UNIVERSITY OF ALBERTA

Economic Analysis of Intensive Silviculture on a Mixed-Wood site in Manitoba on Crown Tenured Lands

BY

DANIEL A. NEEDHAM ©

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And because these few trees were cut down, Leyland burst into a petty indictment of the proprietor.

"All the poetry is going from nature," he cried, "her lakes and marshes are drained, her seas banked up, her forests cut down. Everywhere we see the vulgarity of desolation spreading."

I have had some experience of estates, and answered that cutting was very necessary for the health of the larger trees. Besides, it was unreasonable to expect the proprietor to derive no income from his lands.

"If you take the commercial side of landscape, you may feel pleasure in the owner's activity. But to me the mere thought that a tree is convertable into cash is disgusting."

"I see no reason," I observed politely, "to despise the gifts of nature because they are of value."

from *The Story of a Panic*
by
E.M. Forster (1911)

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **ECONOMIC ANALYSIS OF INTENSIVE SILVICULTURE ON A MIXED-WOOD SITE IN MANITOBA ON CROWN TENURED LANDS** submitted by **DANIEL A. NEEDHAM** in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **FOREST ECONOMICS**.

W.E. Phillips

W.A. White

M.K. Luckert

J.A. Beck

APRIL 5, 1993

This thesis is dedicated to my wife Diane, who has paid dearly to an author who already was in her debt for a book that she will likely never read.

Thank you for proving Dickens' ludicrous character (Mr Gradgrind) right, for showing that:
"in the main, a good Samaritan [is] a bad economist."

ABSTRACT

The economic analysis of a silvicultural prescription must include all opportunity costs. The methodology herein incorporates an opportunity cost associated with taking no regenerative actions whatsoever, but only if taking no regenerative actions whatsoever is an option. Profit functions (for tenure holding firms) and a welfare function (for the Crown in the case where there are multiple tenure holders) are defined in this light.

In the case study, profit and welfare values, given multiple tenure holders, are calculated. It is determined that, at least for this mixed-wood site type, the cost of intensive silviculture, and the opportunity cost associated with natural regeneration, are great enough to make the practice of intensive regeneration questionable.

Specifically, the methods suppose that the Crown will have a welfare function which will account for all goods, priced and unpriced, and that the expectation of the Crown's realization of a Hartman type site expectation value is complete. Welfare is defined as the rental revenue from the existing timber plus the site expectation value (which includes externalities). The profit functions for the tenure holding firms, on the other hand, are assumed only to include the goods (i.e. timber) to which the firms are entitled at present.

The dollar value of the welfare foregone by regulating the use of intensive silvicultural practices instead of relying on natural regeneration, for this mixed-wood site type, ranges from$308.67 to $874.70/ha, depending on the assumptions made and the discount rate used. The sign, let alone the magnitude, of the non-timber value associated with the intensive silvicultural prescription is indeterminate. It is speculated that the only unambiguously positive non-timber value associated with the intensive silvicultural prescription is the value of the public perceiving that intensive actions are being taken.

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Bill Phillips, thanks for everything.

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INTRODUCTION

There are many sorts of values associated with the various outputs from Canadian forests (i.e. industrial use values, non industrial consumptive and non-consumptive use values and non use values such as existence and option values). As almost every Canadian (as well as every industrial forest products firm operating in Canada) holds some subset of these values and, as the production of forest outputs is a function of time, the viability of both present and future forests is rightly the subject of some concern.

Past and present Canadians have realized that current demands placed on Canadian forests will impact on future supplies of forest outputs, and so institutions and frameworks have been developed accordingly. Some of Canada's Crown forest lands have been preserved exclusively for non-industrial purposes. However, most of Canada's more easily accessible Crown forest lands have been slated for primarily industrial purposes. These Crown owned industrial forest lands, along with a much smaller quantity of privately owned industrial forest lands, form Canada's industrial forest base.

Many Canadians also want the industrial forest base (at least the Crown portion of it) to be managed for non-industrial and non-use values. Hence, a multiple use philosophy has been adopted in an effort to meet the needs and wants of these Canadians. But just how do present industrial forest practices affect non-industrial and future timber values?

Canadians are looking for an answer to their particular version of this question. Many Canadians, and all of the industrial forest products firms which operate on Crown forest lands, wish to know how the value of outputs (at least those with which they are concerned) are affected by present forest practices. It is important that the effect of industrial activity in the forest is measured and that some net return or welfare value measures be determined.

In a micro-economic framework, the question of valuing a silvicultural prescription can be answered in a general theoretic manner to account for the effects of current and future regulations and tenure arrangements on forest values. In a similar framework, the question of valuing a silvicultural prescription can also be answered in a site specific manner; in order to judge the value of a silvicultural prescription.[1] Providing a method to find the answer to this latter question is the intent of this study. A site specific case study is included.

General, stand-level objective functions are defined for: the Crown; a tenure holding firm and, for the purpose of comparison; an industrial forest owner. The Crown's and the tenure holding firm's objective functions are developed for use in determining stand-level welfare and profit measures of the effects, of current harvesting and regeneration practices, within the current institutional framework (where private firms lease the right to harvest timber on Crown lands).

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1 A silvicultural prescription is a prescribed regime for cultivating, growing and harvesting a stand of trees.

The case study is set in the boreal forest of Manitoba and is of two tenure holding firms which both use the outputs from a single Crown-owned site. The case study is undertaken in order to determine the profits (to the firms) and the welfare value (to the Crown) of a commonly used silvicultural prescription. This regime has been prescribed for this specific site type by the Crown silviculturalist.

The profit and welfare values are dependent on the discount rate used. Welfare values are also dependent on the assumptions made about the future values of forest outputs -- as would be the profit value for a forest owning firm. Sensitivity analysis is used to provide a range of profit and welfare values. The issue of how to interpret and judge such a range of values is discussed -- as are the issues of valuing non-industrial forest outputs and other non-timber values.

BACKGROUND

The Importance of Canadian Forests

Forests, which presently occur on 45% of Canada's land area (Forestry Canada, 1990), once occurred over an even greater extent and have always played a vital part in the development of the country. Throughout the eighteenth and nineteenth centuries, forests provided raw materials for construction, shipbuilding and export, as well as habitat for the fur-bearing animals that were the other major primary resource.

Forests still play a large part in the Canadian economy. The early trade patterns in forest products have been largely maintained even though the nature of the products has changed. "Wood, by itself, accounted for roughly half the value of all exports from British North America" in the early nineteenth century (Finlay and Sprague, 1984 p.85). At the end of the twentieth century, exports of forest fibre products still add more than the combined net total exports of agriculture, fisheries, mining and energy to the Canadian trade balance (Forestry Canada, 1990).

Like their earlier incarnations, forests today are a source of more than just timber sector jobs and foreign currency. Though the fur trade has declined so as to become almost insignificant, other consumptive and non-consumptive uses of forest-based *Animalia* have increased in importance. For example, "in 1987, 18.3 million Canadians (91.3%) were involved in some sort of wildlife related activity" and spent 5.1 billion dollars doing so (Environment Canada, 1990).

Forests are presently valued for providing habitat for many non-timber vegetative species and products as well: maple syrup, fruits and berries, birch bark and medicinal compounds such as taxol, found in the western yew (*Taxus brevifolia*), are examples of presently utilized non-fibre products. In regards to potentially usable but presently unutilized non-timber vegetative species, it has been estimated that each currently unutilized plant species in the U.S. is worth $203 million (U.S.) as a potential pharmaceutical source (Burton *et al.*, 1992). While such a figure might be suspect in a Canadian context, there is no denying that such values can be large in both monetary and human terms and that there are also large values associated with other forest attributes -- the aesthetic attributes of forest landscapes, for example. In addition to these kinds of values, there are also values associated with the volume of economically viable future timber available in the future (Pearse, 1980).

The production of fibre and non-fibre resources often conflict because harvesting can alter recreational opportunities and aesthetic attributes and may temporarily remove large areas of habitat which are required by some plant and animal species. The production of fibre and non-fibre resources can also conflict because intensive regeneration activities may promote fibre production at the expense of aesthetic or biodiversity considerations.

Silvicultural programs which promote certain species at the expense of others (i.e. plantation forestry) can be a risky undertaking as well. By the time the rotation is complete, utilization patterns, and so prices and rents, might favour a mixed forest or even a forest composed of a formerly unutilized species. Climate change can add a further element of risk to plantation forestry.

It is important that the value of present undertakings in industrial forests are known. Dollars budgeted for silvicultural purposes should be spent wisely in order to maintain or even enhance the value of forest land to all Canadians.

Given the still prominent place of forestry in the Canadian economy and the continued importance of the export trade to forestry in Canada, any erosion of the Canada's competitive position in the global forest products market will put Canadians out of work and lessen the Canadian trade balance. Both of these effects could leave Crown agencies with fewer resources to use in order to protect and enhance forest assets and welfare losses could be compounded. On the other hand, Canada's future position in the world forest products market could be strengthened if dollars spent on silvicultural activities today were spent wisely.

Timber Harvesting and Regeneration

Competition, internationally, continues to stiffen and in order to stay competitive in an international market, Canadian forest companies must use the most efficient methods of harvesting fibre (Benson, 1988). Such efficiency considerations usually imply clear cutting -- in order to take advantage of economies of scale. While there may be some doubt as to the overall, long term, ecological efficiency of present clear cutting methods, judging by their predominant use, at least the financial aspects of these economies of scale must be significant. According to Kuhnke (1989), "clear cut harvesting accounted for 89.6% of all harvesting" (p.2) in Canada between 1986 and 1989.

There are many methods of clear cutting and these methods vary according to: when the trees are harvested; where the trees are delimbed and debarked; what machinery is used; how the skid trails are situated; and; so on. Each of these methods may also affect the regenerative process, so that one or more combinations of clear cutting and regeneration methods (or silvicultural prescriptions) will be suited for use on a particular site -- depending on the site characteristics and the regenerated species desired (Gingras, 1988; Smith, 1986; Martin *et al.*, 1985). Regulations are other variables that can also limit the choice of clear cutting activities. For example, regulations may prevent the use of certain methods and limit the scale of operations (e.g. Alberta's Timber Harvest Operating Ground Rules, 1989 and; Manitoba's Forest Management Guidelines, 1989).

Following clear cut harvesting, regeneration can be achieved by primarily natural (extensive) or mostly human assisted (intensive) methods or something in between (Smith, 1986). There exists, therefore, a continuum of regeneration methods ranging from absolutely extensive to extremely intensive.

The interrelationships that exist between site attributes, harvesting methods and regeneration activities are now well recognized -- if not quantified. The relatively recent recognition and acknowledgment of these interrelationships has led some provincial agencies to require that forest tenure holders who are responsible for regeneration file pre-harvest-silvicultural-prescriptions (PHSP's) as a condition for entitlement to the harvesting rights on Crown lands (e.g. B.C. Ministry of Forests, 1987). In addition, Crown silviculturalists are also attempting to prescribe site specific regimes on areas which are harvested by forest tenure holders but for which the Crown is responsible for undertaking regeneration.

Post harvest regeneration processes must be effective if future timber supplies are to be ensured. In this regard, past regeneration activities have met with mixed success (Kuhnke and Brace, 1986) and future timber supply remains uncertain (Weetman, 1987). Regeneration processes should, ideally, also preserve or even enhance non-timber values. But some regeneration activities can detract from timber and non-timber values alike by, for example, reducing mixed forests to monoculture plantations, where timber crops are more susceptible to pathogens and climactic change and wildlife diversity is lessened. Benson (1988) argues that "extensive management can produce greater values for other [non-timber] uses than [can] intensive management".

Property Rights to Canadian Forests

Historically, Canadians have seen fit to maintain public ownership of the greater part of the forested areas in Canada, but the major consumptive user of the forest, the forest industry, has always been primarily composed of private firms. As a result, the bulk of the timber presently harvested in Canada is harvested on Crown lands by private firms under some sort of tenure arrangement. A lesser amount of timber is harvested and grown by forest owning industrial firms. But "only 6.3% of Canada's 397.92 million hectares of inventoried forest land is in private ownership" (Haley and Luckert, 1990).

In the Canadian forestry context, present property rights range from: freehold land ownership to; limited usufructory rights to only the timber (Pearse, 1988). The limited usufructory rights are of two basic types:

1) Area-based tenures, where the firm has the right to harvest timber, for a certain period of time, within a geographically defined area and;

2) Volume-based tenures, where the firm (or quota holder) has the right to a certain percentage of the annual allowable [timber] cut (AAC) for a certain period of time (Haley and Luckert, 1990; Samson, 1987).

Most forests in Canada are publicly owned, with Crown agencies acting as stewards, but are harvested by private firms under one or the other of these two tenure arrangement types (Pearse, 1988; Haley and Luckert, 1990). However, such firms have been given ever greater responsibility for regenerating the areas where they have harvested and are often required to do so in order to maintain their usufructory rights (Boulter, 1984). Almost universally this has become the case for area-based tenure holders (Luckert and Haley, 1989). Often, though, these firms are reimbursed for their regeneration expenses (Haley and Luckert, 1990) or subsidized through the provision of seedlings. "The only provinces which require most tenure holders to bear most or all costs of reforestation are British Columbia and Alberta" (Haley and Luckert, 1990 p.13).

Optimization

Because of their northern situation, Canada's forests grow slowly and may not reach their peak mean annual increment (MAI) for 40 to 150 years or even longer. Whether the rotational term is based on a forester's or an economist's paradigm, Canadian forests are usually harvested on the basis of a rotational term of close to half a century. Even so, freehold owners can expect to reap what they sow when undertaking regeneration by either waiting for the crop, willing it to their heirs or selling the improved land. Similarly, the public, as owners of Crown forests, can expect that they, their children, and their grandchildren will be able to benefit from both the timber and non-timber assets of their present and future forests.

Unlike freehold forest owners or the public, firms operating within either of the two tenure situations are uncertain that they will be able to benefit in the future from what they are presently required to plant -- or what they are presently paying to plant (Luckert, 1991). Typical area-based tenures are only of a twenty or twenty-five year term and typical volume-based tenures are only of a five or ten year term -- although evergreen clauses[1] are becoming more prevalent under both tenure arrangements (Haley and Luckert, 1990; Pearse, 1990).

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1 Under evergreen clauses, tenure holding firms which meet their responsibilities may have their tenures renewed for the length of a full term well before the term was scheduled to expire.

A rational profit maximizing firm which has freehold rights to a forest has the incentive to weigh the costs of regeneration opportunities against the present value of a stream of future fibre crops (and what it considers to be relevant non-timber assets) and is likely to maximize the value of the site in order to maximize long term profits (see Faustmann, 1968; Hartman, 1976; or Calish *et al.*, 1978). A similar firm but with short term rights to only the harvesting of the timber (i.e. a tenure holder) may not have such an incentive and may be expected to maximize short term profits through short term, cost minimizing actions. Therefore, the rational short term tenure holder may view a regeneration requirement as a constraint, rather than an opportunity (Luckert and Haley, 1989a).

The present value of expected future rewards is likely to be lower for all forest owning firms than it would be for the Crown. This is because the Crown usually discounts future values less than private firms as it has access to capital at a lower cost and has a responsibility to provide for future generations. Furthermore it can be expected that the decision making criteria of forest owners will differ from the optimizing behavior of the Crown because such firms will likely value fewer unmarketed goods or externalities than would the Crown as they do not have property rights to these goods. Tenure holding firms can be expected to use a high discount rate, ignore all unmarketed goods and will likely have no expectation of benefiting from maximizing the value of the site. These tenure holding firms would, therefore, likely choose regeneration prescriptions according to different criteria than would the Crown or a freehold forest owning firm.

LITERATURE REVIEW

While Pearse (1990) lists five relevant levels of economic analysis in forestry, in regional (Canadian) operations there are only two. These are: forest level planning or optimization and; stand level analysis or optimization. These two levels are linked (Pearse, 1990) in that in order to plan or optimize at the forest level, stand treatment options are required (Bowes and Krutilla, 1989). The subject of this study is stand level analysis.

Stand level analyses generally fall into two categories: even aged and; uneven aged (Duerr *et al.*, 1982; Davis and Johnson, 1987). The category of concern, in this study, is even aged stand management. Clear cut harvesting, by its nature, leaves an entire area in a condition conducive to even aged management.

Looking at past studies and previously developed methods for examining even aged stand management, it can be seen that some of the studies and methods have focused on optimization, through calculus (e.g. Faustmann, 1849 and; Hartman, 1976) or linear programming, while others (Johansson, 1987; Payendeh and Field, 1985; Fraser, 1985; Duke *et al.*, 1989) have focused on economic analysis in a benefit cost framework.

The studies that have been undertaken and the methods developed to analyze even aged stand level management, in a benefit cost framework, are those of concern to this study. However, there are notions that were developed in the optimization literature which are directly applicable to benefit cost analysis of forestry investments. It is useful to look at the development of stand level economic analysis of forestry in an historical perspective.

Management decisions can be made on the basis of biological growth functions. The classic forester's rotation, for example, is usually defined as the time when the stand reaches the point in its growth cycle where the mean annual incremental (MAI) is maximized. Under such management it is assured that the area will provide the greatest volume of timber. As Bowes and Krutilla (1989) put it, "the early philosophy of public forest management . . . was based on biological and technocratic, rather than economic, principals" (p. 92).

However, investment theory soon found its place into the forest management literature when value, rather than volume, first became the target of maximization efforts. The notion of an opportunity cost was considered to be the key to the solution of the maximization of value problem. Von Thunen pointed out that capital tied up in forest production could be employed elsewhere and that a rational forest owner should choose to harvest when the growth of value in the stand decreased to the rate of value growth in an alternate investment -- such as investing the capital in the bank (Samuelson, 1976). Only while the value growth of the forest exceeded the opportunity cost of capital, would it be prudent to let the stand continue to grow.

Martin Faustmann added a further dimension to the problem when, in 1849, he pointed out that there were really two opportunity costs to be considered. He demonstrated that, in addition to the opportunity cost of capital tied up in the forest, there was the opportunity cost of the forest tied up in the land. That is, every year that the present forest remains unharvested, the forester is prevented from planting another forest crop and, therefore, not harvesting is the opportunity cost of growing a new forest crop. The solution to dealing with these two opportunity costs lies in maximizing the value of the land rather than maximizing the value of the timber on the land. Forest economists are now familiar with the notion of maximizing the site expectation value (SEV), defined as the net present value of an infinite stream of harvested crops, by harvesting at the optimum economic rotation (OER) age.

Hartman (1976) pointed out that, land which is best suited to producing timber will also provide joint products such as watershed protection, wildlife habitat and amenity services. Hartman maintained that the SEV, for producing all of these products as well as timber, should be maximized in a similar fashion to that proposed by Faustmann. Calish *et al.*, (1978) showed that the inclusion of non timber outputs could shorten or lengthen the OER, depending on the value output functions for these products.

The issue of when to harvest timber has occupied forest economists for more than a century and a half and although the solution has been found within a theoretical context, there are but few instances of forests actually being harvested at the rotation age that maximizes the SEV. This is particularly true in Canada.

There are many reasons why Canadian forests are harvested at ages other than the age that would maximize the SEV. For example, the relationship between forest growth and habitat or amenity values has not been quantified and the values themselves remain elusive. Fibre-based products have also changed in nature and utilization determinants such as diameter or knot distribution may play a greater role in the harvesting decision. If there is a belief that short run conditions might continue over one rotation, it might be thought to be much more cost effective to harvest when the size and condition of the timber is best suited to existing machinery, rather than when the SEV is maximized. In addition, forest level goals, or even regional goals, may dominate a stand level goal such as maximization of the SEV.

SEVs are not always included in silvicultural investment analyses either. Almost invariably, investment manuals are developed to analyze post harvest regeneration of only the subsequent crop (e.g. Payendeh, 1977; Payendeh and Field, 1985; Fraser, 1985). FORCYTE II (Kimmins *et al.*, 1990), a biological growth model capable of some financial analysis, can be used to analyze the gross returns over a few rotations.

While a limited role for SEVs in such methods could be considered consistent with the recognition of the high degree of uncertainty in regards to later crops (i.e. determining robust SEV values is a difficult task), nevertheless, failing to mention SEVs is an oversight. However, Duke *et al.* (1989) do undertake a complete analysis which includes SEV determination. In addition, according to White (1989), all of the dynamic programming applications to stand level optimization since, and including, Lembersky and Johnson (1975) have taken the notion of an optimum economic rotation, based on maximizing the SEV, into account.

There can be a third opportunity cost that is associated with artificial regeneration. This opportunity cost is the SEV associated with natural regrowth which is foregone if intensive silvicultural activities were undertaken. For example, Duke *et al.* (1989) measure the effects of thinning and fertilization on Douglas fir and subtract the SEVs associated with extensive regrowth. Although these SEVs are treated as such, the authors do not refer to them explicitly as opportunity costs. The differetial between an intensively generated SEV and a naturally generated SEV provides a basis for making the decision about which method of silviculture is best. Intensive silviculture is a rational choice only if the SEV associated with the regime is greater than that associated with natural regrowth. Once the decision has been made to use intensive silviculture, choosing among intensive silvicultural prescriptions requires identifying the most efficient or beneficial prescription.

The theoretical underpinnings of this study include both the concept of an Hartman type SEV and the concept of an opportunity cost SEV associated with extensive regeneration.

TOWARDS A METHOD

Every silvicultural prescription will yield an associated stream of physical outputs which will vary in import according to the perspective of an analyst. An analyst for any given organization will measure this import by utility criteria which are determined by the organization's desiderata (Sinden and Worrell, 1979). An organization's desiderata are, in turn, determined by the organization's position in the marketplace and the property rights to which the organization is entitled (Pearse, 1990). According to each decision-maker then, each silvicultural prescription will provide some level of benefits for some associated cost.

Economic efficiency may be defined as the ratio of outputs (benefits) to inputs (costs) -- or the net benefits -- so that, the "simultaneous choice of both the inputs and outputs or products that maximize the net return" would be the most efficient (Davis and Johnson, 1987, p.305). In traditional benefit-cost analysis, there are, according to Duerr *et al.* (1982) and many others, three manners of comparing the benefits to the costs or measuring efficiency:

1) Net benefits (or discounted net worth or its annual equivalent);
2) Benefit-cost ratios and;
3) Internal rate of return.

The outputs associated with a prescription may be priced, may be potentially priced (either in a market or via some evaluation technique), or it may likely never be that there will be a dollar value applied to the outputs. For example, regenerated timber will not become marketable for decades, until the rotation (the length of which will vary with assumptions about the future) has concluded. Past patterns of price fluctuation, caused by "scarcity, new sources of materials, technological changes, or shifts in taste and style" (Burton *et al.*, 1992) may continue. Similarly, markets may develop for presently unmarketed outputs (e.g. aspen or other presently unmarketed tree species, fruits or pharmaceuticals) which are presently not valued in a market sense (Ibid.). Finally, values for unmarketed goods and assets are likely to change with changes in taste (Ibid.), changes in information (Hanley and Munro, 1992) and even over time (Adamowicz, 1991).

Some authorities, Sinden and Worrell (1979) for example, maintain that only the pricing of all goods in dollar terms will allow for absolutely accurate and unbiased decision making. However, the cost and inaccuracy of non market valuation techniques are, at present, significant enough so that what Sinden and Worrell consider to be biased decision making processes, those which must rely on mixed data, may be a more efficient means of assessment.

A convenient method of dealing with such valuation uncertainty is for the decision maker to assume several possible future states of the world (SOW). Under each assumption the valuation exercise will yield different results which can be compared through sensitivity analysis.

Production Functions

One would be hard pressed to provide an example of a non-joint production function in a forestry context. For example, planting seedlings results in fibre, habitat and oxygen production, and perhaps the enhancement of esthetic values.

While a tenure holding forestry firm's concerns will not likely even include future fibre production, the Crown, it is assumed, will undoubted' 'e concerned with most of the joint future production. However ،he present time, production functions for silvicultural prescriptions are rare, expensive and reliability is suspect. As Marshall (1988) states, "predicted treatment responses in most modern growth models are based on limited data and often rely on biological assumptions . . . this can lead to dramatically different predictions among models for the same conditions". To further compound the issue, the growth conditions, especially climatic conditions, are not likely to remain the same. As Thompson and Vertinsky (1991, p2.) assert, "the biophysical uncertainties are associated with our inadequate knowledge for predicting what the future forest will be for a given set of management inputs, and are augmented by our uncertainty about future environmental conditions".

However, for the purpose of developing the proposed method, it will be assumed that joint production functions are, or will become, available. In addition, the decision-maker should have an idea of the risks associated with projects due to factors such as as insect infestations or fire outbreaks. The decision-maker should also have an idea of the associated costs of such disasterous occurances.

Relevant Costs

Relevant costs include those of harvesting, producing and bringing the fibre products to market and of undertaking subsequent silvicultural activities. The acts of harvesting, producing and bringing the harvested fibre products to market usually occur over a very short period of time and are, therefore, already in present value terms. Silvicultural activities and their costs, on the other hand, occur in a stream, over time, and must be discounted to obtain present values.

These silvicultural costs are an investment in the next rotation if the decision maker has equity in future rotations. However, if tenure holders do not have equity in future rotations, they will perceive these costs as additional constraints. The payment for, or the undertaking of, these activities can be a prerequisite to the harvesting rights for tenure holders. In such cases these costs are an additional cost of harvesting.

The Opportunity Cost Associated with Natural Regeneration

When measuring the effects of a silvicultural prescription, there is an opportunity cost equal to the SEV which would occur without any intervention save harvesting. This opportunity cost exists for the forest owning firm which is free to exercise any viable silvicultural options. It also exists for the Crown which has a similar set of options. Therefore, in order to assess the feasibility of an intensive silvicultural prescription, the SEV associated with natural regeneration should be subtracted from the SEV associated with the intensive prescription. If the result is a positive value, undertaking the intensive silvicultural activity is a rational option. The extensively regenerated SEV should be calculated subject to the analyst's notions of uncertainty as should the SEV calculated assuming the implementation of the intensive prescription.

For the tenure holding firm, subject to regulations that require payment for, or the undertaking of, intensive regeneration activities, an option to extensively regenerate does not exist. Such a tenure holding firm may have an option to extensively regenerate if, and only if, the extensive growth would meet the required standards. Presumably, therefore, there could be some least intensive prescription which should be considered as an opportunity cost when more intensive prescriptions are analyzed. However, because tenure holding firms are not likely to hold equity in future crops, the only motivation to practice extra-intensive silviculture would be to take advantage of an allowable cut effect (ACE). However ACE has not provided tenure holders with incentive enough to invest in extra-intensive silviculture (Luckert, personal communication).

Unpriced Goods and Other Externalities

The Crown, or society, also benefits from the production of many unpriced goods (or assets or attributes) and other externalities. Unpriced goods may be public goods that have the characteristic that their transactions costs would be too high to ever enable their being traded in a market. Attributes of these assets or goods, such as their very existence, can (and often do) have some positive value.

Resource economists have wrestled and are still wrestling with the notion of valuing unpriced goods within a money metric. Results are inconclusive and, furthermore, non-timber values can shift and some segments of society may hold the same goods, attributes or externalities to be of a positive nature while other segments consider them to be of a negative nature.

Externalities are the related effects from an activity which are not generally accounted for in market transactions. Externalities can be positive (beneficial) or negative (detrimental). Given an intensive regime for example, any additional employment opportunities from the harvesting of increased future volumes, as well as from regeneration activities such as planting and nursery work, could be considered as positive volume related non-timber value, depending on the opportunity cost of labour. Examples of negative non-volume related non-timber values associated with the same regime might be decreased biodiversity (from monoculture), pollution (from pesticides) and erosion (from site preparation). All non-timber values (whether positive or negative) that are relevant, according to the decision maker, should be included.

Discounting

Goods which will only become available in the future will be valued by the stakeholders who hold rights to those goods according to some rate of time preference. A stakeholder is assumed to have a rate of time preference for marketable goods which is greater than the stakeholder's opportunity cost of capital unless there are bequest concerns involved (Hartwick and Olewiler, 1986) -- as these bequest concerns imply an element of altruism. Because of the public good nature of the welfare of future generations, firms are assumed not to be altruistic. Therefore, a firm's rate of time preference can be assumed to be greater than its opportunity cost of capital. However, it is possible -- even likely -- that the Crown could behave with concern for the welfare of future generations (Hartwick and Olewiler, 1986). Therefore, the Crown's social rate of time preference (SRTP) can be assumed to be less than or equal to its (usually lower) opportunity cost of capital.

Future Values

Marketed forest goods, usually fibre or fibre products, are assumed to have a market-determined price. The variable costs associated with harvest production and other silvicultural activities should be netted out from the gross price to arrive at a true net volume price or conversion return[1]. Fixed costs should not influence the decision unless the firm is operating below its variable cost curve (Binger and Hoffman, 1988).

The Crown will receive some of the variable costs as tax payments, stumpage (or royalty) payments or, in some cases, as regeneration levies. Regeneration levies can be either volume or area based and can be considered as equivalent to rental payments.

The SEV is a function of biological growth over time, prices (or values) and the discount rate. Therefore, if the price of marketed goods changes over time, or new markets develop, or non-timber

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1 A conversion return is a price imputed from a downstream price by subtacting all associated costs and a normal profit.

values change, the SEV and thus the OER length will vary even though the prescription will yield the same physical outputs.

Every decision-maker will have expectations of future market scenarios. A likely SEV is defined as a SEV which the decision-maker expects to exist. The decision-maker will account for potential price and market changes by calculating the likely SEV according to such expectations and can undertake additional (sensitivity) analyses in order to discern the possible costs of errant expectations.

A forest owner will have a complete expectation of realizing the likely SEV and will likely factor the likely SEV into the selling price of the forest land. Forest owners will choose to maximize the likely SEV by choosing to harvest at the OER length. The Crown will also have a complete expectation of realizing the likely SEV. Tenure holders, however, will have no expectation of realizing the likely SEV as they are assumed not to hold any equity in future forest crops.

Estimated dollar figures may be applied to non-timber values and are usually determined for classes or aggregates of all such goods. These estimated values can change over time and are determined, to some extent, by the knowledge base and taste of the owners (whether those owners are private individuals or groups or the public). If the present and future dollar values and the production functions of these goods are known (or assumed), the goods or attributes can be factored into the SEV calculations. If the dollar values are not known (or assumable), physical output levels can be incorporated into the goal structure. For example, the decision-maker may only need to know the extent that appropriate habitat will be provided, not the dollar value of the individual members of the species which would require the habitat, in order to rate goal achievement.

Value (or Benefit) Criteria for the Various Agents

Profits to the Firms

Firms are assumed to be attempting to maximize profit or net returns to entrepreneurship. Forest owning firms will wish to maximize the value of their land as well: through choosing the best management strategy based on its effect on the value of the land. The incremental dollar value of an intensive prescription to a forest owning firm will be the SEV determined for the intensive prescription, less the SEV determined for the extensive prescription, calculated at the discount rate to which the firm is subject. If this value is positive, the firm may choose the intensive regime. The total dollar value of the intensive prescription will be the value of the harvest plus the SEV associated with the intensive prescription.

The net returns (or profit) function, for a tenure holding firm, however, will only include returns to entrepreneurship (i.e. the net value of the harvest) as the firm holds no equity in the site and, therefore, no equity in the SEV. The profits will be net of all regeneration levies which are a cost of the regulation to the firm, but not a cost to society as they represent only a transfer of welfare.

The Crown's Welfare Value

The Crown's goal is assumed to be to maximize public welfare through maximizing the value of the site. The intensive prescription should only be implemented if the associated SEV is greater than the

SEV associated with natural regeneration. The welfare value associated with the prescription is therefore defined as the rental payment and levy based value of the harvest plus the SEV associated with the intensive prescription. If it is not rational to implement the intensive prescription because it has a lesser SEV than does natural regeneration, but the intensive prescription is chosen nevertheless, welfare is foregone. The value of the welfare foregone is equal to the difference between the two SEVs.

METHOD

Physical Outputs

Determinants of biological growth include: spatial factors; soil type and moisture; litter depth; competition; present merchantable volumes (by species) and; the particulars of the harvesting system under consideration. Process-based or hybrid computer growth simulators have information requirements that are much greater than what is available. Therefore, such models were not used in this case study.

In this case study, relevant regeneration prescriptions were obtained through consultation with expert silviculturalists. It was also necessary to solicit these same experts for their opinions as to the associated physical output levels for each prescription over the period of a single rotation. Point estimates for all relevant attributes such as: stems/ha; mean height and, in particular; merchantable volume/ha for all relevant tree species were obtained in this manner.

As time is common to and a significant factor in all of the growth functions and is also crucial to investment maximization, the point estimates obtained were regressed against "years" in order to find best fitting functions of time for the attributes of concern for all relevant tree species. It was most convenient to use adjusted R^2, T-statistics and *a priori* knowledge upon which to base the decision about which was the most appropriate functional form.

Due to the present lack of data on regrowth, it is assumed that the probability and cost of fire or infestation is equal for both the intensive and the extensive prescriptions that are the subject of the case study. This prevents uncertainty from influencing the choice of a silvicultural prescription.

On Non-Timber Values

All of the non-timber values associated with each prescription can be included within the Hartman type SEV formulae. Including the externalities in both the SEV term associated with the intensive prescription and the SEV term associated with the extensive prescription would ensure that only the marginal externalities are included in the marginal net SEV determination. Alternatively, the present value of the non-timber values (PVNTV) can be added to the SEV calculated for timber alone.

For the case study it was not possible to determine value functions or PVNTVs for the externalities and so graphical representations of marginal physical output (MPO) levels were included and discussed. Marginal physical output levels of commonly measured physical traits such as volume, stems or average height, as functions of time, are associated with each intensive regeneration prescription. There might perhaps be some hedonic relationship between the more commonly used physical characteristics (such as volume, stems or average height) and the non-timber values. Absolute increases in desirable characteristics may be considered to be of a positive value if all segments of society view these characteristics as desirable. However, often there are conflicting tastes; some hunters or bird watchers may prefer fewer stems/ha, while hikers may prefer more. Potential Pareto improvements may be assumed if it is considered that the value gained is greater than the value of losses.

In addition, there is also a problem when one species is promoted at the expense of another: is an increase in merchantable volume/ha of spruce more desirable than an increase in the combined merchantable volume/ha of spruce and aspen? Until such hedonic relationships are defined and measured, it is not possible to make a definitive statement about the non-timber values which are associated with the MPOs.

The linkages which might be related to any additional employment in harvesting activities at the time of the next rotation (due to increased available volume) could be considered to be positive volume related non-timber value. This sort of volume related non-timber value can be positive if the opportunity cost of labour is assumed to be zero or negative. Its value is also dependent on the substitutability of other factors of production. However, Binkley (1980) has posited that volume, for its own sake, may be a positive argument in society's welfare function. Therefore, marginal increases in volume should be considered as positive volume related non-timber values. However, the question of whether to use the volume of certain (presently utilized) individual species or the combined volumes (of presently utilized and unutilized species) on mixed-wood sites as the relevant measure of welfare remains and this question is, at present, unresolved.

The Objective Functions

The Tenure Holding Firm's Profit Function

The profits (Π/ha), for a tenure holding firm are defined as:

$$\Pi^{ij}/ha = \sum_m \sum_n p^{ij}_{mn} x_{mn} - \sum_j L^{ij}_{mn} x_{mn} - \sum_m \sum_n R^{j}_{mn} x_{mn}$$

,

where:

Π^{ij} are the returns to entrepreneurship, per ha, from prescription i to firm j;

p^{ij}_{mn} is the conversion return (or gross returns to entrepreneurship), per m^3, (i.e. before royalties and levies are deducted), of species m to be formatted as forest product n, to firm j, given that silvicultural prescription i is to be implemented as a tenure requirement;

x_{mn} is the volume of species m, per ha, made into forest product n by firm j (in m^3) when the firm faces the implementation of prescription i as a part of the tenure arrangement;

L^{ij}_{mn} is any regeneration levy (or cost of prescription) i, per m^3, to firm j for species m, formatted as product n, and;

R^{j}_{mn} is the rental payment, per m^3, which is collected by the crown from firm j for species m when it is formatted as forest product n.

The Forest Owning Firm's Profit Function

SEV^{ij} (i.e. the site expectation value to firm j, given the implementation of prescription i) is defined as:

$$SEV^{ij} = \frac{\left(\sum_m \sum_n p^{ij}_{mn} x_{mn} - C^{ij}/ha(1 + d)^r\right)}{(1 + d)^r - 1} + PVNMV^{ij},$$

where:
$PVNMV^{ij}$ is the present value of the non-marketed values, valued by firm j, associated with prescription i;
C^{ij} is the cost (per ha), to firm j, of the stream of activities that make up prescription i;
d is the discount rate and;
r is the rotation length.

The firm will base its decision, on whether to implement the intensive prescription, on the incremental land value function:

$$\delta SEV = SEV^{ij} - SEV^{0j},$$

where:
i = 0 indicates an absolutely extensive prescription (i.e. SEV^{0j} is the site expectation value associated with natural regeneration and regrowth).
If δSEV is positive, the firm may choose to implement the intensive prescription.

Given the rational choice to implement the intensive prescription, the profit (Π/ha), for a forest owning firm, will be:

$$\Pi^{ij}/ha = \sum_m \sum_n p^{ij}_{mn} x_{mn}/ha + SEV^{ij}/ha.$$

The Crown's Welfare Function

SEV^{i3} is the site expectation value to the crown (j = 3), given the implementation of prescription i, and SEV^{i3} is defined as:

$$SEV^{i3} = \frac{\left(\sum_m \sum_n R^{3}_{mn} x_{mn} - C^{i3}/ha(1 + d)^r \right)}{(1 + d)^r - 1} + PVNMV^{i3},$$

where:

R^{j}_{mn} is the rent collected by the crown for species m, when it is formatted as forest product n, and;

C^{i3} is the value of the costs (per ha), to the crown (j = 3), of the stream of activities that make up prescription i.

For the case of multiple tenure holders operating on the same piece of Crown land, the decision to insist on the use of the intensive prescription should be based on the positive value of δSEV, where:

$$\delta SEV = SEV^{i3} - SEV^{03}.$$

Given the use of the intensive prescription, the welfare value of Crown land (W/ha) would be:

$$W = \sum_{m}\sum_{n} R^{j}_{mn} x_{mn} + \sum_{j} L^{ij}_{mn} x_{mn} + SEV^{i3}.$$

where:

i = 0 indicates natural regeneration.

If δSEV has a negative value and the decision to require the use of the intensive prescription is nevertheless made, the welfare foregone is equal to any difference in the total payments plus the δSEV.

The Crown and two tenure holding firms are the subject of the case study. The private forest owning firm's profit function was included in the above discussion (for completeness), but as such entities are not found in any significant numbers in Manitoba, they were not included in the case study. However, there is little lost by the omission as whatever is relevant for the crown will also be relevant for the forest owning firm, except that the firm's function will include returns to entrepreneurship instead of rental payments and levies will not apply to the firm. The firm may have a different view of the extent of any non-market values and of the proper discount rate to use as well.

THE CASE STUDY

Background to the Case Study

There are two companies which utilize the fibre on the site: Spruce Products Ltd. and REPAP Ltd.. Both companies are based in Manitoba. Spruce Products Ltd., a volume quota holding forest products firm, operates a sawmill which requires 82,500 m^3 of spruce saw timber per year. Spruce Products Ltd. has recently obtained a portable delimber, debarker, chipper so that it now also sells spruce pulp chips to REPAP Ltd.. All spruce that is unsuitable for the sawmill operation is chipped and sent by van to REPAP's millgate for pulping. On the representative site type adopted for this case study, REPAP purchases 75m^3 of pulp chips per hectare.

Spruce Products Ltd. presently pays a volume based regeneration levy of \$1.30/m^3 on only the spruce saw timber (instead of undertaking reforestation activities directly). This levy will increase to \$1.95/m^3 on May 1, 1993. REPAP Ltd., on the other hand, has an agreement with the Crown to reforest one hectare for every 180 m^3 of spruce pulp chips purchased from Spruce Products Ltd. and effectively pays a levy of 0.42(NPV of the total regeneration costs/ha) because they purchase 42% of this amount (i.e. 75m^3/180 m^3) per every hectare of this site type.

In this case study, profits for both firms, as well as the welfare value are calculated for a single intensive silvicultural prescription implemented on one representative hectare. For comparison, the profits and the welfare value associated with natural regeneration of the same site are calculated in the same manner.

Data and Data Collection

A representative one hectare site from within the general area of Spruce Product's operations is the subject of the study and is defined below, in terms of physical characteristics and production potential. This site represents the most common mixed-wood site type within the general area of this firm's operations; as determined by examination of maps in consultation with Spruce Product's personnel. The present, pre-harvest, inventory is assumed to consist of 150 m^3/ha of spruce, of which 75 m^3 is suited for saw log production and 75 m^3 is suited only for pulp chips.

TABLE 1. Description of the representative site
LEGAL DESCRIPTION/LOCATION: Manitoba FMU #14 (TWP 33 Range WEST 24), 52° N Lat.
LEASE ARRANGEMENT: Volume quota holder, subject to a regeneration levy.
SPECIES: #1: Black spruce (*Picea marianna*) at age 100 years comprising 80% of the stocking on a site index of 15-19.9 m at 50 years (site class #3). #2: Aspen (*Populus tremuloides*) at age 65 years comprising 20% of the stocking on a site index of 15-19.9 m at 50 years (site class #3).
SOIL: **Texture**: Very fine silt. **Moisture:** Fresh/moist. **Litter depth**: 10 - 15 cm.
PRIMARY COMPETITION FOR SPECIES #1: Aspen (i.e. species #2).
SLOPE: 8% in general, flat on the landings.
HARVESTING SYSTEM: **Cut block size:** 50 ha. **Utilization**: 100% of species #1, 0% of species #2 which is felled. **Machinery**: feller buncher (harvesting); grapple skidder (skidding) and a portable delimber, debarker, chipper is used to process timber which is not suitable for the sawmill. **Slash treatment**: chipped and spread. **Skid trail configuration**: multiple landings on 5% of the total area with radial skid trails covering 10% of the total area. **Season**: Winter (January).
AVAILABLE REGENERATION STOCK: Black spruce, current crop, in CanAm #1 containers.

Cost-price structures (except for REPAP's gross revenue pulp price which .vas withheld), as well as the details of the terms of tenure, were obtained from Spruce Products Ltd., REPAP Ltd. and the Crown. Conversion return rates/m^3, for both companies, are calculated in Tables 2 and 3.

TABLE 2. Cost price structure of Spruce Products Ltd.	
COST or PRICE	DOLLARS/m^3
GROSS PRICE: DRESSED LUMBER* ($/$m^3$) (i.e. less milling costs)	44.18
TOTAL COST to bring to millgate	25.89
GROSS CONVERSION RETURN for SAWLOGS(i.e. P_{11}^{i1} in \$/m^3)	18.29
PAYMENTS	
Rental payment (i.e. R_{11}^{1} in \$/m^3)	2.15
Levy (i.e. L_{11}^{11} in \$/m^3)	1.30
GROSS PRICE: PULPCHIPS**	38.17
WOODLANDS COST: PULPCHIPS borne by by Spruce Products	30.50
CONVERSION RETURN for PULPCHIPS (i.e. P_{12}^{i1} in \$/m^3)	7.67

* \$243/1000 bf (@5.5m^3/1000 FBM)

** \$100/ODT (@2.62m^3/ODT)

NOTE: $p_{mn}^{11} = p_{mn}^{01}$ and R_{mn}^{1} is constant, but $L_{mn}^{01} = 0$ (i.e. it is assumed that, of all the terms, only the levy would change if natural regeneration were an option)

TABLE 3. Cost-price structure for REPAP Ltd..	
COST or PRICE	DOLLARS/m^3
GROSS CONVERSION RETURN: for PULP ($/$m^3$)	15.00*
PAYMENT: for PULP Rental payment (i.e. R_{12}^{2} in $/$m^3$)	0.84
COST (Regen) Levy payment (i.e. L_{12}^{12} in $/$m^3$)	0.42(NPVC)**
GROSS CONVERSION RETURN: for PULP (i.e. p_{12}^{i2} in $/$m^3$)	14.16/m^3

* assumed

** 75m^3/ha purchased, at one ha of regenreation responsibility/180m^3, implies responsibility for 0.42 ha to REPAP (firm 2). Note: NPVC varies with the rate of time preference and with the silviculture prescription.

NOTE: $p_{mn}^{12} = p_{mn}^{02}$ and R_{mn}^{2} is constant, but $L_{mn}^{02} = 0$ (i.e. again it is assumed that, of all the terms, only the levy would change if natural regeneration were an option)

Tables 2 and 3 provide the relevant terms for use in the profit calculations, as well as in the welfare value calculations.

In order to obtain estimates about post harvest regenerative growth, the information in Table 1, about the harvesting practice used and available regeneration stock as described by the Crown's regional silviculturalist, was enclosed in a questionnaire that was sent to five silviculture experts. A copy of the questionnaire can be found in Appendix 1. Although five experts were consulted in order to attempt to determine the likely extent of any regrowth, only two felt confident enough, or were willing, to provide estimates of regenerated growth.[1] The other silviculture experts felt that, until further research had been done, there was just not enough information available on which to base their estimates. Two estimates of the regrowth that would result for each of two, slightly different, intensive silviculture prescriptions were obtained and the completed questionnaires can be found in Appendix 1. Two estimates of natural, unassisted (or extensive) regrowth were obtained as well.

The silvicultural costs stated by the Crown's expert represent the relatively higher costs associated with unionized workers while those listed by REPAP's expert represent lower, non-union, costs. The costs used in this study are near average estimates which lie between these two stated costs. The prescriptions and the costs as used in this study are listed in Table 4.

TABLE 4. Silviculture prescriptions (activities and costs/ha)

YEAR	PR 0*	PR 1*	PR 2*
0	Harvest	Harvest	Harvest
1		Bracke ($150)	
2		Plant ($505)	Bracke ($150)
3		Survey ($17.75)	Plant ($505)
4		Herbicide($167.5)	Survey ($17.75)
5		Survey ($17.75)	Herbicide($167.5)
6			Survey ($17.75)
7			

* PR = Prescription and: 0 = extensive; 1 = intensive and; 2 = intensive, but delayed one year.

Note: It is assumed that there is no change in activity cost given the one year delay.

1 The completed questionnaires from: John Dojack, a silvicultural forester with Manitoba Natural Resources and; Dave Neufeld, a silvicultural forester with REPAP, can be found in Appendix 1.

The two intensive regimes differed only in that one was undertaken the year immediately following harvest and the other was delayed by one additional year. It was the opinion of the silviculture experts that, although there were a multitude of different regeneration prescriptions that would be suited to such a site, given the type of harvest activities that were to be carried out, the difference in subsequent regrowth response between most of these prescriptions would be negligible. The two silviculture experts both maintained, on the other hand, that a one or two year delay in implementing any regeneration prescription would have a noticeable biological impact. Such delays are common when harvesting and subsequent silvicultural activities are not integrated (e.g. when the firm harvests and the Crown undertakes reforestation).

In terms of net present values, however, the difference between the immediately implemented and the delayed intensive prescription was found by this researcher to be slight; as the lesser NPV of the stream of silvicultural costs of the delayed prescription is offset by the loss in production and vice versa (i.e. the greater NPV of the stream of silvicultural costs associated with the immediately implemented prescription is countered by a gain in production).

As a result of preliminary examination, the case study is limited to an economic analysis of only the intensive prescription that is not delayed (PR 1 designates this intensive, non-delayed, prescription) and natural regeneration. PR 0 designates the natural regrowth functions which are the basis of the opportunity cost associated with the naturally occurring SEV.

While PR 0 and PR 1 are the only two growth functions that are used to determine site expectation values (SEVs) in the welfare value calculations, the PR 2 growth functions are included in Appendix 2. For completeness the growth functions associated with PR 2 are also included in the following discussion on deriving appropriate mathematical regrowth functions.

Deriving Appropriate Regrowth Functions

Although a sample size of two, alone, would be too small to provide real confidence in any derived regrowth functions, the observations are consistent with mensurationists' general observations as to a small variance between prescriptions of the total combined volumes and the average heights.[1] Copies of the silvicultural experts' completed worksheets are in Appendix 1.

Eighteen equations, for the six regrowth functions associated with each of the three prescriptions, were estimated using very small sample statistical analysis and are listed and graphically depicted (with their statistical analyses) in Appendix 2. While a few of the production functions estimated in this manner did not have very high R^2 values (as might be expected), some of the other functions did. For example, the six mean height equations (AVGHT) for both species (SP = spruce and ASP = aspen), as functions of age, all had R^2 (adjusted) values between .934 and .969. As the implementation of an intensive silvicultural prescription is expected to affect mean height very little, the high R^2 values show that both estimates were made with similar height-determined-by-age functions in mind. The

1 Cheikowsky, C. personal communication

three merchantable volume of spruce equations (MVOL SP), as squared functions of age, all had R^2 (adjusted) values between .707 and .774 which would seem to indicate some agreement as to the effects of the prescription on MVOL SP. The three equations for aspen stems per hectare (STEMS ASP) were less well explained by age; their R^2 (adjusted) values were all within the range of .347 to .588. The difference between estimates indicated by the lower R^2 values underlines the two silviculturalists' differences in opinion about the effectiveness of a prescription that is geared towards inhibiting aspen growth. The three equations for each of MVOL ASP and STEMS SP had more variable and less satisfactory R^2 (adjusted) values which further underscore the silviculturalists' differences in opinion about the effectiveness of the prescription in regards to inhibiting the aspen production in order to promote spruce production.

Except for the three equations for each of MVOL ASP and STEMS SP, all of the coefficients were acceptable with 99% confidence; for those three MVOL ASP and those three STEMS SP equations, confidence in the coefficients fell to as low as: 28%, for age^2 in STEMS SP under PR 1 and; 77%, for age^2 in STEMS SP under PR 0, but all others were acceptable to at least 87%.

The MVOL SP and MVOL ASP growth functions for both PR 0 and PR 1 are used, with the appropriate rent· payments and regeneration costs in order to determine SEVs.

Calculations of Tenure Holders' Profits and the Crown's Welfare for the Intensive Prescription (i.e. PR 1)

Profits Given PR 1

Given that Spruce Products Ltd. (firm j = 1) harvests 75 m^3 of spruce saw logs (x_{11}) and 75 m^3 of spruce pulp chips (x_{12}) per ha, the profit for Spruce Products is:

$$\Pi^{11}/ha \quad = \quad \sum_{n=1}^{2} P_{1n}^{11} x_{1n} - L_{11}^{11} x_{11} - R_{11}^{1} x_{11}$$

or,

$$\begin{aligned} \Pi^{11}/ha \quad &= \quad \$18.29/m^3(7\text{[illegible]}) + \$7.67/m^3(75m^3/ha) \\ &- \quad \$1.30/m^3(75m^3/ha) \\ &- \quad \$2.15/m^3(75m^3/ha) \\ &= \quad \$1688.25/ha. \end{aligned}$$

Given that REPAP Ltd. (firm j = 2) purchases those 75 m^3 of spruce pulp chips (x_{12}) and, in turn, markets the pulp, the profit for REPAP Ltd. (j = 2) is:

$$\Pi^{12}/ha \quad = \quad P_{12}^{12} x_{12} - L_{12}^{12} x_{12} - R_{12}^{2} x_{12}$$

or,

$$\begin{aligned} \Pi^{12}/ha \quad &= \quad \$15.00/m^3(75m^3/ha) \\ &- \quad 0.42(NPVC^*/ha) \\ &- \quad \$0.84/m^3(75m^3/ha) \\ &= \quad (\$1,062.00/ha \ - \ 0.42(NPVC/ha)). \end{aligned}$$

* $75m^3$/ha purchased, at one ha of regeneration responsibility/$180m^3$, implies responsibility for 0.42 ha to REPAP (firm 2). Note: NPVC varies with the rate of time preference and with the silviculture prescription.

Depending on the discount rate (d) used by REPAP, the profit is as listed in Table 5.

TABLE 5. Profit for firm 2 (REPAP Ltd.) at various discount rates, given PR 1 in $/ha

d =	2	4	6	8	10
Total NPVC	820.00	784.68	751.80	721.13	692.48
0.42(NPVC)	344.40	329.57	315.76	302.87	290.84
Profit (Π^{12})*	**717.60**	**732.43**	**746.24**	**759.13**	**771.16**

* Profit (Π^{12}) = ($1,062.00 - 0.42(NPVC))/ha

If the Crown is not collecting all of the land rent, these profit figures will include some land rent in addition to the returns to entrepreneurship.

The Crown's Welfare Value of PR1

As will become evident, given Prescription PR 1, SEV^{13} is always negative. Accordingly, it does not make sense to calculate an optimal economic rotation (i.e. OER) based on the SEV. As the Crown presently uses a 50 year rotation, the SEV^{13} for year 50 was used throughout the remainder of this study.

If it is assumed, for the moment, that there will be no change in rental rates for spruce (whether formatted as saw logs or chips) and that no rent will be charged for aspen, then the figures in Tables 6 can be used to determine the desirability of implementing the intensive prescription PR 1. As $\delta SEV^{13} < 0$, the only reason to choose

PR 1 would be that the size of the present value of the non-timber values (i.e. $PVNTV^{13}$) justifies it.

TABLE 6. δSEV^{13} (i.e. SEV^{13} - SEV^{03}) in $/ha.

d =	2	4	6	8	10
SEV^{13}*	-1,198.20	-883.66	-784.61	-732.92	-696.88
SEV^{03}**	14.10	3.17	0.94	0.34	0.13
δSEV^{13}	**-1,212.30**	**-886.83**	**-785.55**	**-733.26**	**-697.01**

* SEV^{13} is based on a 50 year rotation because all SEV^{13}s are negative.

** SEV^{03}, on the other hand, is the $\max(SEV^{03})$, which is based on a rotation of from 30 to 65 years (depending on the discount rate and the relative rental rate of aspen). OERs for SEV^{03} can be found in Appendix 3.

If the decision is made to implement Pr 1, the welfare value of this Crown land (i.e. $W/ha) is:

$$W/ha = \sum_{n=1}^{2} R^{3}_{1n} x_{1n} + \sum_{n=1}^{2} L^{13}_{1n} x_{1n} + SEV^{13}$$

or,

$$\begin{aligned} W/ha &= \$2.15/m^3(75m^3/ha) + \$0.84/m^3(75m^3/ha) \\ &+ \$1.30/m^3(75m^3/ha) + 0.42(NPVC)^{*} \\ &+ \underline{SEV}^{13} \\ &= (\$321.75/ha + 0.42(NPVC/ha) + SEV^{13}/ha). \end{aligned}$$

* Note again that the net present value of regeneration costs (NPVC) will vary with the discount rate used.

Assuming no future market for aspen, the welfare value of PR 1, not including the PVNTV, ranges from: $-\$532.05 < W < -\$84.29$, as shown in Table 7.

TABLE 7. The welfare value* of PR 1 at various discount rates in $/ha.					
d =	2	4	6	8	10
$\sum_{n=1}^{2} R^{3}_{mn} x_{mn}$	224.25	224.25	224.25	224.25	224.25
$\sum_{j=1}^{2} L^{13}_{1n}$	441.90	427.07	413.26	400.37	388.34
SEV^{13}	-1,198.20	-883.63	-784.61	-732.92	-696.88
W	**-532.05**	**-232.31**	**-147.10**	**-108.30**	**-84.29**

* Not including PVNTV

Sensitivity Analysis

If markets develop for aspen forest products and the Crown begins to charge rents for aspen forest products at some rate relative to those rental rates charged for forest products made of spruce, then the SEVs and thus δSEV will change. Table 8 provides the results of the SEV and the δSEV calculations for assumed relative rental rates for aspen forest products of 0.5(the rental rates of similar forest products made of spruce).

TABLE 8. δSEV^{13} when the relative rental rate of aspen equals 0.5(rental rate of spruce) in $/ha.

d =	2	4	6	8	10
SEV^{13}*	-1,197.45	-883.45	-784.54	-732.89	-696.87
SEV^{03}**	71.20	19.72	7.85	3.52	1.65
δSEV^{13}	**-1,268.65**	**-903.17**	**-792.39**	**-736.41**	**-698.52**

* SEV^{13} is based on a 50 year rotation because all SEV^{13}s are negative.

** SEV^{03}, on the other hand, is the max(SEV^{03}), which is based on a rotation of from 30 to 65 years (depending on the discount rate and the relative rental rate of aspen). OERs for SEV^{03} can be found in Appendix 3.

The decision to implement PR 1 yields even greater negative values with the assumed increase in the relative rental rate of aspen. The welfare value of PR 1 is, however as is shown in Table 9, slightly greater under this assumption than it was under the assumption of no future market for aspen forest products. This is due to the fact that the small amount of aspen which still grows (despite the attempt to promote spruce production at the expense of the aspen) has some worth under the assumption that a future market for aspen, where the rental rates are half those of spruce forest products.

TABLE 9. The welfare value* of PR 1 if the relative rental rate of aspen equals 0.5(rental rate of spruce) in $/ha.

d =	2	4	6	8	10
$\sum_{n=1}^{2} R^{j}_{mn} x_{mn}$	224.25	224.25	224.25	224.25	224.25
$\sum_{j=1}^{2} L^{1j}_{1n}$	441.90	427.07	413.26	400.37	388.34
SEV^{13}	-1,197.45	-883.45	-784.54	-732.89	-696.87
W	**-531.30**	**-232.13**	**-147.03**	**-108.27**	**-84.28**

* Not including PVNTV.

Table 10 provides the results of the SEV and the δSEV calculations for assumed relative rental rates for aspen forest products which are equal to the rental rates of similar forest products made of spruce (i.e. the aspen market in the future is even stronger). Once again δSEV is lessened and the decision to proceed with PR 1 becomes more costly as the assumed relative rental rate for aspen is increased.

TABLE 10. δSEV^{13} if the relative rental rate of aspen equals the rental rate of spruce in $/ha.

d =	2	4	6	8	10
SEV^{13}*	-1,183.50	-879.49	-783.15	-732.36	-696.66
SEV^{03}**	133.10	38.76	15.87	7.11	3.39
δSEV^{13}	**-1,316.60**	**-918.25**	**-799.02**	**-739.47**	**-700.05**

* SEV^{13} is based on a 50 year rotation because all SEV^{13}s are negative.

** SEV^{03}, on the other hand, is the max(SEV^{03}), which is based on a rotation of from 30 to 65 years (depending on the discount rate and the relative rental rate of aspen). OERs for SEV^{03} can be found in Appendix 3.

The welfare associated with PR 1, however, increases slightly again as the small amount of aspen that is produced becomes more valuable as is shown in Table 11.

TABLE 11. The welfare value* of PR 1 if the relative rental rate of aspen equals the rental rate of spruce in $/ha.

d =	2	4	6	8	10
$\sum_{n=1}^{2} R^{j}_{mn} x_{mn}$	224.25	224.25	224.25	224.25	224.25
$\sum_{j=1}^{2} L^{1j}_{1n}$	441.90	427.07	413.26	400.37	388.34
SEV^{13}	-1,183.50	-879.49	-783.15	-732.36	-696.66
W	**-517.35**	**-228.17**	**-145.64**	**-107.74**	**-84.07**

* Not including PVNTV.

The welfare measure is a loss which ranges from -$84.07 to -$532.05/ha, depending on the assumptions made about the future state of the world (SOW) and on the discount rate used. In regards to assumptions about the future SOW (particularly concerning future markets), the higher the assumed rental rate of aspen forest products (relative to similar spruce forest products), the more costly is the decision to implement PR 1. However, the welfare loss is mitigated slightly as the relative rental rate for aspen products increases. Concerning the net discount rate used, the higher the net discount rate used, the smaller the welfare loss; as the net present value of the crown's share of regeneration costs (NPVC) is of lesser value.

It is interesting to note that even if the Crown increased the rental rates for spruce forest products by ten times, under the assumption that a market for aspen will not develop, there would only be a positive welfare value at discount rates of 4% or less. If the Crown were able to charge rents great enough so that the firms' profits were zero, the welfare associated with PR 1 would only be positive at a discount rate of something less than 6%.

Calculations of Tenure Holders' Profits and the Crown's Welfare for the Intensive Prescription (i.e. PR 0)

Profits Given PR 0

The last calculations focus on the value of the extensive prescription (i.e. PR 0). The Crown presently dictates that the firms must follow regulations and pay levies for, or undertake, intensive regenerative activities such as in prescription PR 1. The firms have no choice but to follow these regulations and bear the costs. However, the Crown can choose to relax or even remove these regulations. To answer the question of what would be the effect of the removal of these regulations, the value of natural regeneration is examined.

Given natural regrowth and no levies for intensive regeneration, the profit for firm 1 would be:

$$\Pi^{11}/ha = \sum_{n=1}^{2} p_{1n}^{11} x_{1n} - R_{11}^{1} x_{11}$$

or,

$$\begin{aligned} \Pi^{11}/ha &= \$18.29/m^3(75m^3/ha) + \$7.67/m^3(75m^3/ha) \\ &- \$2.15/m^3(75m^3/ha) \\ &= \$1{,}785.75/ha. \end{aligned}$$

Profits are greater by the amount of the levy or (i.e. $75m^3$ * $1.30 = $97.50).

Similarly, given natural regrowth and no cost (i.e. no effective levy) for intensive regeneration, the returns to firm 2 would be:

$$\Pi^{12}/ha = P_{12}^{12}x_{12} - R_{12}^{2}x_{12}$$

or,

$$\Pi^{12}/ha = \$15.00/m^3(75m^3/ha)$$
$$\underline{-\quad \$0.84/m^3(75m^3/ha)}$$
$$= \$1,062.00/ha.$$

The profit for firm 2 is greater by the foregone (effective) levy of 0.42(NPVC).

If all of the land rent has been collected by the Crown, these profit figures represent returns to entrepreneurship for the firms given natural regeneration. Similarly, the profit figures for PR 1 also represented returns to entrepreneurship for the firms, but under extensive regeneration. If the Crown is not collecting all of the rent, the profit figures contain some uncaptured land rent.

The Welfare Value of PR 0

Given that PR 0 was to be implemented, the Crown would realize the SEV associated with such natural regeneration (i.e. SEV^{03}), and the welfare value (W) would be:

$$W/ha = \sum_{n=1}^{2} R_{1n}^{3}x_{1n} + SEV^{03}$$

or,

$$W/ha = \$2.15/m^3(75m^3/ha) + \$0.84/m^3(75m^3/ha)$$
$$\underline{+\quad SEV^{03}}$$
$$= (\$224.25/ha + SEV^{03}/ha).$$

The profit and welfare value figures associated with PR 0, under the assumption of no future market for aspen forest products, are depicted in Table 12.

TABLE 12. Profit and welfare values* associated with PR 0
(assuming no future market for aspen)
in $/ha

d =	2	4	6	8	10
Π^{11}	1,785.75	1,785.75	1,785.75	1,785.75	1,785.75
Π^{12}	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00
W(no mkt)	**238.35**	**227.42**	**225.19**	**224.59**	**224.38**

* Not including PVNTV.

Table 13 contains the profit and welfare values for PR 0 which are associated with the assumption of rental rates for aspen products which are equal to those charged for spruce products.

TABLE 13. Profit and welfare values* associated with PR0
(assuming the relative rental rate of aspen is equal to that of spruce)
in $/ha

d =	2	4	6	8	10
Π^{11}	1,785.75	1,785.75	1,785.75	1,785.75	1,785.75
Π^{12}	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00
W(strong mkt)	**357.35**	**263.01**	**240.12**	**231.36**	**227.64**

* Not including PVNTV.

The figures in Tables 12 and 13 and the welfare figures associated with PR 1 imply that, excluding the present value of the non-timber values (i.e. PVNTV), the total welfare foregone, by implementing regulations that require intensive prescriptions such as PR 1 to be used on this site type, can be great. For example, the least welfare is foregone under the assumption that no market will develop for aspen forest products and at a discount rate of 10%.

Under these assumptions, the welfare foregone is equal to the welfare associated with PR 0 (i.e. W^{pr0}) less that associated with PR 1 (i.e. W^{pr1}). Under these assumptions, the difference, or foregone total welfare if PR 1 is required and implemented (i.e. λW), is $308.67/ha.

If in the future a strong market for aspen forest products does develop so that rental rates for aspen approach the levels charged for spruce forest products, the amount of the welfare foregone increases. Table 14 shows the welfare foregone under two different assumptions about the future, over a range of discount rates.

TABLE 14. Foregone welfare values* from using PR 1
(under two assumptions about future markets for aspen forest produc[ts]) in $/ha

(assuming no future market for aspen)	d = 2	4	6	8	10
W^{pr0}	238.35	227.42	225.19	224.59	224.38
W^{pr1}	-532.05	-232.31	-147.10	-108.30	-84.29
λW(no mkt)	**770.40**	**459.73**	**372.29**	**332.89**	**308.67**
(assuming rental rates for aspen equal those charged for spruce)	d = 2	4	6	8	10
W^{pr0}	357.35	263.01	240.12	231.36	227.64
W^{pr1}	-517.35	-228.17	-145.64	-107.74	-84.07
λW(if equal rental rates)	**874.70**	**491.18**	**385.76**	**339.10**	**311.71**

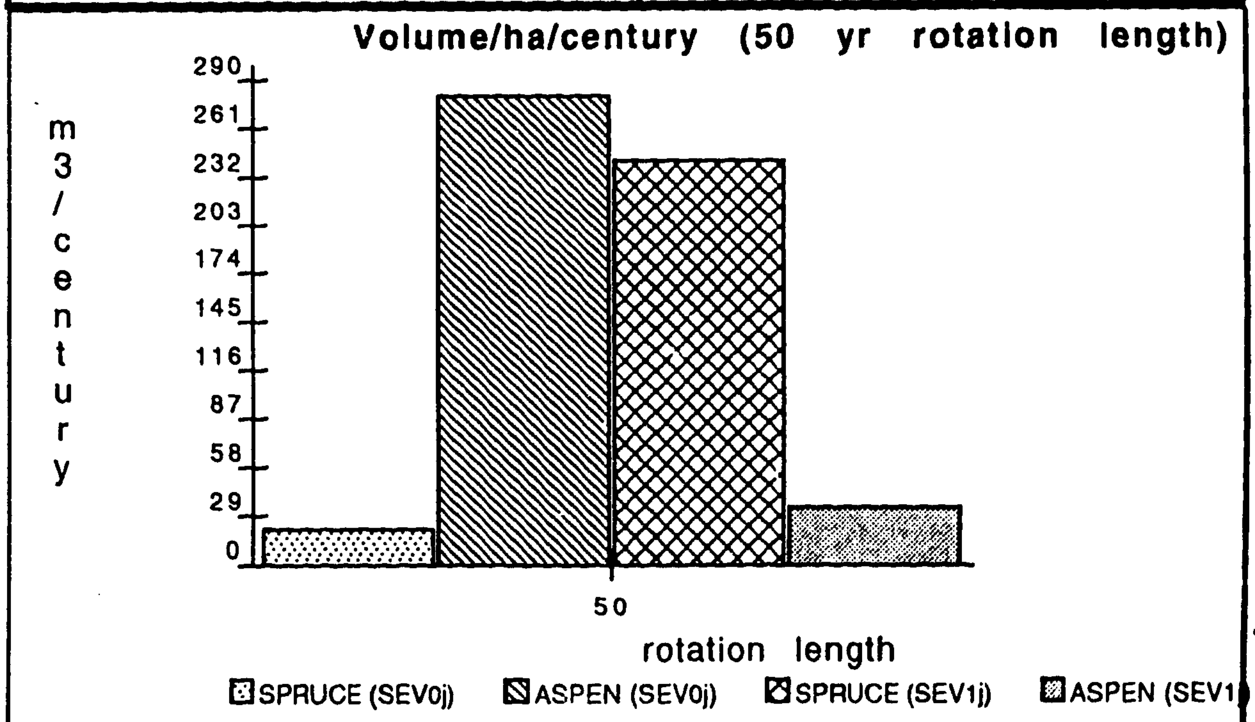
* Not including PVNTV.

The foregone welfare (λW) is greater at a lower discount rate as the net present value of the costs of PR 1 (i.e. NPVC) is greater. The foregone welfare (λW) is also greater if aspen forest products become marketed in the future.

Non-Timber Values (i.e. PVNTV)

If the volume of spruce produced per some period of time (say a century) is a positive measure of utility or welfare, then there is a significant positive volume related non-timber value associated with prescription PR 1, as can be seen in Figure 1. However, the combined volumes/century of spruce and aspen associated with PR 0 are similar (at a 50 year rotation length) to the combined volumes/century of spruce and aspen, given the implementation of PR 1 (again at a rotation length of 50 years). This can also be seen in Figure 1. Therefore, the volume related non-timber value is small if combined volumes are the appropriate utility measure.

FIGURE 1. Volume/ha/century by species and by prescrip



Note: SEV0j indicates the SEV associated with prescription PR 0 and SEV1j indicates the SEV associated with prescription PR 1.

As a hedonic price function for the most commonly monitored attributes of each species (i.e. stems/ha, volume/ha or mean height) does not yet exist, only graphical representations of the marginal physical outputs (MPOs) are included in this case study.

To calculate these MPOs, the extent of regrowth that would occur naturally (under PR 0) was subtracted from that associated with PR1. The MPOs associated with PR 1 are depicted in Figures 2 and 3.

The figures show that there is a decrease in the number of stems/ ha of aspen (STEMS ASP) under the intensive prescription. There might be some non-timber value associated with a decreased number of aspen stems. However, it could be a positive or a negative non-timber value. As expected, the marginal change in average height of both spruce (AVGHT SP) and aspen (AVGHT ASP) is minuscule. Graphical representations such as Figures 2 and 3 could be used in the Crown's (or a forest owning firm's) decision making process. More likely though, site specific wildlife habitat requirements would play a much greater role in determining the sign and size of the non-timber values according to the decision maker.

FIGURE 2. Marginal spruce (SP) production associated with PR1 (/ha).

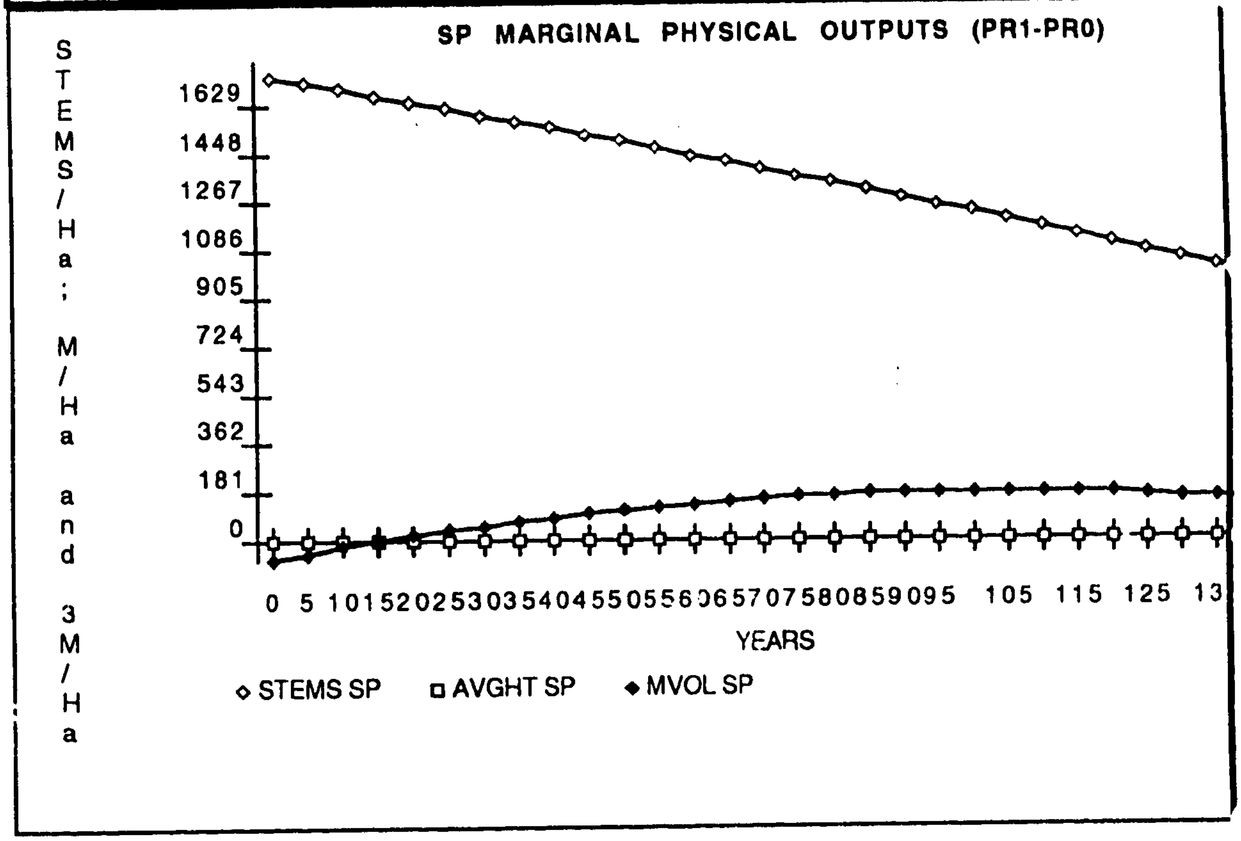
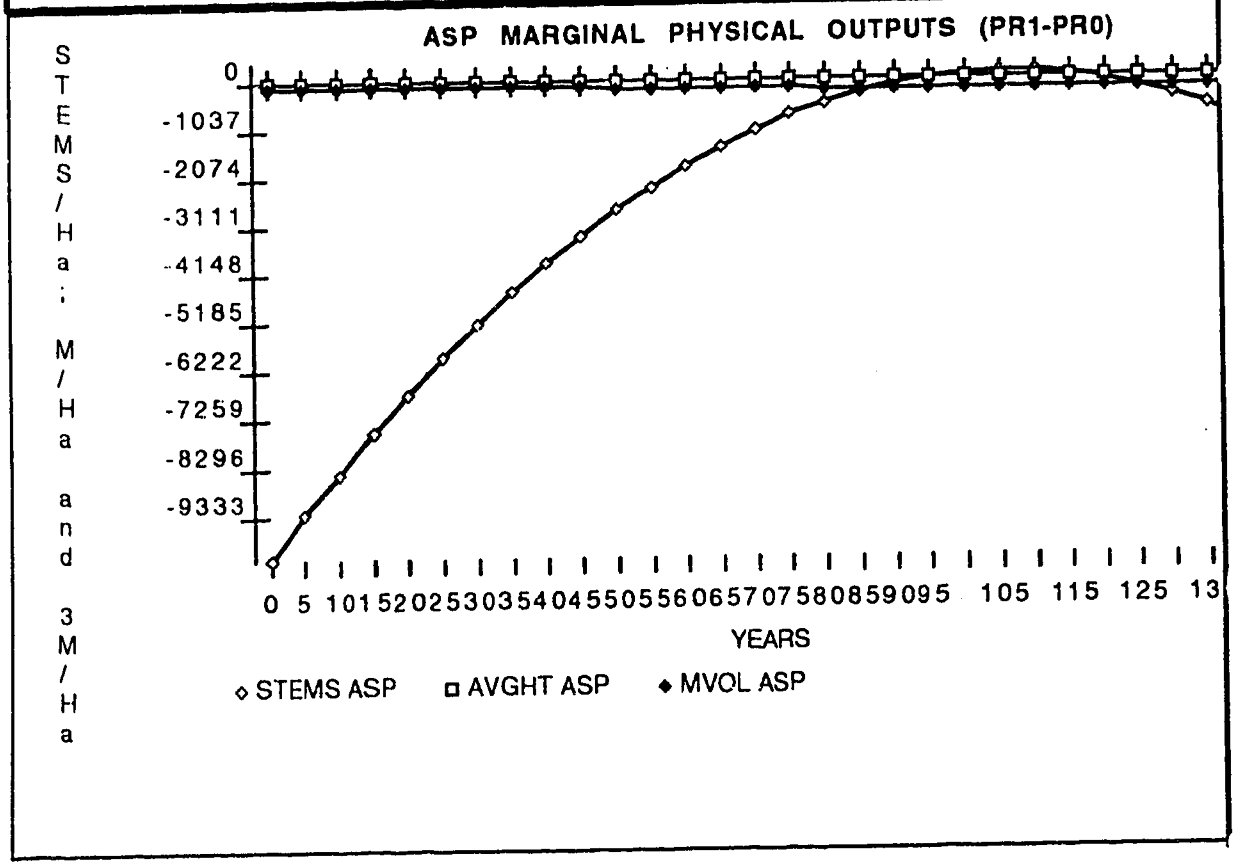


FIGURE 3. Marginal aspen (ASP) production associated with PR1 (/ha).



RESULTS AND CONCLUSIONS

Results

Profits

Given regulations requiring that an intensive prescription such as PR 1 must be implemented, the returns (Π^{11}) for firm 1 are $1,688.25/ha, assuming that there is no expectation of realizing any SEV. The firm will continue to attempt to minimize logging costs and may weigh the expected penalty of not meeting logging regulations against the cost savings of doing so. The firm would realize a further amount of $97.50 if natural regeneration was the policy. This $97.50 is the amount of the levy charged by the Crown.

Given regulations requiring that an intensive prescription such as PR 1 is to be implemented, the returns (Π^{12}) for firm 2 range from $717.60/ha to $771.16/ha, depending on the discount rate used. Minimization of the costs of regenerating according to government regulation is an objective of firm 2 as the firm is required to undertake regeneration activities rather than paying a fixed levy. This firm would realize a further amount of from $290.84 to $344.40 (i.e. .42(NPVC)) if natural regeneration was the policy. This amount is, in effect, a levy charged by the Crown and would not be charged if natural regeneration was the policy.

The difference in welfare between a policy which requires intensive regeneration and a policy favouring natural regeneration can be great if the opportunity cost of intensive regeneration (i.e. any difference in the total rental and levy payments for existing timber plus the naturally occurring SEV) is significant.

The welfare foregone (λW) ranges from \$308.67/ha to \$874.70/ha, over the range of discount rates used herein and depending on the assumptions used. A realistic figure, based on a discount rate of 6%, is in the neighborhood of \$375.00/ha. This figure will be greater (i.e. \$385.76), if a strong market for aspen products develops and rental rates for aspen forest products equal those charged for spruce forest products, and it will be smaller (i.e. \$372.29), if such a market does not develop and there is, therefore, no rental rate for aspen forest products. For the Crown to be willing to forego somewhere in the neighborhood of \$375.00/ha in welfare, for a relatively common mixed-wood site type such as the one used in this study, there must be some rationale such as the value of the non-timber values perhaps.

Non-Timber Values

The Crown decision makers may feel that the non-timber values associated with an intensive prescription may have a dollar value which is equal to or greater than the welfare foregone by regulating and implementing the use of intensive prescriptions such as PR 1. In order to examine this notion, first the volume-related non-timber values and then the non-volume related non-timber values are discussed.

Additional volume produced per century has been assumed to provide some positive welfare value. It is not known, however, if on a mixed-wood site, the individual or the combined volumes provide some positive welfare value. If only spruce volume adds to welfare, then the volume related non-timber value is significant as was shown in Figure 2. However, the combined volumes, as also indicated in Figure 2, are not very different under each prescription. So if combined volumes have some value, the volume related non timber value is insignificant.

What about the non-volume related non-timber values? Until a hedonic price function for a forest site such as the subject of the case study is developed, it is not possible to determine if the non-timber externalities associated with prescription PR 1 are even positive.

If the non-volume related non-timber values are thought to be positive, they and any volume-related non-timber values, combined, could be shadow priced by the dollar loss in welfare. If the non-volume related non-timber values are negative, then the value of the volume-related non-timber values will equal the dollar loss (or shadow price) plus some additional amount. This is most likely the case as, in terms of risk and biological diversity (as was previously mentioned), PR 0 likely offers more non-volume related non-timber value than does PR 1.

Public perception could be an important factor in the Crown's welfare function. The decision makers may believe that there is a significant value in demonstrating that active regeneration measures are being taken.

Conclusions

The dollar-valued portion of the welfare (W) associated with PR 1 is considerably less than that associated with PR 0. The non-volume related non-timber values associated with PR 1 are of an unknown magnitude, but are most likely of a lesser magnitude than those associated with PR 0. The volume-related non-timber values will be significant and positive only under the assumption that combined volumes are not a reasonable welfare measure (i.e. under the assumption that aspen will not become a marketed species in the future). Otherwise these volume-related non-timber values are negligible and the foregone dollar-valued, total welfare figure represents only a portion of the total welfare foregone. Even if rental payments to the Crown are increased to the point where the firms no longer make a profit, the welfare value of PR 1 will only be positive over a very low range of discount rates (i.e. 4% or less).

AREAS FOR FURTHER STUDY

While this case study revolved around a site where intensive regeneration costs were high and the biological results such that the site expectation values were always negative, this will not always be the case. The site expectation value associated with natural regeneration was a positive opportunity cost in this case study. There will be instances where regrowth will be insignificant and the opportunity cost will be negligible. There will also be instances where the opportunity costs associated with natural regeneration will be negative (e.g. when erosion would degrade the site). It is important that welfare values associated with intensive and with natural regeneration be compared for all site types in order that dollars spent on silvicultural activities be spent knowledgeably.

These welfare values should be aggregated for site types to indicate the magnitude of the welfare losses on a province or forest wide basis. For example, if one quarter of the 6,684.1 ha which were planted in 1989-90 in Manitoba (Manitoba Natural Resources, 1990) were of a site type similar to that studied herein, the welfare foregone, at d = 6%, would be in the neighborhood of $626,634 (i.e. $375.00/ha*(6,684.1 ha/4)).

Two other important areas for further study are related to the issues of uncertainty. These include: the development of joint production functions for regenerated timber and other environmental outputs and; the estimation of future market conditions.

The net return, or welfare, functions for forest owning firms should also be studied in a similar manner to this case study.

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APPENDIX 1

SILVICULTURAL PRESCRIPTION QUESTIONNAIRE

DATE (day) 24 (month) 03 (year) 1992

YOUR NAME ____________

YOUR AFFILIATION:

(org) ____________ (position) Silv. For.

SITE:

LEGAL DESCRIPTION MANITOBA FMU # 14 (TWP 33 - R (W) 24) 52° N LAT

LEASE ARRANGEMENT TYPE: VOL QUOTA HOLDER SUBJECT TO REGEN LEVY

CURRENT INVENTORY:

SPECIES #1 BLACK SPRUCE AGE 100 at 80 % stocking.

SITE INDEX 15-19.9m AT 50 YEARS

SITE CLASS # 3

SPECIES #2 ASPEN AGE 65 at 20 % stocking.

SITE INDEX 15-19.9m AT 50 YEARS

SITE CLASS # 3

SITE DESCRIPTION:

SOIL TEXTURE VERY FINE SILT

SOIL MOISTURE FRESH MOIST

LITTER DEPTH 10-15cm

PRIMARY COMPETITION ASPEN

OTHER COMPETITION —

DISEASE PROBLEMS —

SLOPE (and aspect if pertinent) 8% SLOPE (0% ON LANDINGS)

HARVESTING SYSTEM:

SIZE OF CUT 50 Ha

SPECIES # 1 REMOVED 100 %

SPECIES # 2 REMOVED 0 %

HARVESTING MACHINERY FELLER BUNCHER

SKIDDING MACHINERY GRAPPLE SKIDDER

SLASH TREATMENT CHIPPED AND SPREAD

SKID TRAIL CONFIGURATION MULTIPLE LANDINGS W/RADIAL SKID TRAILS

SKID TRAILS at 10 % of total area

LANDINGS at 5 % of total area

MONTH OF HARVEST: (Jan) Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

REGEN STOCK AVAILABLE:

	SPECIES	FORMAT	DESCRIPTION
A.	BLACK SPRUCE	CONTAINER (CAN AM #1)	CURRENT CROP
B.			
C.			
D.			

WORKSHEET NUMBER PR O

YEAR	ACTIVITY	BLACK SPRUCE SPECIES #1 STOCKING stems/Ha	SPECIES #1 AVG HEIGHT M	SPECIES #1 MERCH VOL m3/Ha	ASPEN SPECIES #2 STOCKING stems/Ha	SPECIES #2 AVG HEIGHT M	SPECIES #2 MERCH VOL m3/Ha
0	harvest	100 ⊕	2.0	n.a.	2,000 ⊕⊕	15.0 ⊕⊕	40 ⊕⊕
1	NO ACTIVITIES (IT DOES NOT HAVE [illegible] IF THIS (AS SCRIPTED) [illegible] SOFTWOOD STANDARDS)	300	0.02	n.a.	3,000	0.50	n.a.
2		500	0.05	n.a.	6,000	1.00	n.a.
3		600	0.10	n.a.	10,000	2.00	n.a.
4		600	0.16	n.a.	12,500	2.50	n.a.
5		600	0.24	n.a.	12,500	3.00	n.a.
6		600	0.34	n.a.	12,500	3.50	n.a.
7		590	0.50	n.a.	12,500	4.00	n.a.
8		590	0.75	n.a.	12,500	4.50	n.a.
9		590	1.00	n.a.	12,020	5.00	n.a.
10		590	1.25	n.a.	12,000	5.50	n.a.
11		580	1.50	n.a.	11,500	5.75	n.a.
12		580	1.75	n.a.	11,500	6.00	n.a.
13		570	2.00	n.a.	11,000	6.50	n.a.
14		570	2.25	n.a.	10,500	6.75	n.a.
15		570	2.50	n.a.	10,000	7.00	n.a.
20		540	4.00	n.a.	7,000	8.00	n.a.
30		520	6.50	n.a.	5,000	11.00	n.a.
40		500	9.50	n.a.	3,000	14.00	60
50		480	12.50	5.00	2,000	17.00	200
60		470	15.50	20.00	1,500	20.00	240
70		460	17.00	30.00	1,500	20.00	280
80		440	18.50	40.00	1,400	20.00	260
90		420	19.50	48.00	1,300	20.00	250
100		400	20.00	48.00	1,200	20.00	230
110		400	20.00	48.00	1,100	20.00	220
120		400	20.00	48.00	1,000	20.00	210
130		350	20.00	40.00	750	20.00	200
140		300	20.00	3	500	20.00	160
150							

⊕ Advanced regen/layering following harvest (not include average ht. except yr. 0)

Note: stems/ha figures for both species indicate estimated densities not stocking - stocking in this situation I would estimate as approximately 30-40% at year seven after harvest.

⊕⊕ Residual Aspen shown in year 0 only, other average ht./volume figures refer to regeneration and

WORKSHEET NUMBER PR1

YEAR	ACTIVITY	$/ha	BLACK SPRUCE: SPECIES #1 STOCKING stems/ha	SPECIES #1 AVG HEIGHT M	SPECIES #1 MERCH VOL m3/ha	ASPEN: SPECIES #2 STOCKING stems/ha	SPECIES #2 AVG HEIGHT M	SPECIES #2 MERCH VOL m3/ha
0	harvest		100 (*)	2.00	n.a.	[illegible]00 (1)(2)	18.0 (1)(2)	40 (1)(2)
1	PRM. SS.	$120/ha [illegible]	300	0.02	n.a.	3,000	0.50	n.a.
2	PLANT	$550/ha [illegible]	2,800	0.12	n.a.	5,000	1.00	n.a.
3	[illegible]	$15/ha (17.75)	2,600	0.25	n.a.	8,000	2.00	n.a.
4	HERBICIDE	$200/ha [illegible]	2,600	0.35	n.a.	12,000	2.50	n.a.
5	—		2,550	0.50	n.a.	200	1.00	n.a.
6	[illegible]	$15/ha [illegible]	2,500	0.85	n.a.	150	1.00	n.a.
7			2,500	1.20	n.a.	150	1.00	n.a.
8			2,500	1.55	n.a.	150	1.25	n.a.
9			2,500	1.90	n.a.	200	1.50	n.a.
10			2,500	2.25	n.a.	250	2.00	n.a.
11			2,500	2.70	n.a.	250	2.50	n.a.
12			2,500	3.05	n.a.	250	3.00	n.a.
13			2,500	3.45	n.a.	275	3.50	n.a.
14			2,500	3.85	n.a.	300	4.00	n.a.
15			2,450	4.25	n.a.	350	5.00	n.a.
20			2,350	6.25	n.a.	350	7.00	n.a.
30			2,250	10.25	n.a.	350	9.00	n.a.
40			2,100	14.00	50	350	11.00	n.a.
50			1,950	17.00	140	350	13.00	25
60			1,750	19.00	190	350	15.00	40
70			1,600	20.00	230	300	16.00	45
80			1,500	20.00	230	250	16.50	50
90			1,450	20.00	220	200	17.00	45
100			1,400	20.00	210	150	17.00	35
110			1,350	20.00	200	100	17.00	25
120			1,300	20.00	180	[illegible]0	17.00	15
130								
140								
150								

Note: By site preparing and planting immediately after harvest, herbicide treatment may not be required

(*) Advanced regeneration - height not included in the avg. except at yr. 0

(1)(2) Residual aspen following harvest - statistics [illegible]

WORKSHEET NUMBER PR. 2

YEAR	ACTIVITY	BLACK SPRUCE: SPECIES #1 STOCKING stems/Ha	BLACK SPRUCE: SPECIES #1 AVG HEIGHT M	BLACK SPRUCE: SPECIES #1 MERCH VOL m3/Ha	ASPEN: SPECIES #2 STOCKING stems/Ha	ASPEN: SPECIES #2 AVG HEIGHT M	ASPEN: SPECIES #2 MERCH VOL m3/Ha
0	Harvest	100 (*)	2.0	n.a.	200 (**)	18.0 (**)	40 (**)
1	—	300	0.02	n.a.	3,000	0.50	n.a.
2	Brack. ($120/ha)	400	0.05	n.a.	5,000	1.00	n.a.
3	Plant ($550/ha)	2,800	0.12	n.a.	9,000	2.00	n.a.
4	Survey ($15/ha)	2,500	0.20	n.a.	12,000	2.50	n.a.
5	Herbicide ($220/ha)	2,500	0.30	n.a.	15,000	3.00	n.a.
6	—	2,450	0.45	n.a.	200	1.00	n.a.
7	Survey ($15/ha)	2,400	0.75	n.a.	150	1.00	n.a.
8		2,400	1.10	n.a.	150	1.00	n.a.
9		2,400	1.40	n.a.	150	1.25	n.a.
10		2,400	1.70	n.a.	200	1.50	n.a.
11		2,400	2.00	n.a.	250	2.00	n.a.
12		2,100	2.40	n.a.	250	2.50	n.a.
13		2,100	2.80	n.a.	250	3.00	n.a.
14		2,400	3.20	n.a.	275	3.50	n.a.
15		2,350	3.60	n.a.	300	4.00	n.a.
20		2,250	5.60	n.a.	350	5.00	n.a.
30		2,100	9.50	n.a.	350	7.00	n.a.
40		1,950	13.00	40	350	9.00	n.a.
50		1,750	16.00	110	350	11.00	30
60		1,600	18.50	160	350	13.00	35
70		1,500	20.00	220	300	15.00	40
80		1,450	20.00	220	250	16.00	50
90		1,400	20.00	210	200	16.50	40
100		1,350	20.00	200	150	17.00	35
110		1,300	20.00	190	100	17.00	~~30~~ 20
120		1,200	20.00	180	[illegible]	17.00	~~20~~ 15
130		↓	↓	↓	↓	↓	↓
140							
150							

(*) Advanced regeneration (ht. not included in average past year 0)

Note: I would predict a stocking of 85-90% for Black spruce under this crop plan at age 7

(**) Refers to residuals considered in yr 0 only.

Treatment Option #0 No treatment

SILVICULTURE RESULTS OR OUTPUT WORKSHEET NUMBER ____ Is this a: Prescription . ___? or Likely sequence of activities ___?

YEAR	ACTIVITY	COST $/Ha	VALUE $/Ha	AVG SOIL COND whole Ha	SKID TR SOIL COND 10 % of Ha	LANDING CONDIT'N 5 % of Ha	SPECIES #1 STOCKING stems/Ha	SPECIES #1 AVG HEIGHT M	SPECIES #1 MERCH VOL m3/Ha	SPECIES #2 STOCKING stems/Ha	SPECIES #2 AVG HEIGHT M	SPECIES #2 MERCH VOL m3/Ha	competing veget'n type____	Cover Type used for Volumes
0	harvest													
1														
2														
3														
4	Regen Survey	20												
5							450	0.4	0	2100	2.3			
6														
7	Regen Survey	20												
8														
9														
10							1000	0.4	0	2300	5.0			
11														
12														
13														
14														
15							200	0.7	0	1000	8.0	0		
20														
30														
40							60	4	5.0	585	13	64.0		22-1-[illegible]
50														
60							115	8.5	15.0	325	18	105.0		22-1-4-4
70														
80														
90							123	10	19.0	250	16	94.0		22-1-5-4
100														
110														
120														
130														
140														
150														

HOW MANY YEARS WILL THE SOIL CONDITIONS DELAY GROWTH RELATIVE TO THE AVG ON SKID TRAILS ___?, ON LANDINGS ___?

Treatment Option #1 Bracke Site Preparation – Container Stock Planting

SILVICULTURE RESULTS ON OUTPUT WORKSHEET NUMBER ____ ; Is this a: Prescription ___? or Likely sequence of activities ___?

YEAR	ACTIVITY	COST /Ha	VALUE /Ha	AVG SOIL COND whole Ha	SKID TR SOIL COND 10 % of Ha	LANDING CONDIT'N 5 % of Ha	SPECIES #1 STOCKING stems/Ha	SPECIES #1 AVG HEIGHT M	SPECIES #1 MERCH VOL m3/Ha	SPECIES #2 STOCKING stems/Ha	SPECIES #2 AVG HEIGHT M	SPECIES #2 MERCH VOL m3/Ha	competing veget'n type____	cover type used for volume
0	to:harvest													
1	Bracke site prep.	180	(192)											
2	Plant B.s.	460	(50)				2300	0.15	0		0.5	0		
3														
4	Regen Survey	20	(17.7)							/				
5	Herbicide Spray	135	(167.5)				1500	0.5	0	1750	2.5	← Prior to Spray in Fall		
6														
7	Regen Survey	20	(17.7)											
8														
9														
10							1750	2.0	0	600	3.0	0		
11	Hand Tending	500												
12														
13														
14														
15							1600	4.0	0	100	6.0	0		
20														
30							1650	8.5	10	60	10	0		
40														13-1-2
50							1720	13	128	22	14	5		
60														
70														13-1-4
80							1880	15.5	162	13	16	3		
90														
100														13-1-5
110							2080	16	159	12	13	5		
120														
130														
140														
150														

HOW MANY YEARS WILL THE SOIL CONDITIONS DELAY GROWTH RELATIVE TO THE AVG ON SKID TRAILS ___?, ON LANDINGS ___?

PR 2

SILVICULTURE RESULTS OR OUTPUT WORKSHEET NUMBER ____ Is this a: Prescription ___? or Likely sequence of activities ___?

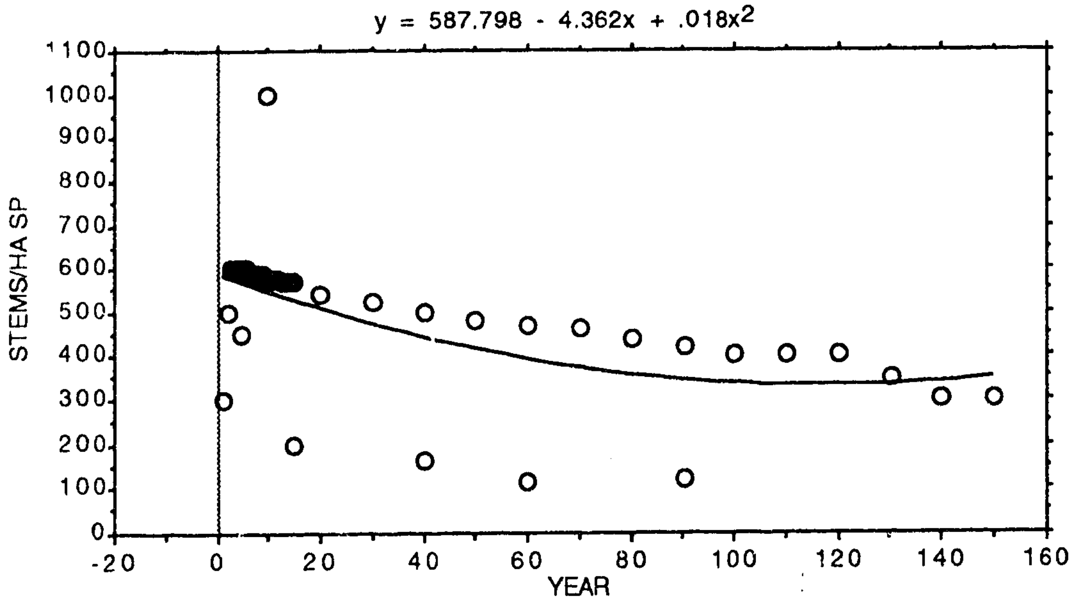
YEAR	ACTIVITY	COST $/Ha	VALUE $/Ha	AVG SOIL COND whole Ha	SKID TR SOIL COND 10 % of Ha	LANDING CONDIT'N 5 % of Ha	SPECIES #1 STOCKING stems/Ha	SPECIES #1 AVG HEIGHT M	SPECIES #1 MERCH VOL. m3/Ha	SPECIES #2 STOCKING stems/Ha	SPECIES #2 AVG HEIGHT M	SPECIES #2 MERCH VOL m3/Ha	competing veget'n type___	cover type used for volume
0	Harvest													
1														
2	Brake Site Prep	200	1.5											
3	Plant Bs	500	5.0				2200	0.15	0	2000	1.3	0		
4	Herbicide Spray	135	(47.50)											
5							1500	0.35	0	1000	1.0	0		
6	Regen Survey	20	11	5										
7														
8														
9	Hand Tending	600												
10	Regen Survey	20	17.7				1400	1.7	0	200	3.5	0		
11														
12														
13														
14														
15							1200	3.5	0	175	6.5	0		
20														
30							1000	8	5	182	11	10		
40														53-1-3
50							880	12	91	193	16	45		
60														
70														53-1-4
80							1340	15	119	214	18	60		
90														
100														
110							1400	15.5	145	150	14	40		
120														
130														
140														
150														

HOW MANY YEARS WILL THE SOIL CONDITIONS DELAY GROWTH RELATIVE TO THE AVG ON SKID TRAILS___?, ON LANDINGS___?

APPENDIX 2

PRESCRIPTION PR 0 (NO ACTIVITIES)

SPRUCE
STEMS/HA



Polynomial Regression X_1: YEAR Y_1: STEMS/HA SP

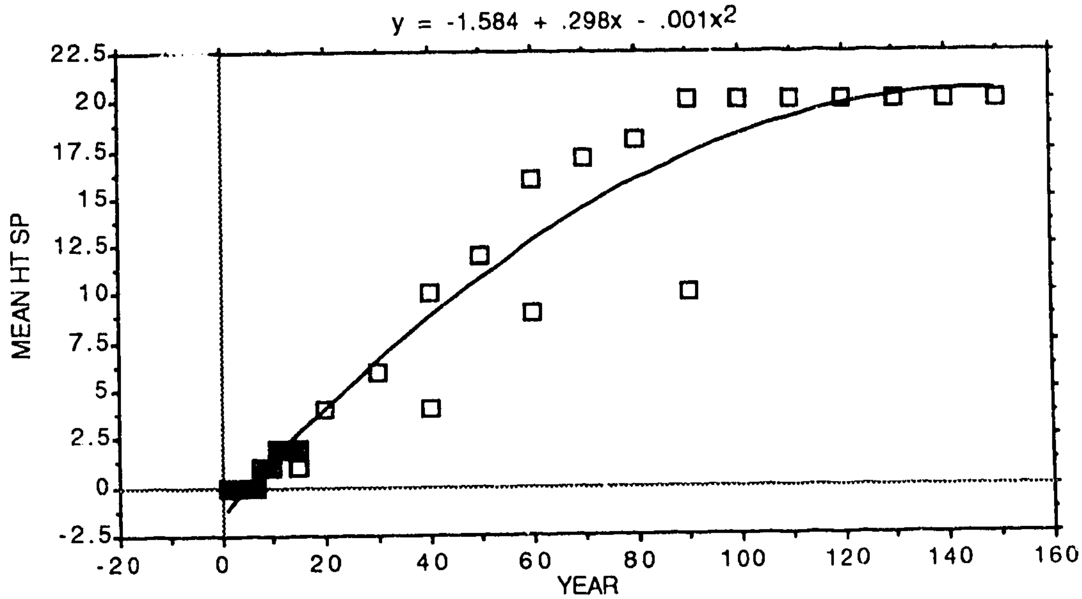
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	587.798				
x	-4.362	2.029	-1.168	2.15	.0392
x^2	.018	.015	.665	1.224	.23

Predicted : Column 46

R2=.311 ADJR2=.268 F=7.222 P=.0026

SPRUCE
MEAN HT



Polynomial Regression X_1: YEAR Y_2: MEAN HT SP

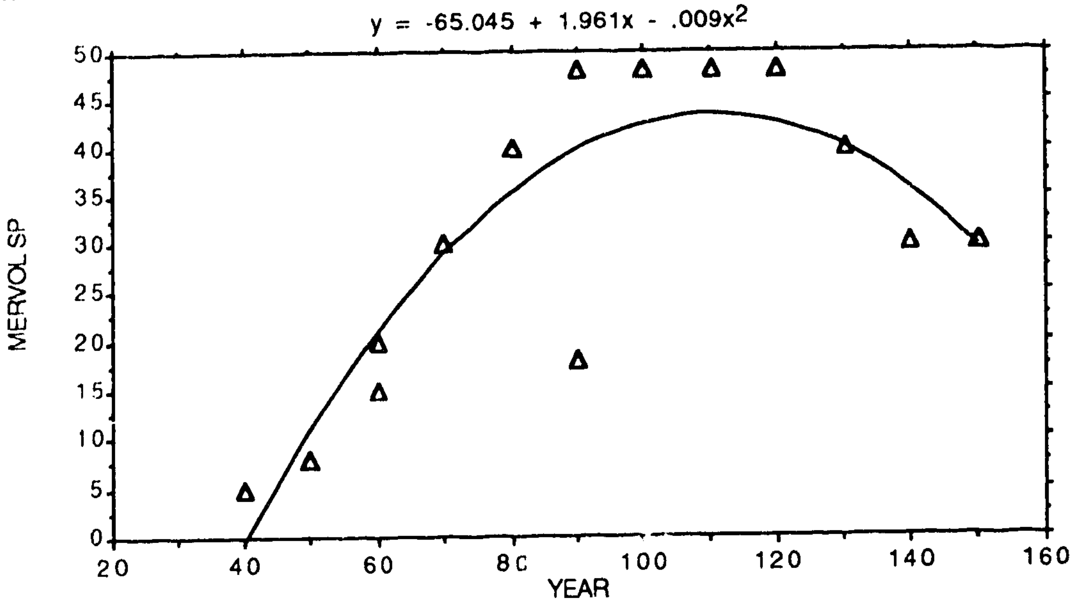
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	-1.584				
x	.298	.03	1.697	10.109	.0001
x^2	-.001	2.168E-4	-.782	4.655	.0001

Predicted : Column 47

R2=.938 ADJR2=.934 F=226.398 P=.0001

SPRUCE
MERCH VOL



Polynomial Regression X_1: YEAR Y_3: MERVOL SP

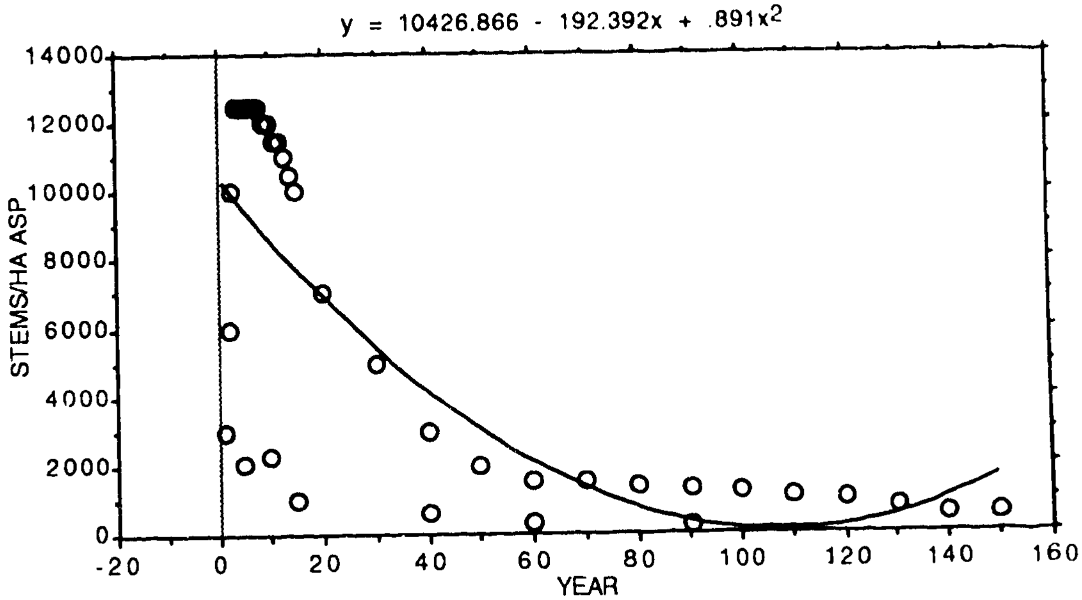
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	-65.045				
x	1.961	.417	4.398	4.707	.0006
x^2	-.009	.002	-3.831	4.1	.0018

Predicted : Column 48

R2=.755 ADJR2=.71 F=16.928 P=.0004

ASPEN
STEMS/HA



Polynomial Regression X_1: YEAR Y_1: STEMS/HA ASP

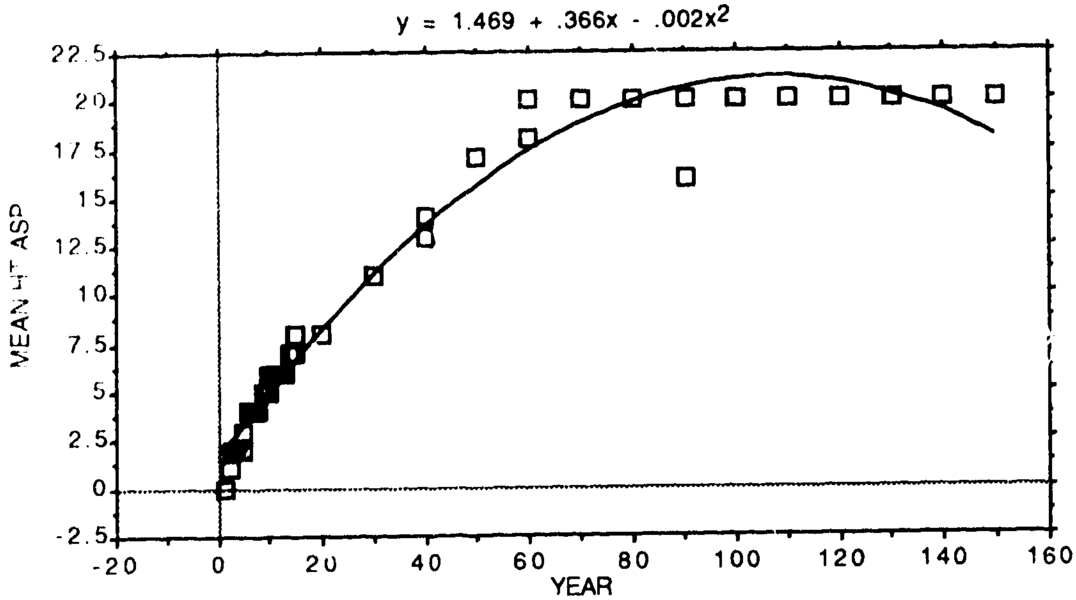
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	10426.866				
x	-192.392	45.482	-1.778	4.23	.0002
x^2	.891	.336	1.114	2.65	.0124

Predicted : Column 49

R2=.588 ADJR2=.562 F=22.839 P=.0001

ASPEN
MEAN HT



Polynomial Regression X_1: YEAR Y_2: MEAN HT ASP

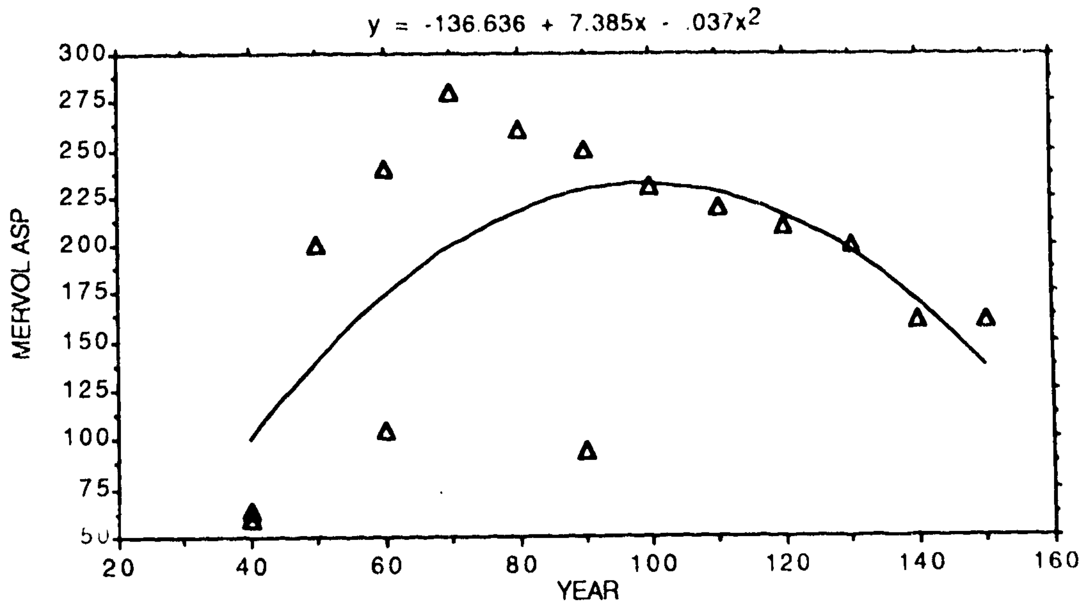
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	1.469				
x	.366	.018	2.298	20.48	.0001
x^2	-.002	1.323E-4	-1.448	12.9	.0001

Predicted : Column 50

R2=.971 ADJR2=.969 F=528.717 P=.0001

ASPEN
MERCH VOL



Polynomial Regression X_1: YEAR Y_3: MERVOL ASP

Beta Coefficient Table

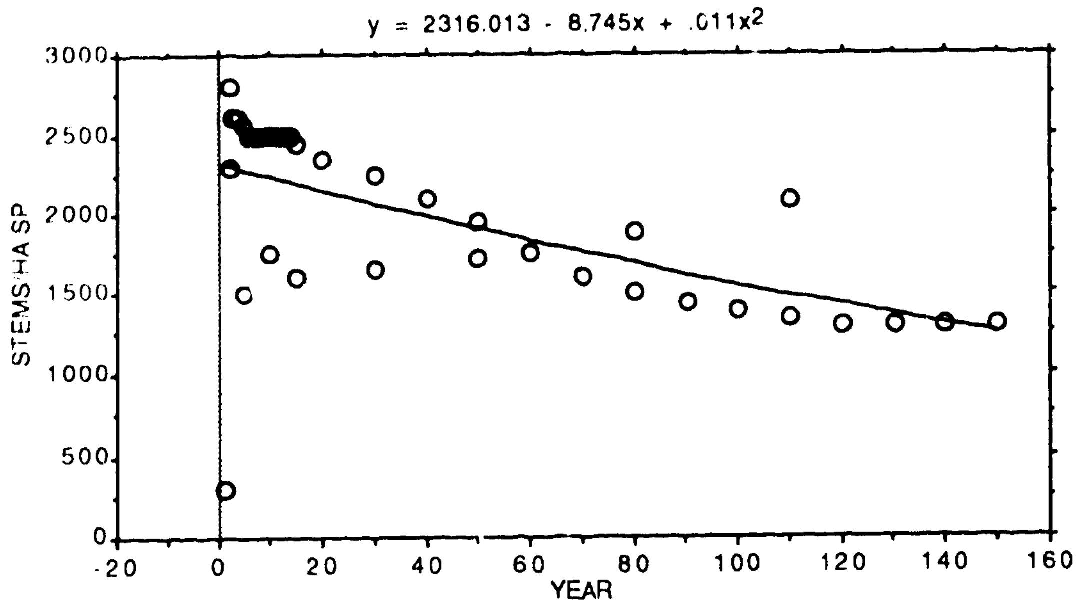
Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability
INTERCEPT	-136.636				
x	7.385	2.682	3.682	2.754	.0175
x^2	-.037	.014	-3.467	2.593	.0235

Predicted : Column 51

R2=.404 ADJR2=.304 F=4.06 P=.045

PRESCRIPTION PR 1 (INTEGRATED ACTIVITIES)

SPRUCE
STEMS/HA



Polynomial Regression X_1: YEAR Y_1: STEMS/HA SP

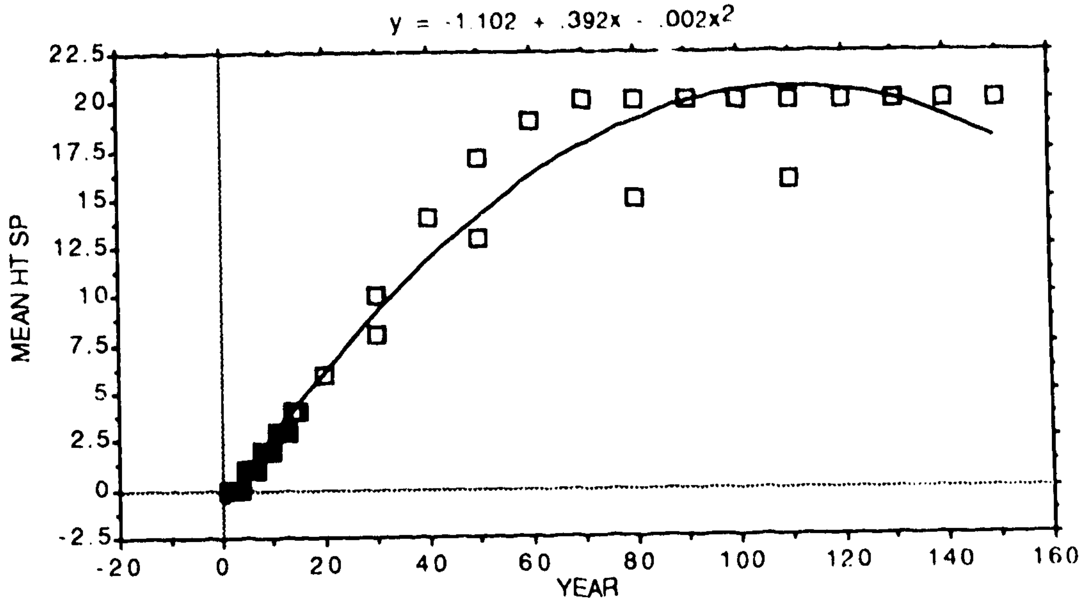
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	2316.013				
x	-8.745	6.32	-.717	1.384	.1755
x^2	.011	.047	.118	.228	.8207

Predicted : Column 8

R2=.364 ADJR2=.327 F=9.737 P=.0005

SPRUCE
MEAN HT



Polynomial Regression X_1: **YEAR** Y_2: **MEAN HT SP**

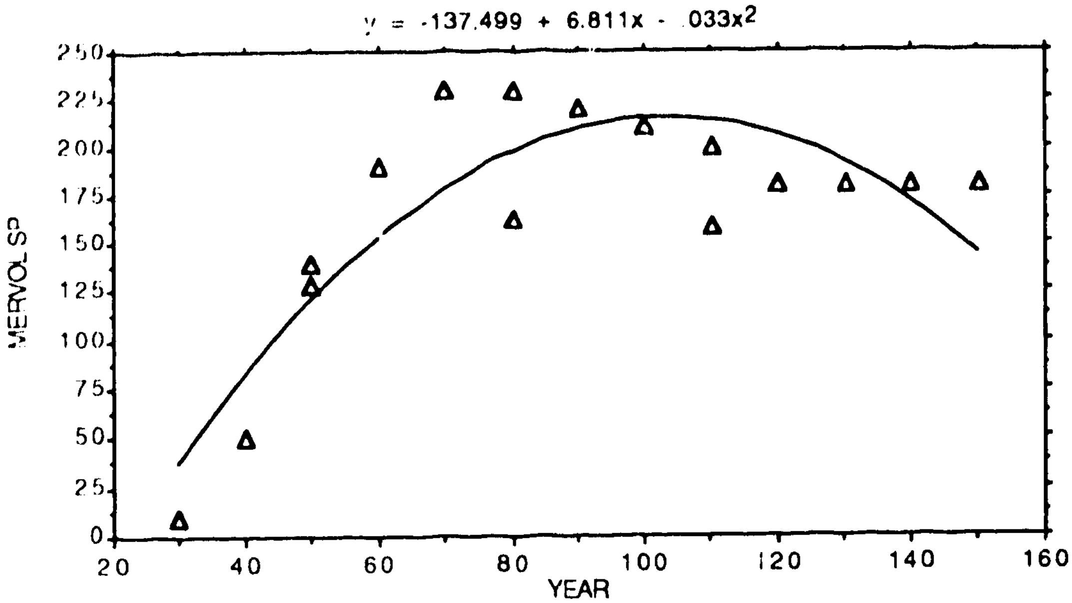
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	-1.102				
x	.392	.021	2.221	18.407	.0001
x^2	-.002	1.577E-4	-1.352	11.203	.0001

Predicted : Column 9

R2=.967 ADJR2=.965 F=481.017 P=.0001
This fntn peaks sooner than under nat regen.

SPRUCE
MERCH VOL



Polynomial Regression X1: YEAR Y3: MERVOL SP

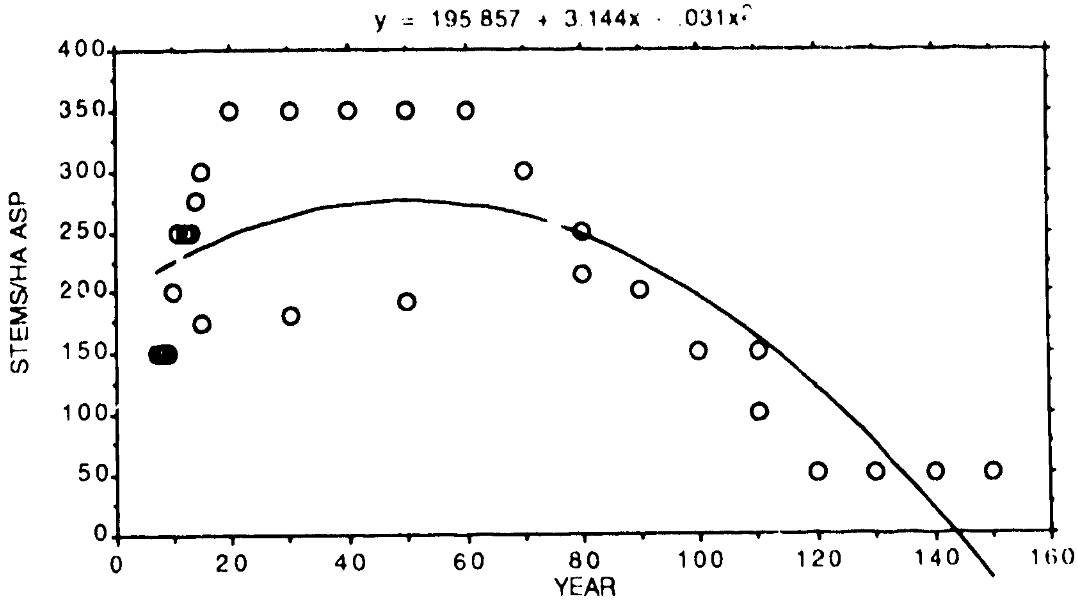
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	-137.499				
x	6.811	1.267	4.112	5.377	.0001
x^2	-.033	.007	-3.618	4.731	.0004

Predicted : Column 10

R2=.746 ADJR2=.707 F=19.067 P=.0001
Also this fntn peaks sooner than under nat regen

ASPEN
STEMS/HA



Polynomial Regression X_1: YEAR Y_1: STEMS/HA ASP

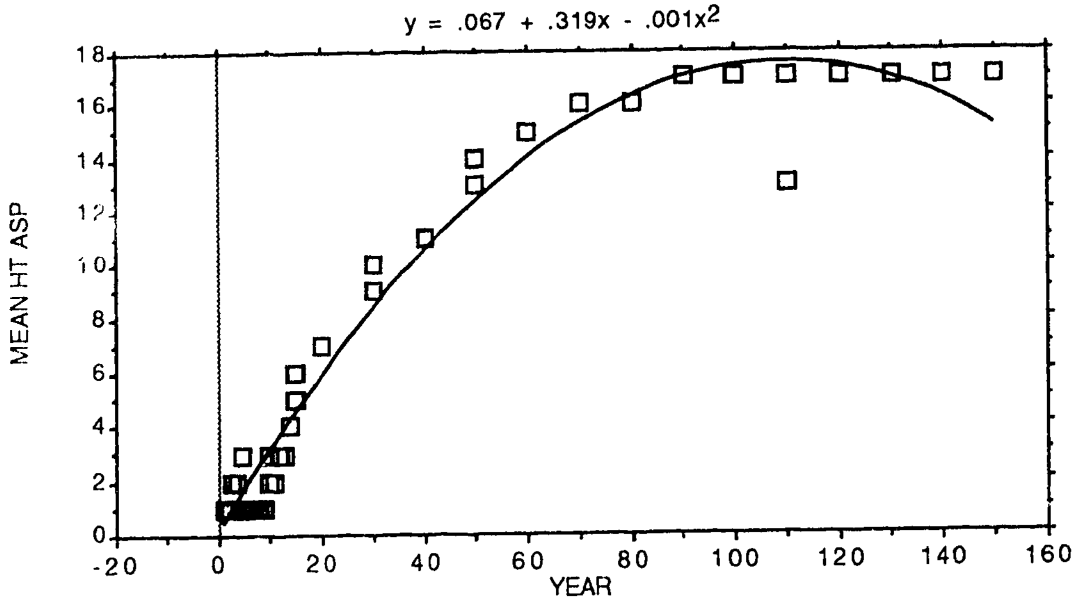
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	259.573				
x	.046	1.793	.017	.026	.9795
x^2	-.012	.012	-.648	.992	.3314

Predicted : Column 8

R2=.399 ADJR2=.347 F=7.645 P=.0028
This fntn used to dip into the neg quadrant until the first 8 years estimations were excluded.

ASPEN
MEAN HT



Polynomial Regression X_1: YEAR Y_2: MEAN HT ASP

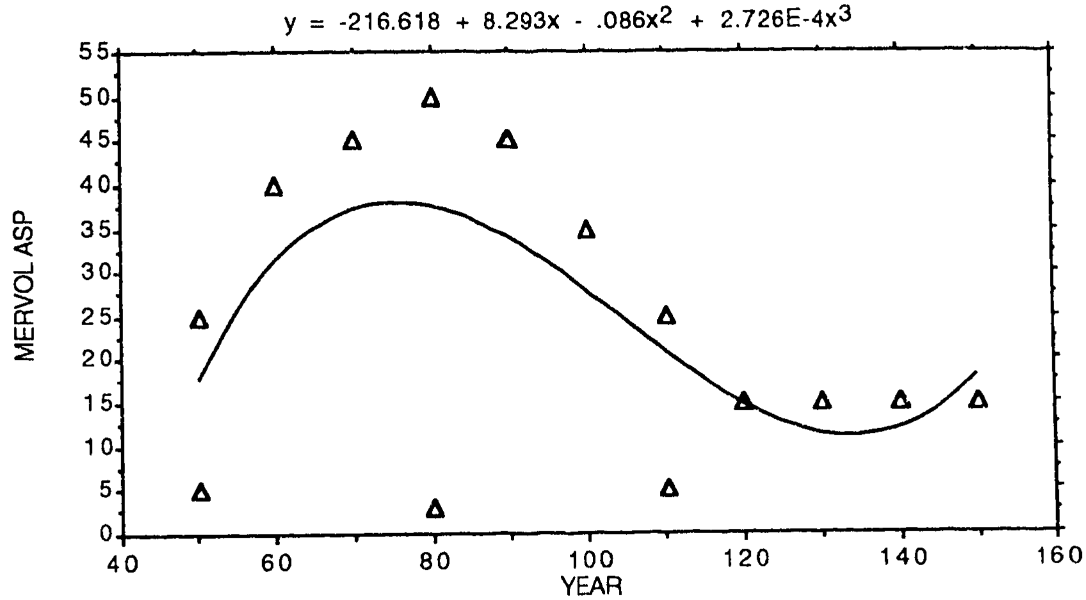
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	.067				
x	.319	.017	2.232	18.508	.0001
x^2	-.001	1.283E-4	-1.367	11.332	.0001

Predicted : Column 16

R2=.966 ADJR2=.964 F=476.256 P=.0001

ASPEN
MERCH VOL



Polynomial Regression X_1: YEAR Y_3: MERVOL ASP

Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	-216.618				
x	8.293	4.54	16.614	1.827	.0977
x^2	-.086	.048	-33.829	1.769	.1074
x^3	2.726E-4	1.633E-4	17.195	1.669	.126

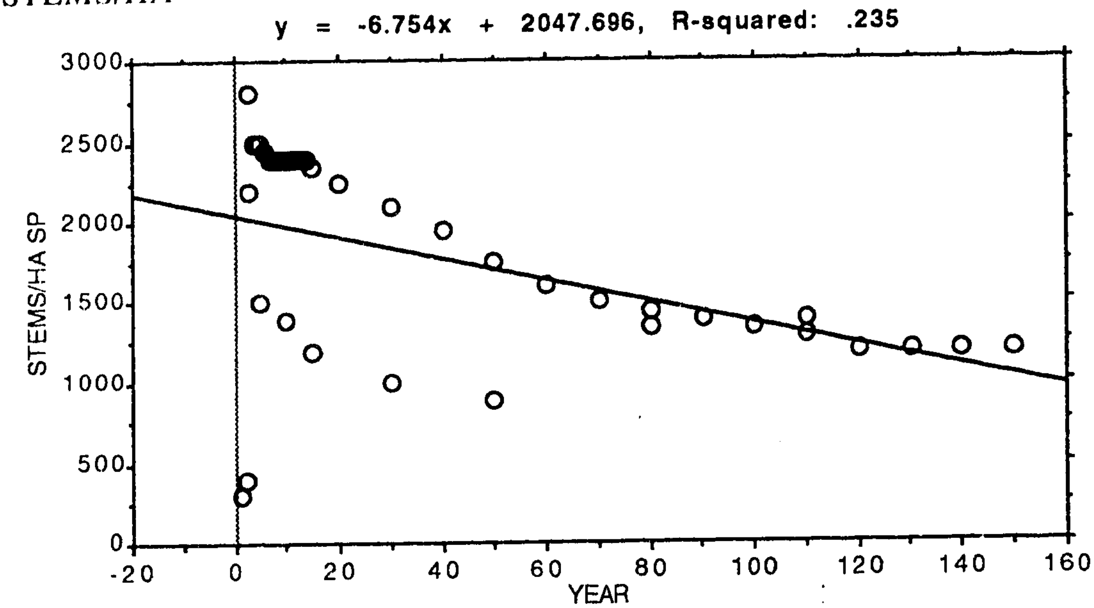
Predicted : Column 20

R2=.362 ADJR2=.171 F=1.895 P=.1944
The lower estimates are for hand tending at year 11; an unlikely response I think

PRESCRIPTION PR 2 (LAGGED ACTIVITIES)

SPRUCE

STEMS/HA



Simple Regression X_1: YEAR Y_1: STEMS/HA SP

Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	2047.696				
SLOPE	-6.754	2.06	-.485	3.279	.0024

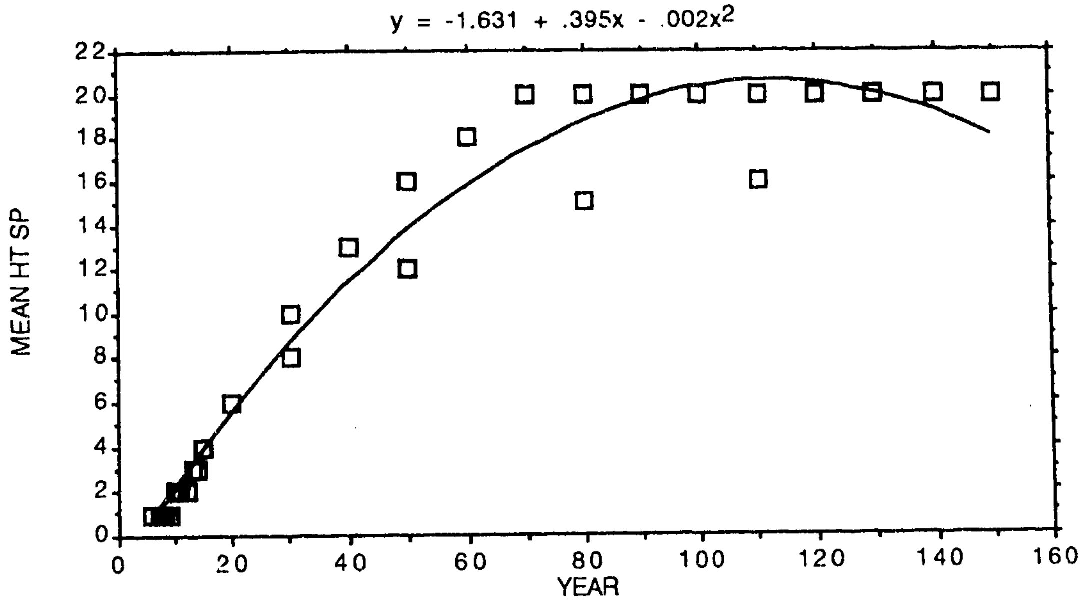
Confidence Intervals Table

Parameter:	95% Lower:	95% Upper:	90% Lower:	90% Upper:
MEAN (X,Y)	1562.348	1944.139	1594.37	1912.116
SLOPE	-10.937	-2.572	-10.235	-3.274

Predicted : Column 16

R2=.235 ADJR2=.213 F=10.751 P=.0024

SPRUCE
MEAN HT



Polynomial Regression X_1: YEAR Y_2: MEAN HT SP

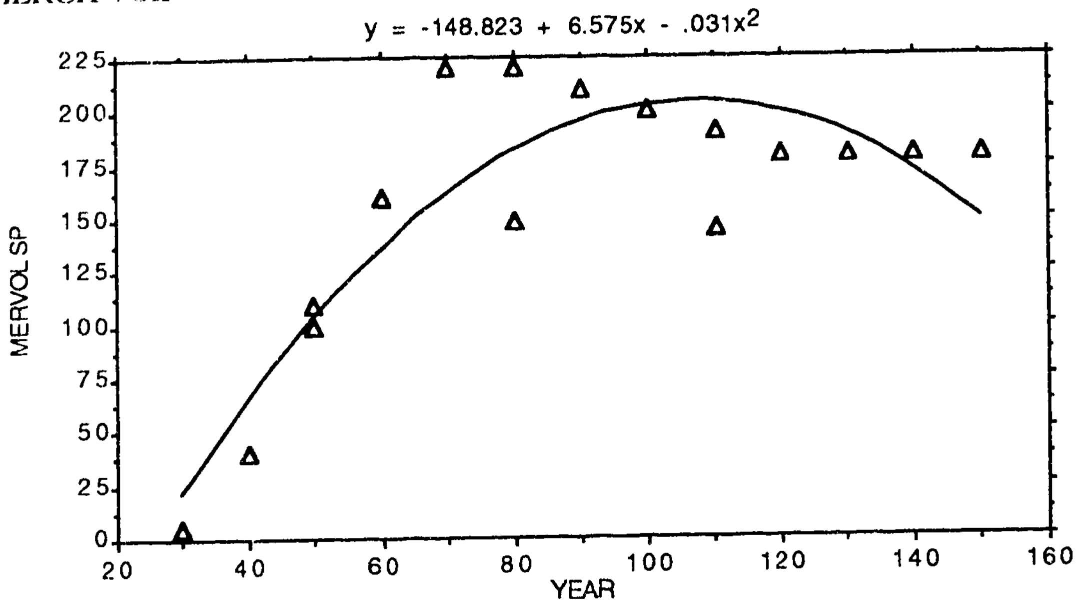
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	-1.631				
x	.395	.025	2.315	15.674	.0001
x^2	-.002	1.785E-4	-1.452	9.831	.0001

Predicted : Column 9

R2=.963 ADJR2=.96 F=346.565 P=.0001
This fntn is to replace a cubic fntn that had slightly better stats but was of a higher order than the ones previous and so its peak was not directly (or easily) comparable.
OLD STATS FOR CUBIC FNTN
R2=.972 ADJR2=.968 F=297.469 P=.0001
TX1=9.229(PR=.0001) TX2=4.648(PR=.0001) TX3=2.904(PR=.0074)

SPRUCE
MERCH VOL



Polynomial Regression X_1: YEAR Y_3: MERVOL SP

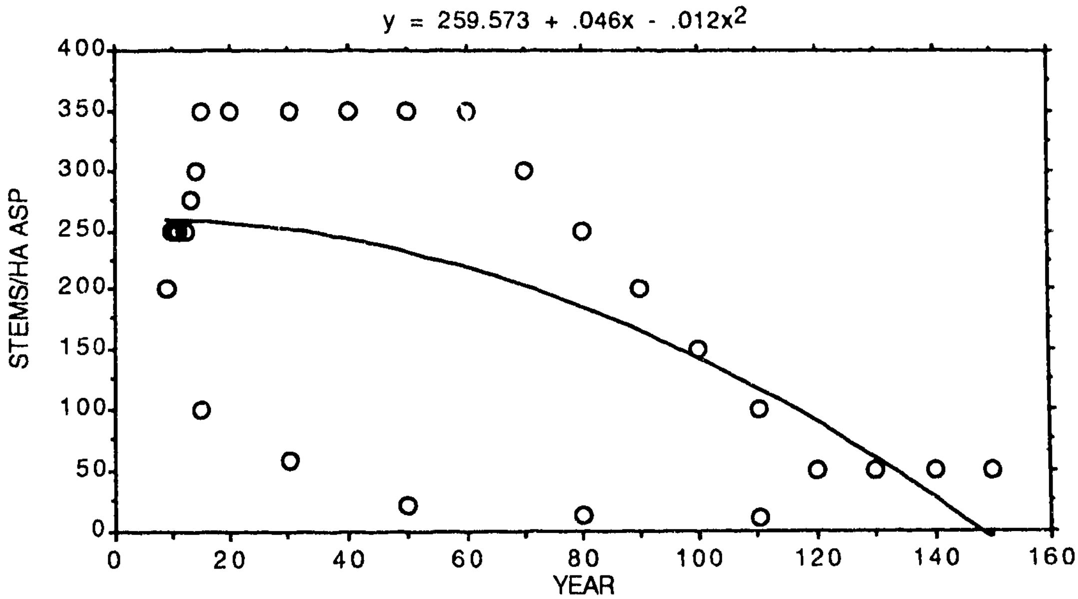
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	-148.823				
x	6.575	1.212	3.876	5.423	.0001
x^2	-.031	.007	-3.285	4.597	.0005

Predicted : Column 10

R2=.778 ADJR2=.774 F=22.775 P=.0001
This fntn is to replace a cubic fntn that had slightly better stats but was of a higher order than the ones previous and so its peak was not directly (or easily) comparable.
OLD STATS FOR CUBIC FNTN
R2=.871 ADJR2=.838 F=26.931 P=.0001
TX1=4.607(PR=.0006) TX2=3.604(PR=.0036) TX3=2.933(PR=.0125)

ASPEN
STEMS/HA



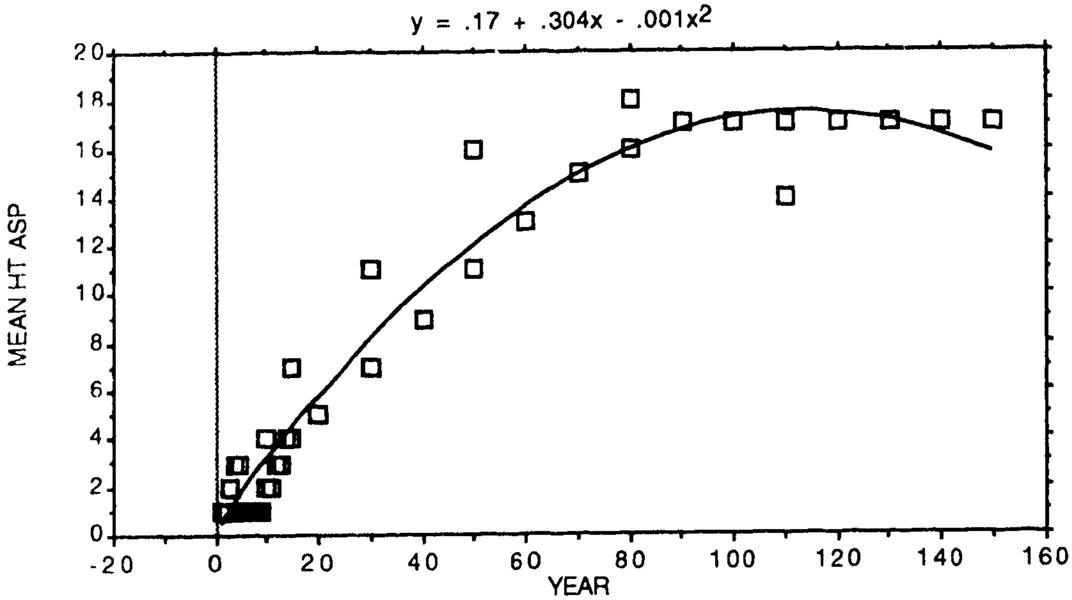
Polynomial Regression X_1: YEAR Y_1: STEMS/HA ASP

Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	195.857				
x	3.144	1.001	1.52	3.14	.0042
x^2	-.031	.007	-2.159	4.458	.0001

R2=.617 ADJR2=.588 F=20.943 P=.0001

ASPEN
MEAN HT



Polynomial Regression X_1: YEAR Y_2: MEAN HT ASP

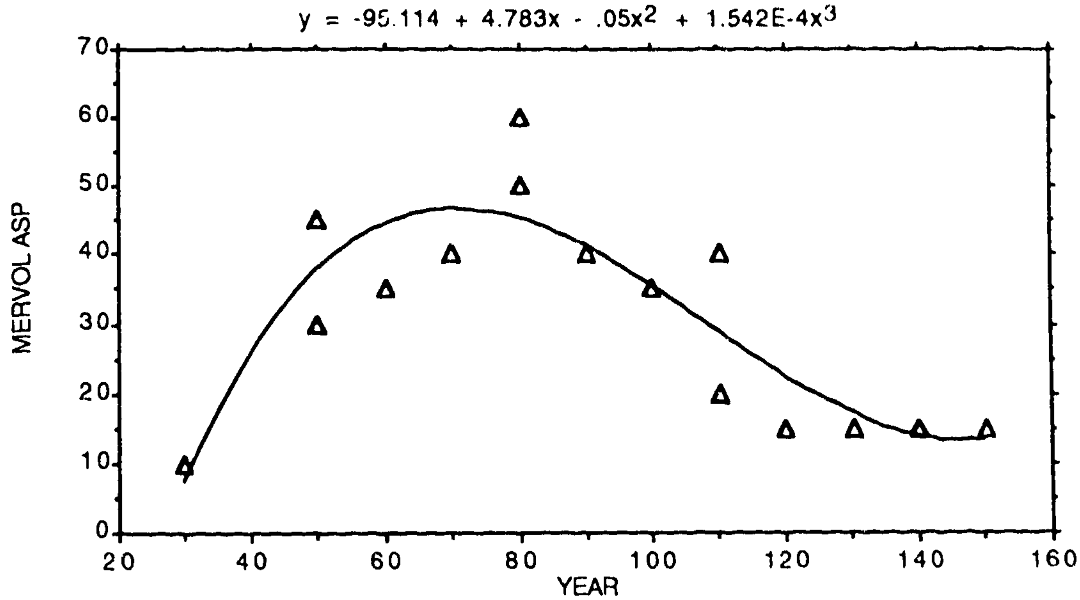
Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	.17				
x	.304	.02	2.133	15.091	.0001
x^2	-.001	1.502E-4	-1.26	8.912	.0001

Predicted : Column 27

R2=.953 ADJR2=.95 F=343.332 P=.0001

ASPEN
MERCH VOL



Polynomial Regression X_1: YEAR Y_3: MERVOL ASP

Beta Coefficient Table

Parameter:	Value:	Std. Err.:	Std. Value:	t-Value:	Probability:
INTERCEPT	-95.114				
x	4.783	1.245	11.168	3.841	.0027
x^2	-.05	.015	-21.761	3.4	.0059
x^3	1.542E-4	5.399E-5	10.397	2.856	.0156

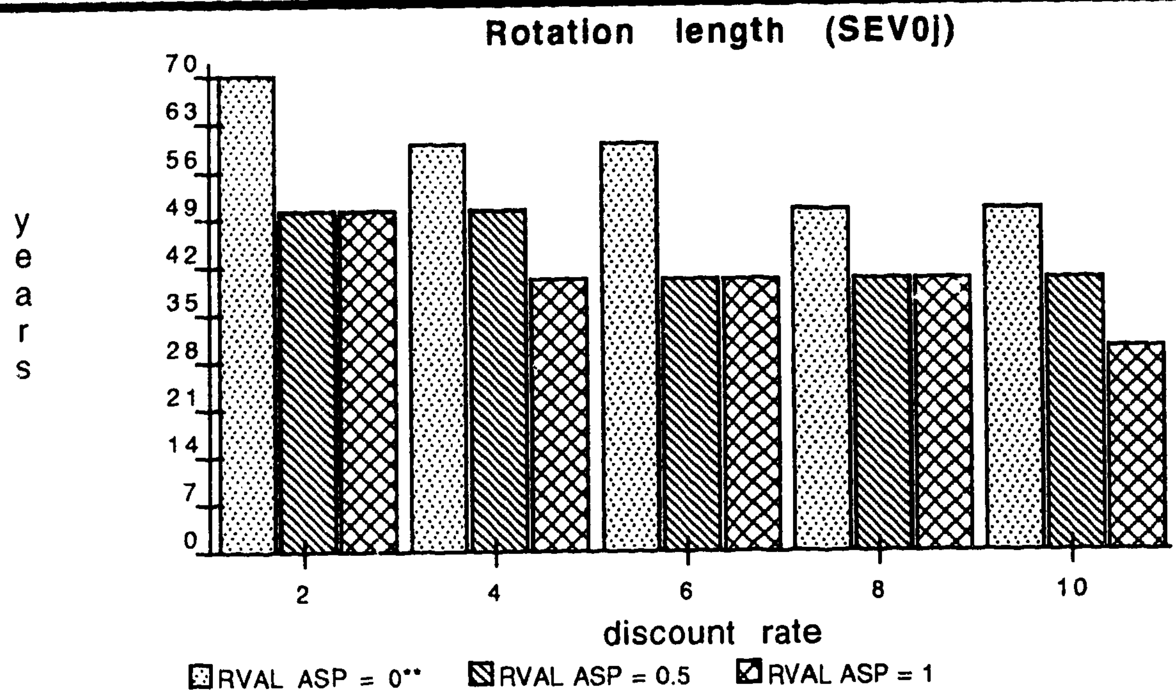
Predicted : Column 31

R2=.766 ADJR2=.702 F=11.996 P=.0009

APPENDIX 3

Under Prescription 0, the combined[1] optimum rotation lengths will vary according to the discount rate used and are as depicted in Figure 3-1.

FIGURE 3-1. Combined* optimum rotation lengths under var relative rental rates for aspen (given PR 0)



* Combined optimum economic rotations for spruce and aspen were determined by choosing the maximum combined SEV. At RVAL ASP = 0 the SEV and the OER is based only on the spruce.

** RVAL ASP indicates the relative rental value of aspen forest products as compared to spruce forest products.

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1 SEVs for spruce and aspen were combined and the maximized under three assumed relative (to that charged for spruce) rental rates for aspen. At a relative rental rate for aspen of 0(rental payment rate for spruce) the SEV and the OER length are determined by and apply only to spruce.