1	23.0	655	9.8
40	30.5	26.3	450	11.3
45	33.5	29.3	440	12.3
50	39.0	32.2	289	13.1
55	42.2	34.7	284	13.7
60	45.0	36.9	279	14.1
65	47.7	39.1	274	14.3
70	53.5	41.2	200	14.6
75	56.3	43.0	198	14.8
80	58.9	44.7	195	14.9
85	63.5	46.4	156	14.9
90	66.4	47.9	156	15.0
95	69.2	49.3	153	15.0
100	71.8	50.6	151	15.0
28	24.1	18.0	156	49.9
36	26.7	23.7	143	74.5
49	31.0	31.4	124	115.5
66	39.1	39.5	72	131.1
84	51.3	46.0	35	123.4

* See previous table for explanation.

\+ Precommercial thinning at age 11 to 988 trees per hectare.

TABLE 35

BIOLOGICAL CHARACTERISTICS OF NATURAL, PRECOMMERCIALLY THINNED+

COMMERCIALLY THINNED* AND FERTILIZED# COASTAL DOUGLAS FIR STAND

SITE INDEX 125

AGE (yrs.)	DBH (cms.)	HT. (m)	STEMS (#/ha.)	MAI* (m^3/ha./yr.)
25	21.7	16.6	731	5.7
30	26.9	20.7	499	9.2
35	31.1	24.2	492	11.4
40	38.2	28.0	311	13.4
45	42.2	31.1	309	14.6
50	45.5	33.9	301	15.4
55	53.2	36.9	210	16.2
60	56.7	39.4	208	16.7
65	62.8	41.6	158	17.0
70	66.4	43.7	156	17.2
75	69.7	45.6	156	17.3
80	75.4	47.6	126	17.4
85	79.0	49.3	123	17.4
90	82.3	50.9	123	17.4
95	88.1	52.6	101	17.3
100	91.7	54.1	101	17.3
29	25.9	19.8	157	60.7
38	29.7	26.4	148	105.3
50	37.1	33.9	91	126.6
63	49.0	40.7	47	133.1
77	60.5	46.4	30	131.4
91	70.6	51.2	20	130.5

* See two tables previously for explanation.

\+ Precommercial thinning at age 11 to 741 trees per hectare.

\# Fertilized at ages 20,35 and 50.

D. COMMENTS ON THE ROTHERY FORMULA

Rothery's innovation seems to have been the proposal that the profit and risk allowance be a percentage of costs plus stumpage rather than simply a percentage of operating costs. He points out a number of weaknesses in the later system which he believes his system will partially overcome. This appendix compares these two appraisal systems algebraically so that Rothery's claims about the relative merits of the two systems can be examined carefully. Let $\bar{R}$, $\bar{C}$ be the selling prices and costs as estimated by the assessor and R and C be the actual selling prices and costs. Under what Rothery calls the overturn method, the profit and risk allowance is calculated as $\bar{P} = t\bar{C}$. Letting S denote stumpage and P actual operator's returns (including the return to capital), then

$$S = \bar{R} - (1 + t)\bar{C} \qquad (1)$$

and $$P = R - \bar{R} - C + (1 + t)\bar{C} \qquad (2)$$

Under Rothery's system, $\bar{P} = t(\bar{C} + S)$ so that

$$S = \bar{R} - \bar{C} - t(\bar{C} + S)$$

Solving this for S gives

$$S = (1 + t)^{-1}\bar{R} - \bar{C} \qquad (3)$$

and $$P = R - (1 + t)^{-1}\bar{R} - C + \bar{C} \qquad (4)$$

The first claim that Rothery makes is that the overturn method "disregards the risk of marketing the product." Clearly, the risk of selling prices changing after stumpage charges have been made falls fully on the operator in either system. Whether or not the operator is compensated for bearing this risk depends, however, not on the appraisal system used but on the magnitude of t. In British Columbia, as well. $\bar{R}$ is adjusted to reflect the average selling prices in the three months prior to the time the logs are scaled (and stumpage is levied). Thus if selling prices change by ΔR before scaling there will be a related change in $\overline{R}$ which for simplicity will be assumed to be ΔR as well.

In overturn method, this risk falls fully on stumpage ($\Delta P = 0$, $\Delta S = \Delta R$) while in Rothery's method, it falls partly on the operator ($\Delta P = t(1 + t)^{-1} \Delta R$) and partly on stumpage ($\Delta S = (1 + t)^{-1} \Delta R$). Thus under Rothery's system, the operator actually bears more of the market risk than under the overturn system.

Rothery's second point is spurious.[70] The third claim, which is interesting, is that if the operator makes an effort to reduce C, then under the overturn method stumpage is increased and operator returns are lowered. This claim is not completely true. Under either system, all savings in C are fully appropriated by the operator unless the assessors make a related adjustment in $\overline{C}$ which is supposed to be the operating costs that would be incurred by an operator of average efficiency. In the case of such an adjustment, $\overline{C}$ can be thought of as a weighted sum of this operator's cost and the average costs $\overline{D}$ of other operators. Thus

$$\overline{C} = w\,C + (1 - w)\,\overline{D} \qquad 0 < w < 1$$

In the overturn formulation, a reduction in operating costs of ΔC increases profit by $\Delta P = (1 - w\,(1 + t))\,\Delta C$. In the Rothery formulation such a cost reduction results in increased profits of $\Delta P = (1 - w)\,\Delta C$. Thus the operator is more fully rewarded under this appraisal system but the difference $w\,t\,\Delta C$ would be quite small except for an extremely large operation.

The next weakness of overturn method is that material of marginal profitability ($\overline{R} > \overline{C}$) may not be sold because the value of stumpage would be negative. This proposition is indeed true and according to (1) happens when $\bar{R} - (1 + t)\bar{C} < 0$. According to (3), stumpage is also negative under the Rothery system when $\bar{R} - (1 + t)\bar{C} < 0$. However, the percentage t used in Rothery's system should be less than that used in the overturn method so that this problem is somewhat alleviated.

Another problem according to Rothery is that stumpage payments are an actual cost to the firm being paid before the firm receives revenue from the sale of wood products. Thus working capital is required to finance these payments and the firm should receive a return on this working capital. The operator undoubtedly deserves such a return but in either system the profit and risk allowance is being computed indirectly via a proxy rather than directly from calculations of the operator's investments and opportunity rates of return. Thus Rothery's point here is irrelevant to the main question which is whether either system provides an appropriate proxy for a normal return on the operator's investment (which should include money tied up in stumpage payments[71]).

Rothery's final point is that "the arithmetic of the overturn process is such that all discrepancies or errors in estimates [of $\bar{R}$ and $\bar{C}$] are reflected in stumpage." Rothery's appraisal system does in fact reduce the impact of such errors on operator's returns. If $\bar{R}$ is overestimated by ΔR, then operator returns are reduced by $\Delta P = -\Delta\bar{R}$ in the overturn method or $\Delta P = -(1 + t)^{-1} \Delta\bar{R}$ in the Rothery method. On the cost side, if $\bar{C}$ is underestimated by $\Delta\bar{C}$, P is reduced by $(1 + t)\Delta\bar{C}$ in the overturn method or by $\Delta\bar{C}$ in Rothery's method.

In summation, it seems that three of Rothery's points are valid. Under his system, firms have greater incentives to reduce operating costs, more marginally profitable stands will be harvested and operator's returns will be impacted less by errors in assessor's estimates of $\bar{R}$ and $\bar{C}$. On the other hand, his system also places more of the market risk on the shoulders of the operators.

Nevertheless, it should be pointed out in conclusion that Rothery's appraisal system discriminates against operators working in adverse conditions. Suppose that the operator is of average efficiency and that selling prices are estimated correctly. Then (4) reduces to $P = t\ (1 + t)^{-1}R$. Imagine two operators operating under identical conditions at identical production rates but differing in the length of haul to the mill. The operator with the longer haul requires extra capital in the form of extra logging trucks but receives no return on his investment in these trucks. As another example, consider two operators who employ identical amounts of capital but where one operator has lower production rates due to adverse operating conditions. This operator requires a longer time to harvest the same volume as the other operator and should be rewarded for the longer period of use of his capital. However, under the Rothery system, he is not so rewarded.

In these examples, it appears that those operators who have the lowest operating cost timber will also employ the least amount of capital to harvest a given volume and quality of timber. Since the profit allowances are identical, it means that the least cost operators will have the highest rate of return on their capital. One would expect then that in the apportionment procedure in TSA's, that operator's would try hard to be assigned the least cost areas to operate in. Logging companies do in practice seem to have this type of concern.

The overturn system of stumpage (2) gives $P = tC$. Thus, in either example above, an operator facing adverse conditions would be rewarded for his additional application of capital.

Financial rotations were calculated for several different stumpages system using the medium site example of Table 1 and 2. Rates were chosen so that operators would make roughly the same profits from logging a 75-year old stand. First, a royalty system was examined where the stumpage payment to the Crown was $8 per cubic metre regardless of the size of the trees. SE was maximized at a value of $410 by a rotation of 40 years. However, this value was largely a subsidy to the Crown from the operator who would lose $13.28 per cubic meter. The basic conclusion here is that maximization of the soil expectation values is impractical with a royalty system.

Two other stumpage systems were tried out (i) the overturn method with a profit and risk percentage of 16% and (ii) a fixed price method where the operator was paid $7 per cubic meter logged (regardless of size) as his profit and risk allowance. Both of these systems also gave financial rotations of 75 years, the same as the Rothery system. An examination of the SE values as a function of deviations from 75 years shows that for the overturn method the fall off from the maximum value is at about the same rate as for the Rothery method. The fixed price value falls off a little less quickly for shorter rotations. Thus this last system might have the advantage of being a little less sensitive to price changes than the other two systems. Otherwise, from the point of view of a financial objective, the three systems seem to perform in much the same way.

E. THE DISCOUNT RATE

It has been customary to use relatively low discount rates in forestry studies. For example, the United States Forest Service has recommended the use of a 4% real rate. A rationalization for this rate is given in Row et al (1981). On the other hand, cost-benefit manuals for B.C. (Loose, 1977) and Canada recommend the use of a 10% rate for the evaluation of public project. Both of these numbers supposedly reflect the social opportunity of capital.

The main component of the 10% rate is the 11-12% social rate of return attributed to displaced private investment. This number represents a weighted average of financial returns (including taxes) divided by the replacement value of the capital stock in each industrial sector. Row et al (1981) quote American studies which come up with similar magnitudes for this number for the United States. They then give three reasons why they do not think it is appropriate to use this number in choosing a discount rate. These criticisms and others have also been made in Canada (Sumner, 1980) and replied to by Jenkins (1980). The most cogent reason involves the treatment of risk. Jenkins (1980) admits his calculations include "the average risk premium demanded by private sector investors in Canada." This risk premium is substantial as may be seen by comparing the average real rate of return on common stocks 7.89% with the average real rate of return on corporate bonds 0.23%. These figures are for Canada for the period 1953-1980.[72] The Cost-Benefit Manuals recommend the use of a risk-free discount rate and the adjustment of costs and benefits associated with the project to reflect different possible outcomes such as the use of expected values. Jenkins' (1980) view is that those who receive benefits or pay the costs of public project face risk in ways similar to private investment and he cites the Come-by-Chance refinery as an example.

The view taken here is that the discount rates used in forestry investment analysis should reflect the risks inherent in forestry. These risks are substantial for any particular stand. Treatments may fail, the stand may be attacked by fire or pests, or market prices may be low when the stand is harvested. However, there is a very large portfolio of different stands in different locations out there and a very long time horizon. Diversified over this large portfolio, these risks should be quite low. Fire losses are now kept to a low average level at a small cost per hectare. Insect infestations are more difficult to control but the losses involved again are not great averaged over space and time and in any case can partly be offset be salvage operations. Market prices go up and down and harvest rates can be reduced in times of low prices.

This study accepts then the calculation of the discount rate in Row et al (1981). Their rate is the average real rate of return on Aaa corporate bonds which are believed to be relatively risk-free plus an upwards adjustment to reflect the loss of taxes from the foregone private investment.

It should be added that any cost-benefit analysis of large scale investment in forestry should try to incorporate explicitly in the calculation of benefits possible losses from the causes mentioned above. It has not been possible to make this adjustment in the calculations here due to lack of data. In any case, there is probably a more important source of bias in that the benefits calculated by the Rothery formula underestimates the true social benefits of forestry, i.e., that portion of the economic rent which accrues to the factors employed in the harvest operation.

Footnotes

1. Davis (1966, 140), however, has an example of loblolly pine where the maximum volume rotation is 44 years and the financial rotation is 43 years.

2. Curtis et al. (1981, 1982). The simulator uses a growth model whose key state variables are number of trees per hectare, stand basal area per hectare and stand age. The model is calibrated against data taken from sample plots in the U.S. Pacific Northwest and in coastal British Columbia.

3. The site index used is the average height in feet at age 50 years at breast height of the largest 40 (by diameter) stems per acre. It cannot be converted readily into the site index used in B.C..

4. Thinning means the harvesting of the dead and smaller diameter trees in the stand. Thinning reduces competition for sunlight and soil nutrients and hence enhances the growth rates of the remaining stems. For a fuller discussion, see Hyde (1980, 100-102 and 208-213).

5. The data used for the revenue calculation was taken from Dobie et al. (1975, Table 2, Case 6). It was inflated by a Douglas-fir wood products price index, D520005 Statistics Canada 62-011. Since 1979 was a peak year, the average index for 1978 to 1980 was used.

6. A milling cost of $20.59/m^3 was used, as a very rough estimate. Really milling cost depends on log size as well, but no data was available on this relationship. It can be shown that the rotation is not sensitive to either a 50% increase or a 50% decrease in the figure used.

7. Descriptive statistics for these parameters are given in Cooney (1981, 86).

8. Existing allocation institutions - tree farm licenses and quotas - allocate most of the timber supply to "established operators". This security of supply is intended to encourage greater investment in the forest industry (Pearse, 1976).

9. Revised Statutes of British Columbia 1979, Ministry of Forests Act, Ch. 272, 4(e).

10. See Rothery (1944, 491).

11. Rothery (1944, 491).

12. In the examples examined in this study, the PNW rotation is always close to the financial rotation. No further comment will be made then about the PNW rotation.

13. Financial rotations were first discussed by Faustmann (1849).

14. Both Calish et al. (1978) and Berck (1979) conclude that the losses in timber values associated with longer rotations far outweigh any possible value of these other uses.

15. See Manning (1977).

16. See Pearse (1976, 63).

17. See Clawson (1979).

18. See Statistics Canada 62-011, Series D630442.

19. See "The Designed Forest" in the Journal of Logging, May 1980, pp. 2542-2549. The plans of B.C. Forest Products are discussed in the British Columbia Lumberman, Jan. 1982, p. 8. Smith (1978) gives a very useful discussion of the potential of intensive management in the Vancouver forest region.

20. See British Columbia.Ministry of Forests (1982).

21. The falling and bucking cost formula used for clearcuts does not give reasonable numbers for thinnings. A formula developed for commercial thinning in Western Oregon was used instead. (U.S. BLM 1979, App.1, 268).

22. The number used for planting cost was taken from Riitters et. al. (1932).

23. Industrial owners often use a different method of evaluating investment in intensive management as discussed below on p.51 . Thus these investments may be carried out even if the bare land values are negative given their own discount rate.

24. See also Sessions (1979).

25. See also Kao (1980).

26. Grayson and Johnston (1970).

27. Defebaugh (1906) has a detailed description of this process.

28. Heyward (1958).

29. Defebaugh (1906) and Hodgins et. al. (1932).

30. Clepper (1971, Ch. 2 and 3) describes the beginnings of forestry in the United States. Lambert and Pross (1967, Ch. 2) do the same for Ontario. Defebaugh (1906, v. 1, 143) mentions E.G. Joly de Lotbinière.

31. Heyward (1958, 18).

32. Harrison (1936).

33. Zavitz (1939).

34. Dana and Fairfax (1930, Ch. 5).

35. Harrison (1936) and Zavitz (1939).

36. Dunn and Hyde (1960, 228-230) and Recknegel (1938).

37. Lewis (1981).

38. Dana and Fairfax (1980, Ch. 6, 7)

39. MacKay (1982, 91)

40. Sloan (1957)

41. Lambert and Pross (1967, Ch. 19)

42. USDA. Forest Service (1974, 39). There was also in the late 50's a large surge in planting on private nonindustrial lands due to the Soil Bank Program which provided financial assistant for farmers converting cropland to woodland. (Plair and Spillers, 1960)

43. Dana and Fairfax (1980, Ch. 7)

44. See the annual reports of the B.C. Forest Service .

45. Sloan (1957, 467-473) and Pearse (1976, 228)

46. See the annual reports of the B.C. Forest Service .

47. Lambert and Pross (1967, 417)

48. Wilson (1966)

49. MacKay (1932, 254-256)

50. Walters (1971, 82)

51. USDA. Forest Service (1974, 41)

52. Hagenstein (1977)

53. Mitchell (1974, 53)

54. See the annual report of the USDA. Forest Service for 1982.

55. Baskerville and Weetman (1978)

56. Crossley (1978)

57. Newnham (1978, 11-13)

58. Atherton (1981)

59. Paillé (1979) and Fisher (1983)

60. See British Columbia. Ministry of Forests (1982).

61. See Forestalk, Summer 1982 and Fall 1981.

62. Roberts (1983). Funds had earlier been made available for intensive management under forestry subsidiary agreements signed with some provinces under the auspices of DREE. The new agreements are to be the responsibility of the Canadian Forest Service.

63. A progress report is given in the April 1984 issue of the Forestry Chronicle, p. 129.

64. See Young (1981).

65. See British Columbia. Ministry of Forests (1983).

66. See British Columbia. Ministry of Forests (1979).

67. See British Columbia. Ministry of Forests (1981, 32).

68. From (4) in the Appendix, if $R=\overline{R}$ and $C=\overline{C}$ then $P=t(1+t)^{-1}R$. If $t=.2$, then $P=(.2/1.2)R$. This is slightly less than $P=(.18/1.18)(1.1R)$.

69. See British Columbia. Ministry of Forests (1984, C8).

70. He claims that the only allowance for capital costs in the overturn method is on those depreciation charges included in $\overline{C}$. This is a misinterpretation of the intention of the overturn method which is to use $\overline{C}$ as a proxy for the total capital investment.

71. In B.C., operators have 30 days to make stumpage payments after the charges are assessed (at the time of scaling). Thus money may not be tied up in stumpage payments for very long.

72. See Pesando (1983, 62). Similar figures pertain to the United States - Ibbotson and Sinquefield (1982).

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