EVALUATING THE COST-EFFECTIVENESS OF PLANTING AND DIRECT SEEDING OF BLACK SPRUCE BY SIMULATION

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ABSTRACT

This paper describes an evaluation of the cost-effectiveness of direct seeding versus planting of black spruce, (*Picea mariana* [Mill.] B.S.P.), based on a recently developed simulation model that employs subjective probability estimates. Results of three examples based on estimates of current cost structure for both regeneration systems are presented and discussed. In the first example, estimates for stocking level and probability of success for both planting and seeding are approximated from historical data. The second and third examples are based on modified estimates for stocking level and probability of success, and also on higher stocking standards, the objective being to examine the effects of these factors on the relative economic merits of the two regeneration systems.

Results indicate that, based on the current cost structure and historical results, planting on the average will be cheaper than direct seeding in terms of future cost/unit of volume. However, if sites suitable for direct seeding can be readily identified, about half the cut-over areas might be seeded successfully, with considerable savings. In terms of present cost/acre, direct seeding will be cheaper than planting, i.e., if the objective is to regenerate as many cut-over areas as possible with a given annual regeneration budget, direct seeding should be chosen over planting.

Results also indicate that if higher stocking standards are established, or if the level of success from planting rises, planting will outperform seeding by a wide margin. However, a modest increase in either stocking level or probability of success from seeding would make seeding the more cost-effective technique. Recent studies and operational trials suggest that such gains may be within reach.

RÉSUMÉ

L'auteur compare la rentabilité de l'ensemencement direct et du plantage de l'Epinette noire (*Picea mariana* [Mill.] B.S.P.) en se fondant sur une simulation d'un type nouveau qui utilise les estimations subjectives de probabilité. Il présente et discute les résultats de trois méthodes fondées sur des estimations des coûts actuels des deux modes de régénération. Dans la première méthode, il estime les niveaux de densité et la probabilité de succès à partir de données historiques. Les deuxième et troisième méthodes sont basées sur des estimations modifiées des niveaux de densité et de probabilité de succès, et aussi sur des normes de densité plus élevées, afin de'étudier les effets de ces facteurs sur les mérites économiques comparatifs des deux modes de régénération.

Selon les résultats obtenus, et si on se fonde sur les coûts actuels et les résultats passés, le plantage sera en moyenne moins coûteux que l'ensemencement direct en termes de coût par unité de volume à venir. Cependant, si on peut identifier facilement les stations favorables à l'ensemencement direct, on pourrait ensemencer avec succès environ la moitié des aires coupées à blanc, ce en sauvant beaucoup d'argent. En termes des coûts actuels à l'acre, l'ensemencement direct coûtera moins que le plantage, i.e., si on voulait reboiser le plus possible d'aires coupées à blanc avec un montant d'argent fixé à l'avance, on devrait choisir l'ensemencement direct plutôt que le plantage.

Par ailleurs, selon les résultats obtenus, si on fixait des normes plus élevées de densité, ou si le niveau de succès obtenu par le plantage devenait plus élevé, le plantage sera beaucoup plus rentable que l'ensemencement. Cependant, une légère augmentation du niveau de densité obtenu par l'ensemencement ou de probabilité de succès de celui-ci, fera de l'ensemencement le mode le plus rentable. Selon des études et des essais récents sur le terrain, il semble que de tels gains seraient accessibles.

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Cover by J. M. Shoup

INTRODUCTION

Artificial regeneration is one of the first and most obvious silvicultural practices that mark the beginning of intensive forest management. Unfortunately, most comprehensive and serious efforts to reforest cut-over areas arise solely in response to current wood supply problems. This type of pressure usually focuses efforts on the immediate problem of regenerating cut-over areas. Much less attention is paid to the stands which develop from regeneration efforts, their needs for subsequent silvicultural treatment, and the total cost of the wood produced by the various regeneration practices.

Since black spruce (*Picea mariana* [Mill.] B.S.P.) is the most important pulpwood species in Ontario, and because harvesting is approaching the limit of the annual allowable cut, much emphasis has been placed on the regeneration of black spruce cutovers. Natural regeneration of black spruce on large clearcuts that have been recently harvested mechanically is generally inadequate, particularly on upland sites.[1] Planting bare-root or container stock has met with only moderate success (Anon. 1974) and has become increasingly expensive. Except in a few instances operational direct seeding of black spruce has been a failure (Scott 1966, Waldron 1974). Some of the possible reasons for failure of black spruce seeding operations have been identified as: a) inadequate quantity or poor quality of seed b) wrong season of application c) adverse climatic factors d) inadequate site preparation e) loss of seed to rodents and f) competition from minor vegetation. However, research into black spruce seeding operations is under way, and recent studies and operational trials have shown much more promising results (Fraser 1975, Frisque 1975 and Winston 1975).

While research continues, it is of prime importance to evaluate the relative economic desirability of various methods and search for a regeneration system which is optimal both silviculturally and economically. This is not an easy task because it demands that the silvicultural requirements and economic conditions at stand establishment be related to the projected future demand for various species and forest products. However, it is the only way that forest managers can develop an overall management strategy to utilize regeneration funds as efficiently as possible. As a first step, all feasible regeneration systems must be compared in terms of their costs and the kind of stands they can be expected to produce.

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1 Fraser, J. W., V. F. Haavisto, J. K. Jeglum, T. S. Dai and D. M. Smith. 1975. Black spruce regeneration on strip cuts and clear cuts in the Nipigon and Cochrane areas of Ontario. Can. For. Serv., Sault Ste. Marie, Ont. (unpubl. rep.)

Take, for example, planting and direct seeding as two regeneration systems to be compared. Planting has a higher probability of success and a shorter regeneration period than seeding, but it costs several times as much. Plantations usually produce higher volumes per acre and are less likely to require thinning. Therefore, a valid comparison must take into account all these differences. That is, it should resolve the problem of how well the higher probability of success, shorter rotation, higher yield and reduced requirement for thinning can compensate for the higher cost of planting. Conversely, it should indicate whether the longer regeneration period, lower probability of success, lower yield and greater need for thinning offset lower cost of seeding. Neither the cost nor the probability of success determines the best regeneration technique; all factors should be considered together to determine cost-effectiveness. The objective of this paper is to present the results of a study comparing the cost-effectiveness of seeding versus planting of black spruce, using a recently developed simulation model (Payandeh and Tucker 1975).

ECONOMIC COMPARISON OF REGENERATION TECHNIQUES

There are several major problems involved in the economic comparison of any two regeneration systems:

a) how to estimate the probability of success and stocking level for each regeneration method

b) how to project future costs and prices based on limited past cost and price data

c) how to resolve the problem of different regeneration periods[2] and rotation lengths and their influence upon the choice of techniques

d) how to relate the initial stocking level at stand establishment to final stocking at rotation age

e) how to account for possible difference in future volume and value of wood produced via each regeneration method.

A possible solution to the above problems was described in detail recently (Payandeh and Tucker 1975), and is briefly outlined as follows.

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[2] Considered here as the length of time between initial treatment and final successful stand establishment on a site.

Since data on the probability of success and the expected stocking level for various regeneration techniques are inadequate, they may be estimated by subjective probability estimates employing the Weibull probability density function (Weibull 1951, Bailey and Dell 1973, Payandeh and Tucker 1975). For example, to estimate the stocking level produced by a particular regeneration technique, the following five input estimates are required:[3]

1) a low estimate for stocking level (e.g., 20%)

2) a high estimate for stocking level (e.g., 90%)

3) a probability estimate that stocking level might be less than the low estimate (e.g., 10%)

4) a probability estimate that stocking level might be less than the high estimate (e.g., 95%)

5) the absolute minimum stocking level that might be achieved (e.g., 5%).

From the above estimates, a Weibull distribution is constructed which closely approximates the forest manager's judgment regarding the expected stocking level for the regeneration method under consideration. Once the Weibull distribution is constructed the stocking level can be generated for each trial of that regeneration method (Payandeh and Tucker 1975).

The various regeneration costs, such as cost of scarification for seeding or planting, cost of seeding or planting, and cost of thinning for both seeding and planting are also estimated based on subjective probability estimates (similar to stocking level estimates) provided by the forest manager. Application of subjective probability estimates has the following unique advantages:

1) Since the input estimates, i.e., probability of success, stocking level and various cost estimates for each regeneration technique, are based on limited data and subject to error, and because the economic comparison requires a projection into the future, the use of subjective estimates and probability distributions provides a basis for comparison and decision making under uncertainty.

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[3] These can be provided by any experienced forest manager. They need not be accurate estimates, but the validity of the results produced by the model will be enhanced by realistic estimates.

2) The use of subjective estimates provided by the forest manager in effect capitalizes on his total experience regarding the various aspects of the regeneration techniques, and when properly analyzed enables him to make valid economic comparisons.

3) The forest manager's subjective estimates need not be exact nor based entirely on actual data. *However, they should be as free from bias as possible.*

The problem of different regeneration periods and their influence on the choice of regeneration techniques can be resolved by discounting or compounding all costs and returns to a common point in time and then comparing the present (discounted) or future (compounded) costs and returns by one of the several economic criteria. The cost-effectiveness criterion used here consists of calculating future cost/unit of output at the end of the rotation to determine which regeneration technique results in the lowest cost wood (Chapman and Meyer 1947, Lundgren 1966, 1973).[4] This criterion does not require projection of future prices and in effect provides an estimate of the price that wood must attract at rotation age to justify the investment, i.e., cost-price (Lundgren 1973).

Relating initial to final stocking levels for various regeneration techniques is very difficult owing to the lack of information in this area. It is desirable to plant enough trees or sow enough seed to produce nearly fully stocked stands at rotation age. Such a stocking level varies for different regeneration techniques and different species, depending on site quality. In the case of black spruce, for example, planting of 1000 to 1500 3-year-old seedlings per acre (2470-3705 per ha) is considered adequate, or if seeding results in 60 percent stocking, it is considered successful. These generally accepted standards are to some extent based on the assumption that stands which are initially understocked or overstocked will approach normal stocking by rotation age.

Because of the above loose standards and lack of data on the relationship between initial and final stocking the following exponential growth model was used to represent such a relationship.

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[4] An assumption implicit in the cost-effectiveness criterion is that various alternatives will produce output of similar quality for the same price; otherwise, future cost/unit of output should be weighted to account for product quality differences.

$$y = b_1 + b_2 \left(1 - e^{-b_3 x} \right)^{b_4} + \varepsilon$$

where: y = stocking expressed as percent of normal stocking at rotation age

x = percent stocking at stand establishment

b's = parameters of the model

ε = a stochastic element to account for deviations from trial to trial due to variation in natural regeneration and random variation.

Figure 1 (solid line curve) shows the above relationship where the parameters (b_1 = 13.5, b_2 = 90.5, b_3 = .05885, and b_4 = 10.12) were estimated such that this relationship possesses certain "reasonable" characteristics (Payandeh and Tucker 1975). The broken line curves in Figure 1 demonstrate the effect of ε or the stochastic deviation band imposed on the above relationship to account for deviations in the general trend from one operation to another that are due to variation in natural regeneration and random variation. In the case of black spruce seeding and planting, the maximum deviation of final stocking from the above general trend was set at about ±20% and ±10%, respectively, when the initial stocking was classified as either success or failure. However, when initial stocking falls in the "gray area"[5], the estimated final stocking according to the above relationship is further modified by a stochastic multiplier expressed as a function of the initial stocking x. This is to reflect the additional uncertainty regarding the final stocking of such stands. Figure 2, for example, demonstrates the range of possible final stocking levels estimated for two cases where initial stocking falls within the gray area (ibid.).

Equations expressing merchantable volume from normal yield tables (Plonski 1960, Kabzems 1971, Payandeh 1973) as a function of site index and stand age were used to provide a guide curve for the volume of fully stocked seeded stands at rotation age. To allow for deviations from trial to trial a normally distributed error term with a maximum of ±15% was added to the volume equation. The volume of an understocked or overstocked stand was then adjusted by the percent of final stocking. Owing to lack of data on plantation volume for black spruce, it was approximated as above, but then was adjusted upwards by using

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[5] When stocking level falls between the failure and success levels as defined in the stocking standards (see Payandeh and Tucker 1975 for further explanation).

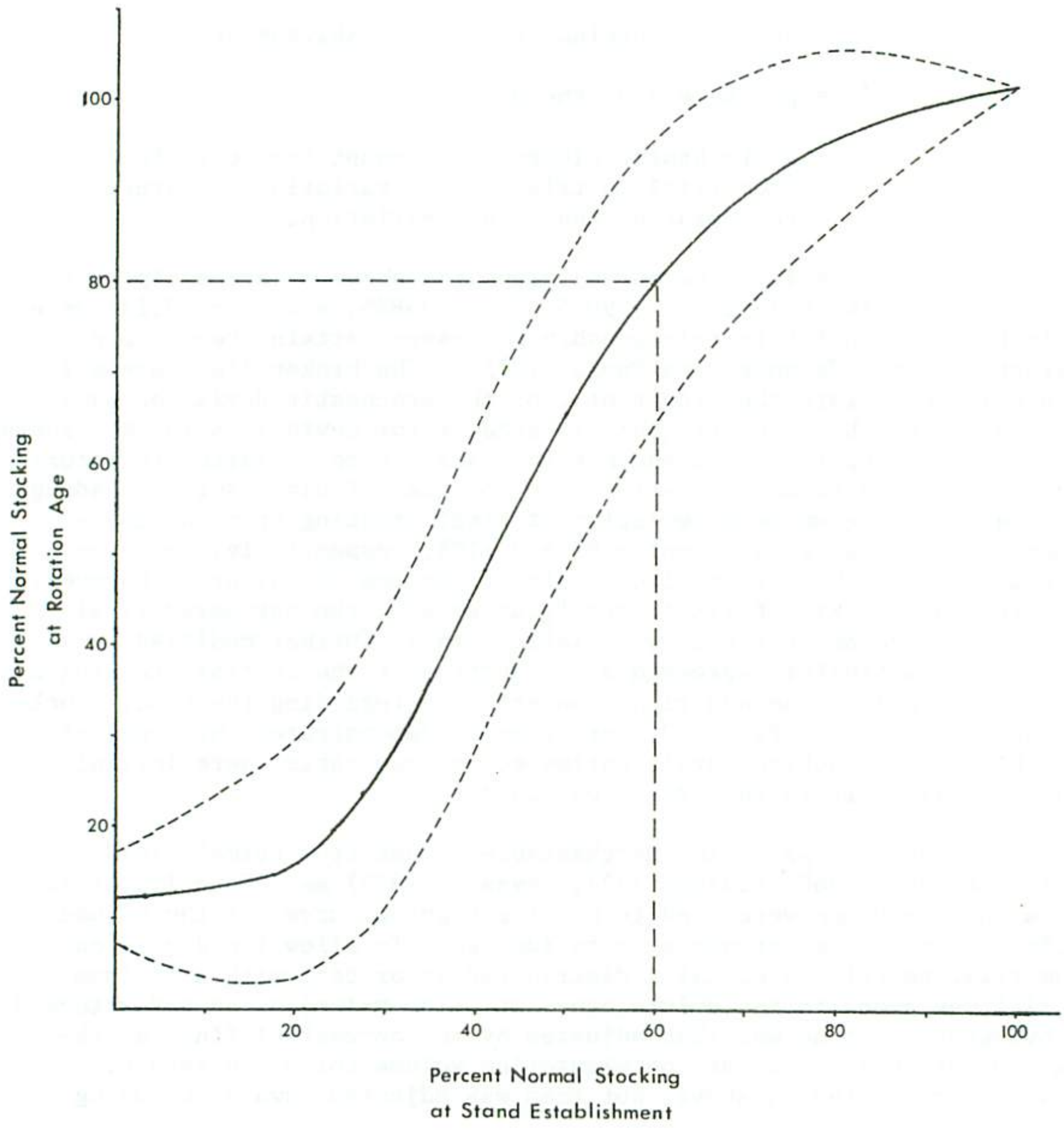

Figure 1. Assumed relationship between initial and final stocking and its projected deviation band due to natural regeneration and random variation.

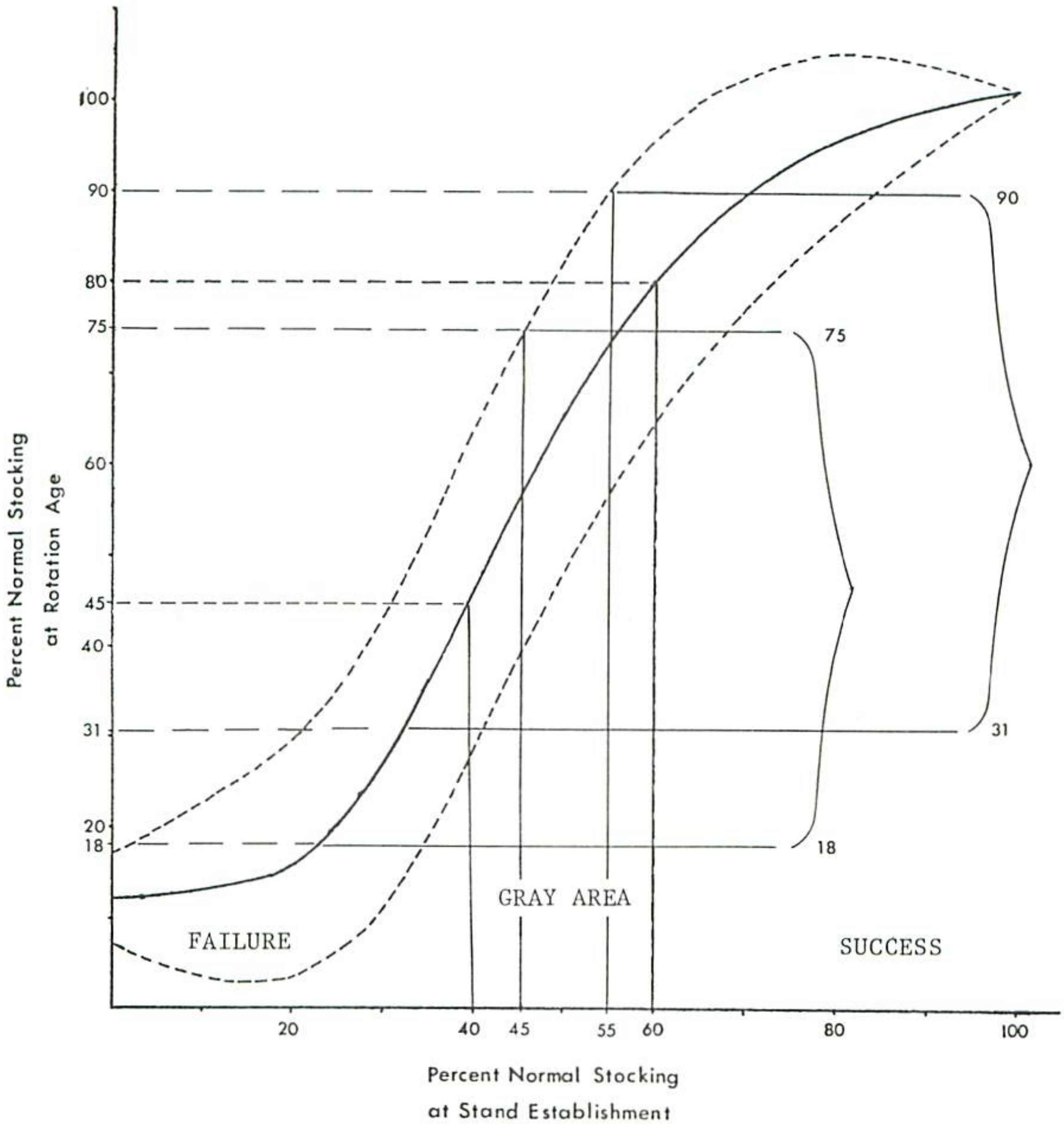

Figure 2. Examples demonstrating stochastic generation of final stocking when initial stocking falls within the "gray area".

a multiplier, the ratio of plantation volume over natural stand volume of white spruce (*Picea glauca* [Moench] Voss) (Kabzems 1971, Stiell and Berry 1973, Payandeh and Tucker 1975).

BRIEF DESCRIPTION OF THE MODEL

The model "REGEN" was developed to aid forest managers in making rational economic decisions regarding the various regeneration systems. It may be used to compare the cost-effectiveness of seeding versus planting (or any other regeneration techniques) for several species, rotation lengths, and interest rates. The model employs subjective probability estimates provided by forest managers to generate appropriate distributions via the Weibull function. Each distribution so generated will represent the frequency distribution of a given cost or stocking level specified by the forest manager. Figure 3, for example, shows frequency distributions generated for cost of planting (including stock) and cost of scarification/acre. Input estimates for the first frequency distribution (cost of planting/acre) are: a) low estimate = \$25 b) high estimate = \$65 c) the probability that cost of planting might be less than the low estimate = 5% d) the probability that cost of planting might be lower than the high estimate = 90%, and e) the minimum estimate for cost of planting = \$20/acre. The second frequency distribution (cost of scarification/acre) is based on: a) low estimate = \$10 b) high estimate = \$30 c) the probability that cost of scarification might be less than the low estimate = 8% d) the probability that cost of scarification might be lower than the high estimate = 96% and e) the minimum cost of scarification = \$7/acre.

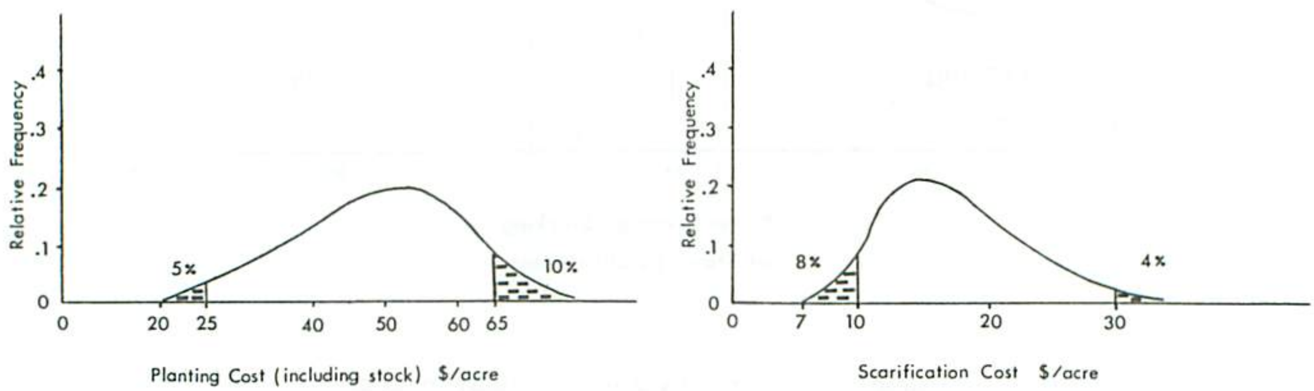

Figure 3. Examples of subjective probability distributions generated by the Weibull function for cost of planting and cost of scarification/acre.

A simplified flowchart of the model is shown in Figure 4 and the format and description of the input variables are given in Appendix A. As Figure 4 indicates, the model is constructed to simulate the two operations of planting and seeding in a parallel manner. An area characterized by the input variables is first planted and then seeded enough times to produce a desired number of successful regeneration treatments, e. g., 300. Every stand resulting from a successful regeneration[6] is then grown to a desired rotation age while all the costs incurred for stand production (including the cost of unsuccessful treatments) are properly compounded and accumulated. Finally, a frequency distribution of future cost/cunit of wood for each regeneration technique and for the desired number of "successes" is constructed, and from this, future wood cost/cunit for a desired probability interval is obtained. Since planting and seeding operations are simulated in a parallel manner to produce equal numbers of "successes" and because the future cost is calculated per unit of volume, the results of the two operations are directly comparable. All differences in costs, probabilities of success and stocking levels, regeneration periods, rotation ages, volumes, thinning requirements, etc., are accounted for.

RESULTS AND DISCUSSION

Several trial runs were conducted with the simulator "REGEN" to evaluate the cost-effectiveness of planting versus direct seeding black spruce. The results of three such trials are presented and discussed here. The input variables for the first example are given in Appendix A. These were based on limited data available in the literature, and estimates provided by forest managers from the Ontario Ministry of Natural Resources and other professional foresters. The cost estimates for planting (including stock), seeding (including seed cost), scarification and thinning for both regeneration systems are assumed to be reasonably well within the range of the present cost structure. The estimates for probability of success and stocking level for direct seeding of black spruce are closely approximated from historical data given by Waldron (1974). The estimates for stocking level and success for planting are based in part on two published reports (Stiell 1958, Anon. 1974).

The results of the first example are given in Table 1. The second and third examples are based on modified input estimates of the first example and their results are given in Tables B1 and B2 in Appendix B. The first page of each table summarizes the input variables, the top portion giving the subjective estimates for cost of planting, cost

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[6] Hereafter referred to as a "success".

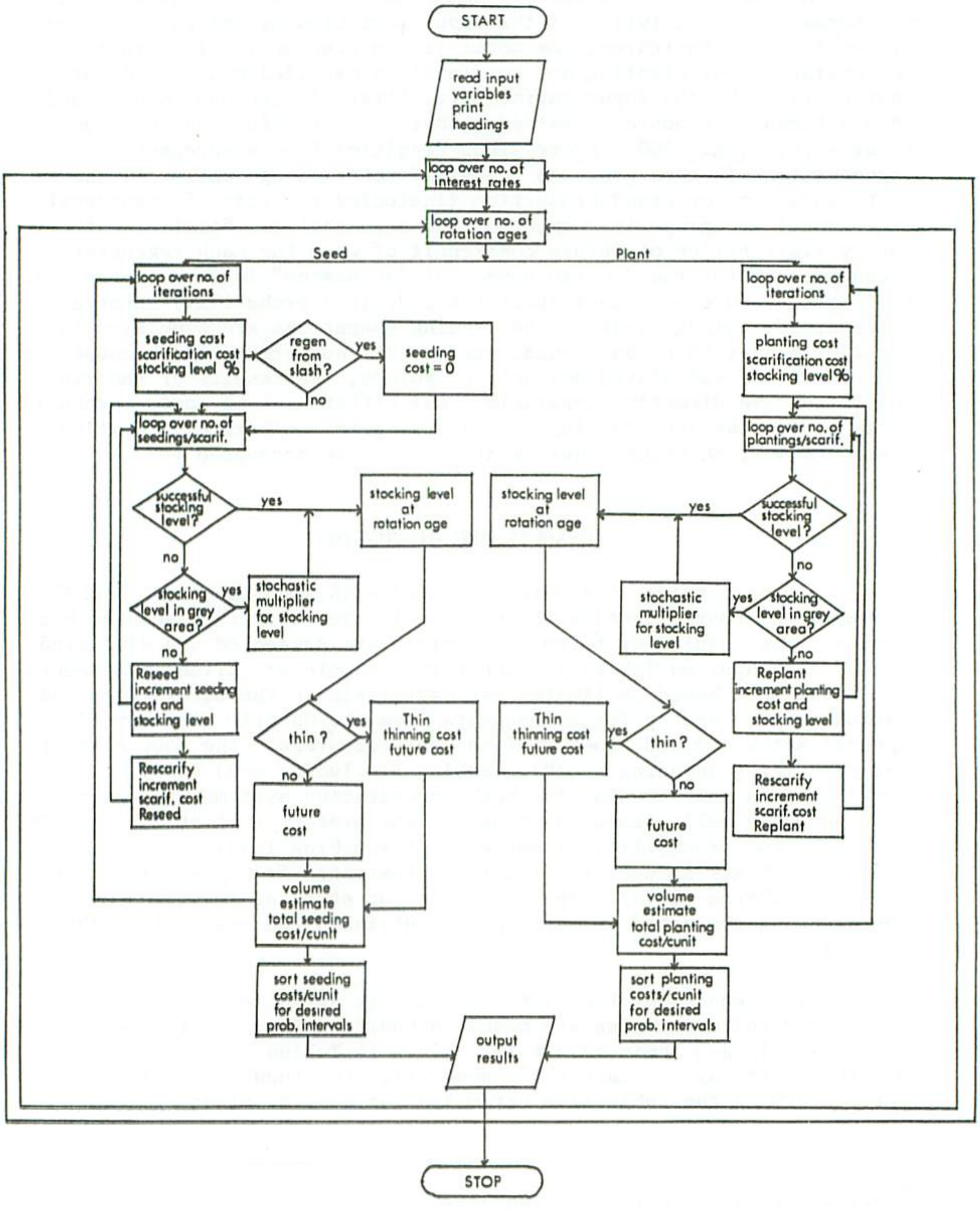

Figure 4. A simplified flowchart of the model "REGEN".

of scarification for planting, cost of thinning plantations, stocking level and success for planting, cost of seeding, cost of scarification for seeding, cost of thinning seeded stands, and stocking level and success for seeding operations. For the first example, subjective estimates for cost of planting/acre were: a) low estimate = $40 b) high estimate = $75 c) the probability that cost of planting might be lower than the low estimate = .05 d) the probability that cost of planting might be lower than the high estimate = 0.9 and e) the minimum of planting = $30. Similarly, the five subjective estimates for cost of seeding/acre were: $8, $15, .2, .9 and $5. The estimates of stocking success for planting were: a) low estimate = 20% b) high estimate = 85% c) the probability that stocking might be lower than the low estimate = 10% d) the probability that stocking level might be lower than the high estimate = 90% and e) the minimum stocking = 15%. The estimates for stocking level and success for seeding were: a) low estimate = 10% b) high estimate = 75% c) the probability that stocking level might be lower than the low estimate = 25% d) the probability that stocking level might be lower than the high estimate = 95% and e) the minimum stocking level = 2%.

The lower portion of page 1 of Table 1 gives other input variables briefly described here. These include the stocking level for success = .5 or 50% and the stocking level for failure = .4 or 40% used both for seeding and planting. The number of iterations is set to 300, i.e., the simulation will continue until 300 successful seeding and planting operations are obtained. Species code 1 is for black spruce and both seeding and planting are simulated on areas with similar site quality designated by site index 36. Numbers of possible plantings and seedings per scarifications are given as 3 and 2, respectively. This means an area might be partially replanted twice after the initial planting, if necessary, before the site becomes unacceptable for additional planting owing to brush competition. On the other hand, an area might be reseeded only once, if necessary, without rescarifying it. The maximum number of scarifications for planting and seeding is given as 3 and 2, respectively; i.e., an area might be partially and/or fully replanted with two additional rescarifications, if necessary, to produce a satisfactory regeneration before the area is abandoned as a complete failure. On the other hand, an area might be rescarified only once, if necessary, to obtain a satisfactory seeding, before the area is abandoned as a complete failure. The time of regeneration survey is set for one year after planting and 3 years after seeding operations. Probabilities of precommercial thinning of overstocked plantations and seeded stands are given as 10% and 25%, respectively. The stand age for thinning plantations is set between 15 and 25 years while for seeded stands it is between 15 and 35 years. For seeding operations, the probability that the site might regenerate naturally is given as 10%. The beginning, end and intervals for rotation ages and interest rates are given as 70, 100, 15 years and 8%, 10% and

Table 1. Input estimates and results of simulator "REGEN" for comparing the cost-effectiveness of seeding versus planting of black spruce for rotation ages of 70, 85 and 100 years and interest rates of 8 and 10%

Input Variables for This Run Are:

	Planting				Seeding			
	Cost ($/acre)[a]			Stocking success	Cost ($/acre)[a]			Stocking success
Subjective estimates	Plant.	Scar.	Thin.		Seed.	Scar.	Thin.	
Low	40.00	20.00	15.00	0.20	8.00	25.00	15.00	0.10
High	75.00	30.00	25.00	0.85	15.00	35.00	35.00	0.75
Prob. value lower than low	0.05	0.10	0.10	0.10	0.20	0.10	0.10	0.25
Prob. value lower than high	0.90	0.85	0.85	0.90	0.95	0.90	0.95	0.95
Absolute minimum	30.00	15.00	10.00	0.15	5.00	15.00	8.00	0.02

Other Input Variables

Stocking level for success	0.50	Low thinning age for plantation	15.00
Stocking level for failure	0.40	High thinning age for plantation	25.00
No. of iterations	300	Low thinning age for seeded stands	15.00
Species code	1	High thinning age for seeded stands	35.00
Site index for planting area	36.00	Prob. site may regenerate from slash	0.10
Site index for seeding area	36.00	Starting rotation age	70
No. possible plantings/scarification	3	End rotation age	100
No. possible seedings/scarification	2	Rotation age interval	15
Max. no. of scar. for planting	3	Low interest rate %	8
Max. no. of scar. for seeding	2	High interest rate %	10
Regen survey for planting-years	1	Interest rate interval %	2
Regen survey for seeding-years	3	Inflation rate	0.06
Prob. planted stand may be thinned	0.10	Probability interval for output	10.00
Prob. seeded stand may be thinned	0.25	Any integer no. 9 digits or less	987653

(continued)

Table 1 (continued - page 2)

	Rotation age = 70 years		Interest rate - 8%
Probability of exceeding:	Future cost ($/cunit)[b] planting	seeding	Cost of planting-seeding
0.0	75.86	371.37	-295.51
0.100	40.57	70.70	-30.13
0.200	30.57	42.90	-12.32
0.300	25.85	31.34	-5.49
0.400	22.64	22.61	0.03
0.500	20.49	19.46	1.03
0.600	18.58	16.35	2.23
0.700	17.04	12.19	4.84
0.800	15.13	10.08	5.05
0.900	13.29	8.59	4.71
1.000	8.28	5.40	2.88

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	19.16	14.54
Expected cost $/acre	81.53	35.39
Expected cost of scarification $/acre	24.59	60.25
Total cost (regen, scarification, thinning) $/acre	106.85	96.79
Average stocking %	0.62	0.62
Avg no. of complete and/or partial regen treatments	1.59	4.11
No. of scarifications	1.00	2.09
No. of times stocking in gray area	0.28	0.42
No. of thinnings	0.05	0.08
No. of times regenerated from slash	0.0	0.02
No. of abandoned areas due to regen failures	0.0	0.34
Expected future cost $/cunit	21.01	26.62

(continued)

Table 1 (continued - page 3)

Probability of exceeding:	Rotation age = 85 years Future cost ($/cunit) planting	seeding	Interest rate = 8% Cost of planting-seeding
0.0	129.66	283.62	-153.96
0.100	45.53	80.67	-35.14
0.200	33.11	43.56	-10.45
0.300	25.87	31.83	-5.95
0.400	23.84	24.96	-1.12
0.500	22.13	20.37	1.76
0.600	20.09	15.97	4.11
0.700	17.32	12.62	4.70
0.800	14.69	10.82	3.87
0.900	12.19	9.10	3.09
1.000	9.89	5.11	4.79

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	25.18	19.49
Expected cost $/acre	82.35	37.14
Expected cost of scarification $/acre	24.36	63.76
Total cost (regen, scarification, thinning) $/acre	107.31	102.10
Average stocking %	0.63	0.62
Avg no. of complete and/or partial regen treatments	1.62	4.34
No. of scarifications	1.00	2.21
No. of times stocking in gray area	0.29	0.35
No. of thinnings	0.05	0.09
No. of times regenerated from slash	0.0	0.01
No. of abandoned areas due to regen failures	0.0	0.38
Expected future cost $/cunit	21.61	28.20

(continued)

Table 1 (continued - page 4)

Probability of exceeding:	Rotation age = 100 years Future cost ($/cunit) planting	 seeding	Interest rate = 8% Cost of planting-seeding
0.0	124.12	203.09	-78.97
0.100	41.71	76.77	-35.06
0.200	32.70	53.42	-20.72
0.300	27.75	34.40	-6.64
0.400	24.93	27.13	-2.20
0.500	22.56	22.62	-0.05
0.600	20.96	18.05	2.91
0.700	19.00	14.73	4.27
0.800	16.37	12.20	4.17
0.900	14.37	9.85	4.52
1.000	10.27	6.48	3.79

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	31.23	22.59
Expected cost $/acre	80.85	32.87
Expected cost of scarification $/acre	24.32	56.65
Total cost (regen, scarification, thinning) $/acre	105.71	90.53
Average stocking %	0.64	0.60
Avg no. of complete and/or partial regen treatments	1.60	3.83
No. of scarifications	1.00	1.97
No. of times stocking in gray area	0.26	0.37
No. of thinnings	0.04	0.07
No. of times regenerated from slash	0.0	0.01
No. of abandoned areas due to regen failures	0.0	0.27
Expected future cost $/cunit	23.11	29.03

(continued)

Table 1 (continued - page 5)

Probability of exceeding:	Rotation age = 70 years Future cost ($/cunit) planting	seeding	Interest rate = 10% Cost of planting-seeding
0.0	325.38	988.66	-663.28
0.100	168.74	266.81	-98.07
0.200	117.30	174.30	-57.00
0.300	99.86	126.12	-26.26
0.400	85.47	89.28	-3.81
0.500	71.24	73.06	-1.82
0.600	65.92	55.27	10.66
0.700	58.98	46.46	12.52
0.800	51.29	39.52	11.76
0.900	44.84	33.92	10.93
1.000	30.84	22.66	8.19

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	19.16	14.61
Expected cost $/acre	80.66	32.77
Expected cost of scarification $/acre	24.42	58.43
Total cost (regen, scarification, thinning) $/acre	105.43	91.80
Average stocking %	0.63	0.59
Avg no. of complete and/or partial regen treatments	1.58	4.07
No. of scarifications	1.00	2.07
No. of times stocking in gray area	0.29	0.34
No. of thinnings	0.04	0.06
No. of times regenerated from slash	0.0	0.02
No. of abandoned areas due to regen failures	0.0	0.32
Expected future cost $/cunit	76.18	97.83

(continued)

Table 1 (continued - page 6)

Probability of exceeding:	Rotation age = 85 years Future cost ($/cunit) planting	seeding	Interest rate = 10% Cost of planting-seeding
0.0	427.57	1680.23	-1252.67
0.100	211.43	394.00	-182.57
0.200	160.53	218.44	-57.90
0.300	141.65	142.06	-0.41
0.400	118.14	114.48	3.66
0.500	105.10	96.00	9.10
0.600	95.73	70.90	24.82
0.700	83.60	59.93	23.67
0.800	70.24	53.10	17.14
0.900	61.46	44.62	16.83
1.000	42.64	20.45	22.19

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	25.06	19.68
Expected cost $/acre	82.15	32.43
Expected cost of scarification $/acre	24.36	59.92
Total cost (regen, scarification, thinning) $/acre	106.78	93.18
Average stocking %	0.63	0.63
Avg no. of complete and/or partial regen treatments	1.64	4.10
No. of scarifications	1.00	2.11
No. of times stocking in gray area	0.31	0.35
No. of thinnings	0.03	0.09
No. of times regenerated from slash	0.0	0.03
No. of abandoned areas due to regen failures	0.0	0.35
Expected future cost $/cunit	106.20	132.80

(concluded)

Table 1 (continued - page 7)

Probability of exceeding:	Rotation age = 100 years Future cost ($/cunit) planting	 seeding	Interest rate = 10% Cost of planting-seeding
0.0	605.59	1558.65	-953.05
0.100	302.93	576.15	-273.22
0.200	237.13	312.44	-75.31
0.300	200.05	242.67	-42.62
0.400	166.18	183.78	-17.60
0.500	150.12	151.43	-1.31
0.600	137.44	126.23	11.21
0.700	121.56	98.44	23.12
0.800	106.23	81.46	24.77
0.900	91.07	71.33	19.74
1.000	57.42	38.71	18.71

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	30.70	22.93
Expected cost $/acre	81.26	31.57
Expected cost of scarification $/acre	24.41	56.83
Total cost (regen, scarification, thinning) $/acre	105.93	89.13
Average stocking %	0.64	0.62
Avg no. of complete and/or partial regen treatments	1.59	3.89
No. of scarifications	1.00	1.99
No. of times stocking in gray area	0.26	0.40
No. of thinnings	0.03	0.08
No. of times regenerated from slash	0.0	0.02
No. of abandoned areas due to regen failures	0.0	0.29
Expected future cost $/cunit	154.91	196.29

[a] 1 acre = 0.40 ha

[b] 1 cunit = 2.83 cu m

2%, respectively. The inflation rate and probability interval for the output are set at 6% and 10%, respectively, while the random number for starting the stochastic process is given as 987653.

Page 2 and each of the remaining pages of Tables 1-3 give the results for each rotation age and an interest rate. The first portion of each page provides future cost/cunit for both planting and seeding at 10% probability intervals, while the second portion gives other related statistics *per successful regeneration ("success")*.

Page 2 of Table 1, for example, gives the results for a rotation age of 70 years and an interest rate of 8%. The first column, i.e., probability of exceeding, refers to the next three columns. The second line indicates that the probability that the future cost/cunit of wood produced in planted stands might exceed $40.57, is 10%, or conversely, there is a 90% chance that the cost/cunit of planting will be equal to or less than $40.57. Similarly, it indicates that there is a 10% chance that future cost/cunit of wood produced in seeded stands might exceed $70.70. Therefore, there is also a 10% chance that future cost/cunit of planting will be at least $30.13 less than the future cost for seeding (column 4).

The fifth line of this table shows that there is a 40% chance that the future cost/cunit for planting will be between $22.64 and $75.86 or conversely, there is a 60% chance that it will be between $8.28 and $22.64. Similarly this line indicates that there is a 40% chance that future cost/cunit for seeding will exceed $22.61, i.e., between $22.61 and $371.37, or on the other hand, there is a 60% chance that it will be between $5.40 and $22.61. Therefore, it also indicates that there is a 60% chance that the future cost/cunit of wood for seeding will be less than cost of planting by at least 3¢. Going down the lines of this table, similar comparisons can be made between future cost/cunit for planting and seeding at a 10% probability interval. The first and last lines in the table give the maximum and minimum cost/cunit, respectively, for both planting and seeding.

As stated above, the bottom portion of page 2 and the remaining pages of each table provide related statistics *per "success"*. Page 2 of Table 1, for example, shows that for a rotation age of 70 years, the expected volumes/acre for planting and seeding were 19.16 and 14.54 cunits, respectively. It also shows that the expected total present costs, i.e., costs of scarifications, regeneration treatments and thinnings, were $106.85/acre for planting and $96.79/acre for seeding. This means that in terms of present cost and based on the input estimates of this example, seeding will cost $10.06/acre less than planting, on the average, to produce a "success". However, because plantation volumes are higher than those of seeded areas, the present total cost/cunit for planting and seeding will be $5.56 ($106.85 ÷ 19.16 = $5.56) and $6.65

(96.79 ÷ 14.54 = \$6.65) i.e., planting will cost \$1.09/cunit less than seeding. In terms of future cost/cunit, however, the results indicate that the expected cost of planting (\$21.01) will be less than the cost of seeding (\$26.62) by \$5.61/cunit.

The related statistics given also provide other useful information. For example, the average number of scarifications per "success" for a rotation age of 70 years were 1.00 for planting and 2.09 for seeding. This simply indicates that in the simulation process no planting trial required rescarification to produce an acceptable stocking level, i.e., either a successful one or one in the "grey area" (28% of the time stocking level fell in the grey area for planting). On the other hand, it took 2.09 scarifications to produce either a successful stocking level or one in the "grey area" (42% of the time the stocking level fell in the grey area for seeding.) The average number of complete and/or partial regenerations for planting was 1.59, while that for seeding was 4.11.[7] This means that 59% of planting trials required partial replantings, while on the average it took 4.11 complete and/or partial seedings to produce an acceptable stocking level. Results also indicate that the average stocking level was 62% for both seeding and planting, and that 5% of planting trials and 8% of seeding trials required thinnings. In the case of seeding, the results also indicate that 2% of trials were regenerated naturally and that it resulted in 0.34 abandoned area per "success", i.e., approximately one area was abandoned for every three areas regenerated successfully, or about one out of four trials resulted in abandonment of the site because of repeated failures.

Since these related statistics are calculated *per successful regeneration*, all differences between the two regeneration techniques are accounted for in terms of initial cost, required additional treatments, i.e., partial and/or complete reseeding or replanting, etc., required thinning and, particularly, expected stocking success for the two operations. For instance, seeding cost estimates per regeneration treatment for this example were between \$8 and \$15 with a minimum of \$5/acre; however, the expected seeding cost/"*success*" turns out to be \$35.39. This is simply because, as indicated above, it took 4.11 seeding treatments to produce one "success". Similarly, scarification

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7 It should be noted that the economies of scale and its effect on the availability of labor, material and the cost of regeneration are not considered in the model, i.e., the cost of regeneration/unit area is the same regardless of the size of the area to be regenerated annually via each regeneration system.

cost estimates for seeding were between $25 and $35 with a minimum of $15/acre. However, the expected cost of scarification *per "success"* turns out to be $60.25/acre because it took 2.09 scarifications to produce one successful seeding. Differences in thinning requirements and the possibility that an area might be regenerated from slash are also accounted for in the expected total cost/"success".

Page 3 of Table 1 provides the results for a rotation age of 85 years and an interest rate of 8%. Note that future cost/cunit for most probability levels and therefore the expected future cost/cunit ($21.61 and $28.20, see lower portion of page 3, Table 1) for both planting and seeding are higher than those for a rotation age of 70 years. This is due mainly to the fact that the 85-year rotation was longer and that it required slightly more planting and seeding treatments to produce a "success". As a result seeding performance was slightly poorer than it was in the previous rotation as compared with planting.

Page 4 of Table 1 gives the results for 100 years' rotation. These results are similar to those above except that most future costs/cunit, and therefore the expected future costs/cunit, are higher than before because of longer rotation. Other related statistics are similar to those for the previous rotations; some minor differences are due to random chance. This is expected in any stochastic process and represents what might happen from treatment to treatment in a real field application. Pages 5 through 7 of Table 1 give the results for rotation ages 70, 85 and 100 years for a 10% rate of interest. As expected, these results are also similar to the above, except that all future costs are higher simply because the interest rate is higher.

Table B1 (Appendix B) presents the results of the second example in which the input estimates of the first example were modified by increasing the low and high estimates for stocking level and probability of success of planting by 5%, i.e., the low estimate = 25% and the high estimate = 90%; also the stocking standards for failure and success were raised by 10% from 40 to 50% and from 50 to 60%, respectively. Other input estimates for the two examples are identical except those for the random number generator starter. With these modifications, it is, of course, expected that planting will perform much better than seeding.

Page 2 of Table B1 gives the results for a rotation age of 70 years and an interest rate of 8%. When the future cost/cunit for planting and seeding are compared, it should be noted that seeding has only a 30% chance of being cheaper than planting by at least 98¢/cunit (35¢/cu. m). The expected future costs/cunit (lower portion of page 2, Table B1) indicate that, on the average, planting will be cheaper than seeding by $19.19 ($36.48 - $17.29 = $19.19). Related statistics for this rotation indicate that in terms of total present cost/acre, planting will be cheaper than seeding by $50.65 ($153.23 - $102.58 = $50.65). In terms of present cost/cunit, planting will be cheaper than seeding by $4.53 ([$153.23 ÷ 16.8] - [$102.58 ÷ 22.36] = $4.53).

Results here indicate that 55% of planting trials needed partial replanting to produce an acceptable stocking level, while it took 6.83 complete and/or partial seedings to produce a satisfactory regeneration. Other related statistics also indicate that no planting trial required rescarification, while it took 3.35 scarifications to produce a satisfactory regeneration from seeding. Nearly one complete area was abandoned for every site regenerated successfully, or about one out of every two areas was abandoned owing to repeated failures from seeding trials.

Page 3 of Table B1 contains the results for a rotation age of 85 years and an interest rate of 8%. It should be noted that most estimates of the future cost/cunit for both planting and seeding are higher than in the previous example, mainly because of the longer rotation. Results indicate that seeding has only a 30% chance of being cheaper than planting by 15¢/cunit (5¢/cu. m), while in terms of expected future cost/cunit planting was cheaper than seeding by $16.80 ($35.10 - $18.30 = $16.80). All related statistics for this rotation, except for expected volume/acre, are similar to those for the previous one; some minor differences are due to random chance.

Page 4 of Table B1 gives the results for a rotation age of 100 years and an interest rate of 8%. Results are similar to those for the previous rotation except that all future costs are higher, mainly because of the longer rotation. Here again, seeding had only a 30% chance of being cheaper than planting in terms of future cost/cunit, while its expected cost/cunit exceeded that of planting by $19.41 ($40.83 - $21.42 = $19.41).

The results of this example for rotation ages 70, 85 and 100 years and an interest rate of 10% were similar to those for an interest rate of 8% except, of course, that all future cost figures were higher. Seeding in every case had only a 30% chance of being cheaper than planting and, in terms of both expected present and future cost/cunit, planting outperformed seeding. This portion of the results is omitted from Table B1.

The results of the third example are given in Table B2 (Appendix B). The input estimates for this example were similar to those for the previous two, except that stocking level and probability of success for seeding were higher, as follows: a) low estimate = 15% b) high estimate = 80% c) the probability that stocking might be less than the low estimate = 20% d) the probability that stocking level might be less than the high estimate = 95% and e) the minimum stocking = 5%. The estimates used for stocking level and probability of success for planting were identical to those used in the second example. The stocking standards employed, however, were the same as those of the first example, i.e., stocking for success = 50% and stocking level for failure = 40%. This example was tried for a poorer site, i.e., site index 30 was assigned to both planting and seeding. The rotation ages examined were 80, 95 and 110 years. Other input estimates were identical to those for the first example, except for the random number generator starter. Because a higher stocking success was assumed for seeding in this example than in the previous two, it is to be expected that seeding will show better results than before.

Page 2 of Table B2 gives the results for a rotation age of 80 years and an interest rate of 8%. Line 3 of this table indicates that there is an 80% chance that future cost/cunit for seeding will be less than that for planting by at least $1.99. In terms of the expected future cost/cunit (lower portion of page 2, Table B2), seeding will be cheaper than planting by $1.51 ($24.43 - $22.92 = $1.51). Related statistics for this rotation indicate that in terms of present cost/acre, seeding will be cheaper than planting by $30.48 ($97.40 - $66.92 = $30.48) while in terms of present cost/cunit seeding will be cheaper than planting by 61¢ ([$97.40 ÷ 18.32] - [$66.92 ÷ 14.23] = $0.61). Other related statistics indicate that 39% of the planting trials required partial replanting to produce an acceptable stocking level, while it took 2.57 complete and/or partial seeding trials to produce a satisfactory regeneration. Results also show that no planting trial required rescarification while 47% of the seeding trials need rescarification and only about 12% of the sites were abandoned because of repeated seeding failures.

Page 3 of Table B2 gives the results for a rotation age of 95 years and an interest rate of 8%. Results are similar to those for the previous rotation, with some minor differences, i.e., the probability that seeding might be cheaper than planting by at least 21¢/cunit was 60% and the expected future cost/cunit for seeding was $1.43/cunit ($25.05 - $24.63 = $1.43) less than that for planting. Results of the next rotation age (110 years) given on page 4 of Table B2 are also similar to the above except that all future costs are higher, mainly because of the longer rotation.

SUMMARY AND CONCLUSIONS

Results of the present study are summarized below along with some general conclusions about the cost-effectiveness of planting versus direct seeding of black spruce.

1) Based on the approximate present cost structure assumed for planting and seeding of black spruce (Tables 1, B1 and B2) and based on the estimated stocking level and probability of success derived from limited historical data for both regeneration systems (Table 1), the expected future cost/cunit for planting will be less than that for direct seeding. That is, if all cut-over areas are to be regenerated by either planting or direct seeding, planting will be the more economical regeneration system in terms of future cost. However, if sites suitable for seeding

can be identified, the results of Table 1 indicate that about one half of the cut-over areas may be seeded successfully with a considerable saving. In terms of *present* cost/acre, Table 1 indicates that direct seeding will be cheaper than planting in every case. That is, if the objective is to regenerate as many cut-over areas as possible with a given annual regeneration budget, direct seeding should be chosen over planting. Nevertheless, the results also show that on the average it takes two scarifications and about four complete and/or partial seedings to obtain one satisfactory regeneration and that about one fourth of the areas will be abandoned because of repeated failures. Of course, the latter areas may be regenerated by planting.

2) The results of the second example (Table B1) indicate that under the same regeneration cost structure, but with a higher stocking level and probability of success for planting than historical data show, and when stocking standards are raised by 10%, i.e., from 40 to 50% and from 50 to 60% for failure and success levels, respectively, planting on the average will outperform seeding by a great margin. That is, in terms of both expected future cost/cunit and present cost/acre, planting will be a more economical means of regeneration than direct seeding. However, if both seeding and planting are considered and if sites suitable for seeding can be identified, the results show that about 30% of the areas might be regenerated more cheaply by direct seeding than by planting. However, it might take as many as three scarifications and six complete and/or partial seedings to obtain satisfactory stocking. A comparison of the results of Tables 1 and B1 indicates that raising the stocking standards by 10% nearly doubles the required number of scarifications and complete and/or partial seedings for a successful regeneration, and that it more than doubles the number of areas abandoned because of repeated seeding failures. This comparison also indicates that a 5% general increase in the expected stocking level of planting, i.e., raising both low and high estimates by 5%, almost counterbalances the 10% increase in the stocking standards. That is, the number of required scarifications and complete and/or partial planting for the two examples is about the same (compare Tables 1 and B1). It is also noted that average stocking per successful regeneration for both planting and seeding in example 2 is about 10% higher than that in example 1.

3) The results of the third example (Table B2) are based on the same regeneration cost structure as the previous two; the stocking standard is the same as in the first example, stocking level and probability of success estimates for planting are identical to those of the second example, but estimates of stocking level and probability of success for seeding are raised by less than 10%. Since this example was run for a poorer site and longer rotation ages, its results are not directly comparable with those of the previous two. Nevertheless, they indicate the significant effects that a relatively small improvement in the stocking level and probability of success of seeding might have on its comparison with planting. Results indicate that the probability that direct seeding is more economical than planting is better than 70% in terms of future cost/cunit. In terms of present cost/acre direct seeding will be cheaper than planting by about $25/acre. Results also indicate that the increase in stocking level and probability of success effectively reduces the required number of reseeding operations per "success" by about one half. Similarly the number of required scarifications per "success" is reduced considerably and the percentage of areas abandoned because of repeated failures is reduced to one third (compare Tables 1 and B2).

RECOMMENDATIONS

Results of the present study indicate that, despite the extremely poor historical results, direct seeding of black spruce shows considerable economic merit as compared with planting. The main reasons for these apparently surprising results are threefold: 1) The historical data are based on single seeding trial/site, i.e., no complete and/or partial reseedings were applied on the same site, while in the present study such an allowance is made for both seeding and planting operations. 2) Because the initial cost of seeding is much lower (two to six times) than that of planting, it is economically feasible to seed an area several times to obtain a satisfactory regeneration. 3) Recent studies (Fraser 1975, Winston 1975, and Frisque 1975) indicate that, with proper site preparation and seed treatments, stocking levels and probabilities of success for black spruce seeding will be far better than in the past, and higher than the most optimistic estimates (example 3) used in the present study. Therefore, the fact that direct seeding of black spruce has a lower probability of success than planting should not eliminate it from consideration.

As the results of example 3 of the present study show, if the stocking level and probability of success of direct seeding improve to some extent, direct seeding will become a more attractive regeneration system than planting. Thus the results of current studies and operational trials should be watched closely to determine whether they will provide further evidence that could alter drastically the comparative cost-effectiveness of planting and seeding.

Because of the poor regeneration results from direct seeding in the past, particularly for black spruce in Ontario, relatively little research has been conducted in this area in comparison with the research done on planting. As stated earlier, some possible reasons for the failure of black spruce seeding operations are: a) inadequate and poor quality seed used b) wrong season of application c) inadequate site preparation d) adverse climatic condition e) competition from minor vegetation and f) loss of seed to rodents. Each of these factors plus any others which might influence the results of seeding must be carefully investigated to determine ways and means of improving its rate of success. In particular, extensive studies and operational trials must be conducted to determine the optimum site preparation and seed treatment methods for best regeneration results. Also, studies should be conducted to identify the type of site suitable for seeding and to determine whether the rate of success and stocking level with these and other site types can be improved significantly by reseeding. Finally, more intensive economic evaluation such as that described here must be undertaken. It should be based on improved estimates of cost, probability of success, and expected stocking level for both seeding and planting to determine the overall economic merit of direct seeding of black spruce.

The author would like to emphasize that the results of this study should be viewed as a broad indication of the relative economic merits of direct seeding versus planting of black spruce based on the cost structure and probability of success assumed for the two regeneration systems. The results of this study like those of any other simulation modeling of this type are highly dependent on their underlying assumptions and input estimates used. If the input estimates are biased and unrealistic, the results will also be biased and unrealistic. Nevertheless, the model "REGEN" has been developed as a practical tool to help forest managers make rational economic decisions with respect to their choice of regeneration techniques. Anyone wishing to use the model or to receive more information should contact the author.

LITERATURE CITED

Anonymous. 1974. Survival and growth of tree plantations on Crown lands in Ontario. Div. For., For. Manage. Br., Ont. Min. Nat. Resour.

Bailey, R. L. and T. R. Dell. 1973. Quantifying diameter distributions with the Weibull Function. For. Sci. 19(2): 97-104.

Chapman, H. H. and W. H. Meyer. 1947. Forest valuation. McGraw-Hill Book Co. Inc., New York. 521 p.

Fraser, J. W. 1975. Direct seeding of black spruce. Is it feasible? *In* Black Spruce Symposium, Thunder Bay, Ont. Sept. 1975. Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. O-P-4. (In press)

Frisque, G. 1975. Black spruce: stocking five years after seeding. Can. For. Serv., Ottawa, Ont. Bi-mon. Res. Notes 31(4): 31.

Kabzems, A. 1971. The growth and yield of well stocked white spruce in the mixedwood section in Saskatchewan. Sask. Dep. Nat. Resour. For. Br. Tech. Bull. No. 5. 75 p.

Lundgren, A. L. 1966. Estimating investment returns from growing red pine. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn. Res. Pap. NC-2. 48 p.

Lundgren, A. L. 1973. Cost-price: a useful way to evaluate timber growing alternatives. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn. Res. Pap. NC-95. 16 p.

Payandeh, B. 1973. Plonski's yield tables formulated. Can. For. Serv., Ottawa, Ont. Publ. No. 1318.

Payandeh, B. and T. L. Tucker. 1975. Application of subjective probability and Weibull distribution in evaluating cost-effectiveness of regeneration techniques. p. 129-156 *in* V. G. Smith and L. P. Aird, *Ed.* Canadian Forest Inventory Methods Proceedings, Dorset, Ont., June 1975. Univ. Toronto Press.

Plonski, W. L. 1960. Normal yield tables for black spruce, jack pine, aspen, white birch, tolerant hardwoods, white pine and red pine for Ontario. Ont. Dep. Lands For., Silvic. Ser. Bull. 2. 39 p.

Scott, J. D. 1966. A review of direct seeding projects carried out by Ontario Department of Lands and Forests from 1956 to 1964. Ont. Dep. Lands For., Silvic. Notes. No. 5.

Stiell, W. M. 1958. Pulpwood plantations in Ontario and Quebec. Can. Pulp Pap. Assoc. Woodl. Sec. Index No. 1770.

Stiell, W. M. and A. B. Berry. 1973. Development of unthinned white spruce plantations to age 50 years at Petawawa Forest Experiment Station. Dep. Environ. Publ. No. 1317. 18 p.

Waldron, R. M. 1974. Direct seeding in Canada 1900-1972. p. 11-27 *in* J. H. Cayford, *Ed.* Direct Seeding Symposium, Timmins, Ont., Sept. 1973. Dep. Environ., Can. For. Serv. Publ. 1339.

Weibull, W. 1951. A statistical distribution function for wide applicability. J. Appl. Mech. 18: 293-297.

Winston, D. A. 1975. Black spruce seeding experiments on the central plateau forest section, B.8 Manitouwadge, Ontario. *In* Black Spruce Symposium, Thunder Bay, Ont., Sept. 1975. Can. For. Serv., Sault Ste. Marie, Ont., Symp. Proc. O-P-4. (In press)

APPENDICES

Appendix A

Description of INPUT variables for Simulator REGEN

I. Title: Up to 80 alphameric characters, the first 40 of which might include name and abbreviated address and the remaining identifying remarks regarding a run, e.g., Mr. R. J. Smith, OMNR, Thunder Bay. Run no. 2 revised estimates, July 25, 1975.

II. Subjective estimates or actual data: These must be formulated according to example no. 1 as follows:

Order	Description	Input data
1	A stocking level at or above which regeneration is considered successful	.50
2	A stocking level below which regeneration is considered a failure	.40
3	Low estimate for cost of planting (including stock)	40.0
4	High estimate for cost of planting	75.0
5	A probability that cost of planting might be lower than the high estimate	0.05
6	A probability that cost of planting might be lower than the high estimate	0.90
7	A minimum estimate for cost of planting. This must be lower than or equal to the low estimate	30.0
8	Low estimate for cost of seeding (including seed cost)	8.0
9	High estimate for cost of seeding	15.0
10	A probability that cost of seeding might be lower than the low estimate	0.20
11	A probability that cost of seeding might be lower than the high estimate	0.85
12	A minimum cost for seeding	5.0
13 - 17	Subjective estimates for cost of scarification for seeding - similar to above	25, 35, .1, .95 and 15

(continued)

Appendix A (continued)

Order	Description	Input Data
18 - 22	Subjective estimates for cost of scarification for planting - similar to above	20, 30, .1, .85 and 15
23 - 27	Subjective estimates for cost of thinning for seeded areas - similar to above	15, 35, .1, .95 and 8
28 - 32	Subjective estimates for cost of thinning of plantation - similar to above	15, 25, .1, .85 and 10
33	A low stocking estimate for planting	0.2
34	A high stocking estimate for planting	0.85
35	A probability that stocking for planting might be lower than the low estimate	0.1
36	A probability that stocking for planting might be lower than the high estimate	0.90
37	The lowest stocking level for planting	0.15
38 - 42	Subjective estimates for the success of seeding and its respective probability	.10, .75, .25, .95, .02
43	No. of successful planting and seeding trials to be compared/interest rate and rotation age	300
44	Species code, e.g., 1 = black spruce 2 = jack pine, etc.	1
45	Site index for planting	36.0
46	Site index for seeding	36.0
47	No. of possible complete and/or partial plantings/scarification	3
48	No. of possible complete and/or partial seedings/scarification	2
49	Maximum no. of scarifications for planting	3
50	Maximum no. of scarifications for seeding	2

(continued)

Appendix A (concluded)

Order	Description	Input data
51	Regeneration survey for planting, i.e., years after planting	1
52	Regeneration survey for seeding, i.e., years after seeding	3
53	Probability that a plantation may be thinned	0.1
54	Probability that a seeded area may be thinned	0.25
55	Low thinning age for plantation-years	15.
56	High thinning age for plantation-years	25.
57	Low thinning age for seeded stands-years	15.
58	High thinning age for seeded stands-years	35.
59	Probability that a site might be generated from slash-similar to seeding	0.1
60	Starting rotation age (years)	70
61	End rotation age (years)	100
62	Rotation age interval (years)	15
63	Low interest rate %	8
64	High interest rate %	10
65	Interest rate interval %	2
66	Inflation rate, e.g., 0.08 = 8%	.05
67	Probability interval for output	10
68	Output form: 1 for short form, other than one, detail output	345
69	Randon number generator starter, i.e., any integer no. up to 9 digits	987653

APPENDIX B

Table B1. Input estimates and results of simulator "REGEN" for comparing the cost-effectiveness of seeding versus planting of black spruce for rotation ages 70, 85 and 100 years and an interest rate of 8%

Input Variables for This Run Are:

Subjective estimates	Planting: Cost $/acre Plant	Planting: Cost $/acre Scar	Planting: Cost $/acre Thin	Planting: Stocking success	Seeding: Cost $/acre Seed	Seeding: Cost $/acre Scar	Seeding: Cost $/acre Thin	Seeding: Stocking success
Low	40.00	20.00	15.00	0.25[a]	8.00	25.00	15.00	0.10
High	75.00	30.00	25.00	0.90[a]	15.00	35.00	35.00	0.75
Prob. value lower than low	0.05	0.10	0.10	0.10	0.20	0.10	0.10	0.25
Prob. value lower than high	0.90	0.85	0.85	0.90	0.95	0.90	0.95	0.95
Absolute minimum	30.00	15.00	10.00	0.15	5.00	15.00	8.00	0.02

Other Input Variables

Stocking level for success	0.60[a]	Low thinning age for plantation	15.00
Stocking level for failure	0.50[a]	High thinning age for plantation	25.00
No. of iterations	300	Low thinning age for seeded stands	15.00
Species code	1	High thinning age for seeded stands	35.00
Site index for planting area	36.00	Prob. site may regenerate from slash	0.10
Site index for seeding area	36.00	Starting rotation age	70
No. possible plantings/scarification	3	End rotation age	100
No. possible seedings/scarification	2	Rotation age interval	15
Max. no. of scar. for planting	3	Low interest rate %	8
Max. no. of scar. for seeding	2	High interest rate %	10
Regen. survey for planting-years	1	Interest rate interval %	2
Regen. survey for seeding-years	3	Inflation rate	0.06
Prob. planted stand may be thinned	0.10	Probability interval for output %	10.00
Prob. seeded stand may be thinned	0.25	Any integer no. 9 digits or less	98765

(continued)

[a] Modified input estimates

Table B1 (continued - page 2)

Probability of exceeding:	Rotation age = 70 years Future cost ($/cunit) planting	seeding	Interest rate = 8% Cost of planting-seeding
0.0	47.29	388.12	-340.83
0.100	26.46	117.47	-91.01
0.200	23.01	58.48	-35.47
0.300	20.55	38.76	-18.22
0.400	18.62	29.17	-10.55
0.500	17.27	20.68	-3.42
0.600	15.96	16.67	-0.71
0.700	14.02	13.04	0.98
0.800	12.48	10.50	1.98
0.900	10.85	9.09	1.76
1.000	8.42	5.85	2.56

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	22.36	16.80
Expected cost $/acre	77.41	55.00
Expected cost of scarification $/acre	24.48	95.71
Total cost (regen, scarification, thinning) $/acre	102.58	153.23
Average stocking %	0.74	0.70
Avg. no. of complete and/or partial regen treatments	1.55	6.83
No. of scarifications	1.00	3.35
No. of times stocking in gray area	0.25	0.39
No. of thinnings	0.05	0.17
No. of times regenerated from slash	0.0	0.02
No. of abandoned areas due to regen failures	0.0	0.88
Expected future cost $/cunit	17.29	36.48

(continued)

Table B1 (continued - page 3)

Probability of exceeding:	Rotation age = 85 years Future cost ($/cunit) planting	 seeding	Interest rate = 8% Cost of planting-seeding
0.0	47.34	529.70	-482.36
0.100	28.56	95.42	-66.87
0.200	24.05	60.20	-36.15
0.300	21.14	39.82	-18.68
0.400	19.19	28.75	-9.56
0.500	17.89	20.52	-2.63
0.600	16.56	18.35	-1.78
0.700	14.91	14.76	0.15
0.800	13.21	11.09	2.12
0.900	11.73	9.35	2.38
1.000	8.63	5.98	2.65

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	29.30	22.08
Expected cost $/acre	80.41	52.44
Expected cost of scarification $/acre	24.66	89.78
Total cost (regen, scarification, thinning) $/acre	105.70	143.98
Average stocking %	0.73	0.72
Avg no. of complete and/or partial regen treatments	1.65	6.41
No. of scarifications	1.00	3.13
No. of times stocking in gray area	0.26	0.39
No. of thinnings	0.05	0.12
No. of times regenerated from slash	0.0	0.02
No. of abandoned areas due to regen failures	0.0	0.76
Expected future cost $/cunit	18.30	35.10

(continued)

Table B1 (concluded - page 4)

Probability of exceeding:	Rotation age = 100 years Future cost ($/cunit) planting	seeding	Interest rate = 8% Cost of planting-seeding
0.0	68.41	269.31	-200.90
0.100	32.34	97.65	-65.31
0.200	28.11	65.85	-37.74
0.300	24.88	46.68	-21.80
0.400	22.66	33.83	-11.17
0.500	21.13	25.73	-4.59
0.600	19.73	21.32	-1.60
0.700	17.98	15.31	2.67
0.800	15.59	11.73	3.86
0.900	13.78	9.63	4.15
1.000	8.65	5.14	3.51

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	34.15	25.94
Expected cost $/acre	81.66	52.71
Expected cost of scarification $/acre	24.82	91.86
Total cost (regen, scarification, thinning) $/acre	107.14	146.18
Average stocking %	0.70	0.69
Avg no. of complete and/or partial regen treatments	1.65	6.54
No. of scarifications	1.00	3.22
No. of times stocking in gray area	0.29	0.43
No. of thinnings	0.05	0.11
No. of times regenerated from slash	0.0	0.02
No. of abandoned areas due to regen failures	0.0	0.83
Expected future cost $/cunit	21.42	40.83

Table B2. Input variables and results of simulator "REGEN" for comparing the cost-effectiveness of seeding versus planting of black spruce for rotation ages 80, 95 and 110 years and an interest rate of 8%

Input Variables for This Run Are:

	Planting				Seeding			
	Cost ($/acre)			Stocking success	Cost $/acre			Stocking success
Subjective estimates	Plant	Scar	Thin		Seed	Scar	Thin	
Low	40.00	20.00	15.00	0.25[a]	8.00	25.00	15.00	0.15[a]
High	75.00	30.00	25.00	0.90[a]	15.00	35.00	35.00	0.80[a]
Prob. value lower than low	0.05	0.10	0.10	0.10	0.20	0.10	0.10	0.20[a]
Prob. value lower than high	0.90	0.85	0.85	0.90	0.95	0.90	0.95	0.95
Absolute minimum	30.00	15.00	10.00	0.15	5.00	15.00	8.00	0.05[a]

Other Input Variables

Stocking level for success	0.50	Low thinning age for plantation	15.00
Stocking level for failure	0.40	High thinning age for plantation	25.00
No. of iterations	300	Low thinning age for seeded stands	15.00
Species code	1	High thinning age for seeded stands	35.00
Site index for planting area	30.00[a]	Prob. site may regenerate from slash	0.10
Site index for seeding area	30.00[a]	Starting rotation age	80[a]
No. possible plantings/scarification	3	End rotation age	110[a]
No. possible seedings/scarification	2	Rotation age interval	15
Max. no. of scar. for planting	3	Low interest rate %	8
Max. no. of scar. for seeding	2	High interest rate %	10
Regen survey for planting-years	1	Interest rate interval %	2
Regen survey for seeding-years	3	Inflation rate	0.06
Prob. planted stand may be thinned	0.10	Probability interval for output %	10.00
Prob. seeded stand may be thinned	0.25	Any integer no. 9 digits or less	975311

[a] Modified input estimates

(continued)

Table B2 (continued - page 2)

Probability of exceeding:	Rotation age = 80 years Future cost ($/cunit) planting	seeding	Interest rate = 8% Cost of planting-seeding
0.0	83.80	263.60	-179.80
0.100	44.43	55.67	-11.24
0.200	35.43	33.44	1.99
0.300	29.75	25.99	3.76
0.400	26.86	21.43	5.44
0.500	24.45	17.08	7.37
0.600	22.25	14.85	7.40
0.700	19.87	13.31	6.56
0.800	17.75	11.64	6.12
0.900	15.57	10.44	5.13
1.000	10.06	6.54	3.52

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	18.32	14.23
Expected cost $/acre	72.33	22.16
Expected cost of scarification $/acre	24.57	43.34
Total cost (regen, scarification, thinning) $/acre	97.40	66.92
Average stocking %	0.66	0.63
Avg no. of complete and/or partial regen treatments	1.39	2.57
No. of scarifications	1.00	1.47
No. of times stocking in gray area	0.25	0.33
No. of thinnings	0.04	0.10
No. of times regenerated from slash	0.0	0.04
No. of abandoned areas due to regen failures	0.0	0.12
Expected future cost $/cunit	24.43	22.92

(continued)

Table B2 (continued - page 3)

Probability of exceeding:	Rotation age = 95 years Future cost ($/cunit) planting	seeding	Interest rate = 8% Cost of planting-seeding
0.0	110.08	211.99	-101.90
0.100	41.73	65.65	-23.92
0.200	32.87	39.49	-6.62
0.300	28.70	30.51	-1.81
0.400	26.78	26.57	0.21
0.500	23.84	22.18	1.66
0.600	21.48	17.69	3.80
0.700	19.62	15.24	4.38
0.800	17.62	13.50	4.12
0.900	16.07	11.64	4.42
1.000	11.66	6.66	5.00

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	24.56	17.20
Expected cost $/acre	72.70	23.41
Expected cost of scarification $/acre	24.58	43.77
Total cost (regen, scarification, thinning) $/acre	97.83	68.29
Average stocking %	0.63	0.60
Avg no. of complete and/or partial regen treatments	1.41	2.67
No. of scarifications	1.00	1.46
No. of times stocking in gray area	0.19	0.40
No. of thinnings	0.04	0.08
No. of times regenerated from slash	0.0	0.04
No. of abandoned areas due to regen failures	0.0	0.09
Expected future cost $/cunit	26.06	24.63

(continued)

Table B2 (concluded - page 4)

Probability of exceeding:	Rotation age = 110 years Future cost ($/cunit) planting	seeding	Interest rate = 8% Cost of planting-seeding
0.0	140.01	291.39	-151.38
0.100	54.29	60.36	-6.07
0.200	41.55	41.60	-0.05
0.300	34.79	33.56	1.23
0.400	30.75	26.30	4.45
0.500	28.09	21.11	6.98
0.600	25.36	17.51	7.86
0.700	23.24	15.21	8.02
0.800	20.80	13.72	7.08
0.900	18.13	12.35	5.78
1.000	12.29	8.14	4.15

Related Statistics per Successful Regeneration ("success")

Statistics	Planting	Seeding
Expected volume cunits/acre	28.63	21.59
Expected cost $/acre	73.40	22.35
Expected cost of scarification $/acre	24.53	40.78
Total cost (regen, scarification, thinning) $/acre	98.57	64.17
Average stocking %	0.66	0.62
Avg no. of complete and/or partial regen treatments	1.41	2.50
No. of scarifications	1.00	1.40
No. of times stocking in gray area	0.23	0.34
No. of thinnings	0.05	0.07
No. of times regenerated from slash	0.0	0.02
No. of abandoned areas due to regen failures	0.0	0.07
Expected future cost $/cunit	28.66	26.26