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Direct seeding symposium

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(Résumés en français)

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Foreword

Forest managers have long considered direct seeding as an alternative reforestation technique to planting. Among the advantages cited for seeding are lower cost, a low requirement for labor and supervision, an opportunity to regenerate large areas quickly from the air, flexibility, and a resulting stand of trees with a naturally undisturbed root system. Conversely its disadvantages include a lower rate of success than planting, coupled with the fact that stands of excessively high density may result.

At the present time direct seeding accounts for slightly more than 10% of the Canadian artificial reforestation program. Success has been variable, being achieved quite consistently with jack pine, but rarely with black spruce, lodgepole pine, eastern white pine and white spruce.

This symposium was co-sponsored by the Canadian Forestry Service and the Ontario Ministry of Natural Resources. Its purpose was to review the current state of the art and stimulate further research and development of direct seeding as an operational regeneration technique for the Canadian pines and spruces. This symposium was considered as a follow-up to one held at Amherst, Massachusetts, in 1964, the proceedings of which were published by the University of Massachusetts.

All of the 17 papers presented at the symposium are included in these proceedings, and the program committee wishes to extend its appreciation to all those who prepared the papers. It is considered that this volume clearly outlines the current status of direct seeding in Canada, summarizes the results achieved to date, and indicates the problems that remain to be solved. Additionally, three papers discuss various aspects of direct seeding in the United States.

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Direct seeding in the United States

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ABSTRACT

Approximately 210,000 acres are direct seeded annually in the United States, which constitutes 14% of the land reforested. The largest area has been in the West, consisting largely of sowing Douglas-fir (*Pseudotsuga menziesii*) in Oregon, Washington and California. This practice has recently declined, especially in Oregon, due chiefly to seed depredations by rodents, aggravated by new restrictions on the use of protective chemicals by federal agencies. Seeding in the South, principally with loblolly pine (*Pinus taeda*) and slash pine (*Pinus elliottii*), has been most extensive in Louisiana, Florida, Alabama, Mississippi and Georgia. Rodent problems are less severe here and most seeding is on private land where Endrin can still be used to protect seed. Seeding of the southern pines is continuing at a relatively constant rate although increased use of genetically improved seed and emphasis on controlled density give preference to planting seedlings where ecologic and economic factors permit. Thus, the banning of Endrin is decreasing the federal acreage sown in the West and if extended to private lands, will not only cause further decline of seeding there but also reduce it in the South. The development of a permissible seed protectant is urged.

RÉSUMÉ

Aux États-Unis d'Amérique, l'on sème directement environ 210,000 acres de terrain chaque année, ce qui constitue 14% de la superficie reboisée annuellement. C'est dans l'Ouest que cette méthode est la plus commune, où l'on sème du Sapin de Douglas (*Pseudotsuga menziesii*) en grandes quantités en Oregon, au Washington et en Californie. Récemment, surtout en Oregon, cette méthode fut moins employée vu surtout que les rongeurs mangent les graines, et que les agences fédérales limitèrent l'usage permis de produits répulsifs. Dans le Sud, surtout en Louisiane, en Floride, en Alabama, au Mississippi et en Georgie, on sème principalement le Pin à encens (*Pinus taeda*) et le Pin de Floride (*Pinus elliottii*). Les problèmes causés par les rongeurs sont moins importants ici et la plupart des ensemencements ont lieu dans les terrains privés où l'usage de l'Endrin est encore permis pour protéger les graines. Dans le Sud, on continue de semer autant qu'auparavant bien que l'usage plus grand de graînes améliorées génétiquement et le fait que l'on doive

mieux contrôler la densité fassent préférer des plantations de semis en terrains écologiquement et économiquement favorables. Bref, la défense d'utiliser l'Endrin entraine une diminution des superficies de terres fédérales semées dans l'Ouest et si cette défense venait à inclure les terres privées, un déclin plus fort se produirait dans l'Ouest, et le Sud serait affecté. L'auteur réclame de toute urgence la mise au point d'un nouveau produit répulsif dont l'usage serait permis légalement.

INTRODUCTION

In April 1959, I attended my first symposium on direct seeding, which was held at Duke University in Durham, North Carolina. I can vividly recall the tremendous enthusiasm which prevailed there over the promising success of this primitive forestry method, then so recently modernized by new technology. In retrospect, it was the "coming-out" party of the first forestry debutante to make the society page of our profession for a long time. As things transpired, direct seeding became "Miss Silviculture" of the 1960's and the purpose of this paper is to tell you something of her career. In more technical terms, this will constitute an attempt to brief you on the present state of the art of direct seeding in the United States.

Statistics published by the U. S. Forest Service (1952-1972) provide the best source of quantitative information on the contribution of direct seeding to the reforestation program. Prior to 1952, only 15 states had reported any seeding. The acreage totalled 65,000 and 95% of it was conducted on publicly-owned lands, largely in Oregon, Missouri and South Dakota (Table 1). These were the "old days" and there was little interest in seeding anywhere, other than for experimental purposes, with the possible exception of Oregon. But the situation changed drastically in the late 1950's with the advent of new chemical seed protectants, the enthusiasm for seeding the southern pines and the willingness of private landowners, especially forest industry, to accept direct seeding as a silvicultural method to supplement tree planting. By 1960, seeding was practiced in 6 more states and the total acreage had reached 500,000, 75% of it done during the formative 4-year period, 1957-1960 (Table 1).

Table 1. Direct seeding in the U. S. prior to 1961.

	Prior to 1952	1952-56	1957-60	Total
Alabama	26	—	17,981	18,007
Alaska	—	—	1,709	1,709
Arkansas	—	—	2,979	2,979
California	4,781	1,803	6,917	13,501
Colorado	2,641	162	714	3,517
Florida	—	633	6,878	7,511
Georgia	—	—	1,447	1,447
Idaho	1,376	—	1,693	3,069
Illinois	1,780	—	—	1,780
Louisiana	1,230	2,472	134,166	137,868
Michigan	1,126	—	202	1,328
Minnesota	3,045	10	35	3,090
Mississippi	550	700	9,075	10,325
Missouri	10,209	74	228	10,511
Montana	2,276	11	180	2,467
N. Mexico	—	1,538	592	2,130
Oregon	18,567	37,561	140,014	196,142
S. Dakota	13,186	1,254	1,539	15,979
Tennessee	14	265	595	874
Washington	1,868	6,488	57,376	65,732
Wisconsin	—	—	319	319
Total, 21 states	62,675	52,971	384,639	500,285
Total, all states	64,544	54,332	387,281	506,157
Federal	47,743	20,347	75,037	143,127
State	13,529	23,853	38,414	75,796
Private	3,272	10,132	273,830 [1]	287,234

[1] 55,376 acres previously unreported is not included.

Since 1960, approximately 210,000 acres have been seeded each year, two-thirds of it on private lands. The total area reforested annually by both tree planting and seeding has been about 1.5 million acres, so direct seeding's contribution to the reforestation program has averaged 14% over the past 12 years (Table 2).

By 1971, some seeding had been reported in most states but the acreage sown has been rather insignificant (less than 1000 per year) in 30 of them (Table 3). Each of the other 20 states have sown more than 10,000 acres since 1961 and the combined area seeded by them constitutes 97% of all land reforested by direct seeding. Thus, while seeding may seem to have become established throughout the country, it is important to look to the various regions and even individual states to determine where it has attained a useful status.

Table 2. Contribution of direct seeding to reforestation in the U.S., 1961-1972.

Year	Total acres reforested (in thousands)	Number acres planted (in thousands)	Number acres direct-seeded (in thousands)	Percent of area reforested by direct seeding
1972	1,680.2	1,455.7	224.5	13.3
1971	1,692.9	1,450.0	242.9	14.3
1970	1,599.8	1,336.3	263.5	16.4
1969	1,457.5	1,232.9	224.6	15.4
1968	1,468.6	1,250.6	218.0	14.8
1967	1,407.7	1,225.7	182.0	12.9
1966	1,319.8	1,141.0	178.8	13.5
1965	1,325.0	1,136.2	188.8	14.2
1964	1,353.6	1,169.6	184.0	13.5
1963	1,362.7	1,141.2	221.5	16.2
1962	1,402.1	1,191.2	210.9	15.0
1961	1,796.2	1,614.8	181.4	10.1
Totals	17,866.1	15,345.2	2,520.9	14.1 (avg.)

NORTHEAST

Paradoxical as it may seem, the six New England states and New York are included among those where direct seeding is of no practical importance since only 1162 acres have been reported (Table 3). In this region, reforestation has waned, rather than increased, and if it were not for specialty plantings, such as Christmas trees, even forest nurseries could be phased out with little effect upon forestry programs. Nevertheless, seeding techniques have been developed which could be used successfully. Some of these were reported during the symposium held at the University of Massachusetts in 1964 and you will hear about more recent developments from my two New England colleagues.

My own personal efforts in seeding research have been largely terminated because the use of Endrin is not permitted in Massachusetts and without a replacement for it, seed losses to small mammals

Table 3. Thirty states seeding less than 1000 acres annually, to 1972.

State	Number acres seeded 1961-71	Prior to 1961	Total
Wyoming	9,075	2,462	11,537
Colorado	8,125	3,510	11,635
Arizona	8,106	706	8,812
Kansas	4,898	—	4,898
Oklahoma	3,972	505	4,477
Michigan	3,923	1,378	5,301
Alaska	3,085	1,719	4,804
South Dakota	2,811	15,979	18,790
Tennessee	2,762	874	3,636
Wisconsin	1,542	726	2,268
Utah	1,370	44	1,414
Ohio	1,099	414	1,513
Northeastern States (7) [1]	1,114	48	1,162
Other States (11) [2]	4,050	2,333	6,383
Total	55,932	30,698	86,630

[1] New England states and New York.

[2] Delaware, Hawaii, Illinois, Indiana, Iowa, Maryland, Nebraska, Nevada, New Jersey, North Dakota and Pennsylvania.

are too great to make seeding reliable. I am convinced that there is a place for direct seeding in the management of our northeastern forests, especially in regenerating areas burned by wildfires and in supplementing natural reproduction after logging. However, until the larger industrial landowners start practicing more intensive silviculture, direct seeding in the Northeast will continue to be potential.

LAKE STATES REGION

The Lake States (Minnesota, Michigan and Wisconsin) have the closest affinity to forestry in Ontario because of their more boreal forest types. However, both Wisconsin and Michigan are also among those states where less than 1000 acres per year have been seeded since 1960 (Table 3). Most of the recent interest has been centered in Minnesota (Table 4), where direct seeding is increasing and has equalled the national average of 14% of the reforestation in the state during the past 5 years. The U. S. Forest Service has been the leader here and has done about 80% of the seeding, most of it on the Superior National Forest. Seeding with jack pine (*Pinus banksiana*) has been very successful and about 75% of the acreage

Table 4. **Acreage seeded in 20 Leading States, to 1972.**

State	Acres Seeded Prior to 1961	Acres Seeded 1961-1971	Total
Alabama	19,743	133,577	153,320
Arkansas	2,979	66,488	69,472
California	12,970	107,473	120,443
Florida	7,511	134,618	142,129
Georgia	1,557	96,521	98,078
Idaho	3,083	10,492	13,575
Kentucky	660	27,352	28,012
Louisiana	139,426	243,902	383,328
Minnesota	3,290	30,378	33,668
Mississippi	9,803	119,472	129,275
Missouri	10,511	18,473	28,984
Montana	2,863	37,897	40,760
New Mexico	2,130	18,787	20,917
North Carolina	328	34,629	34,957
Oregon	207,551	664,949	872,500
South Carolina	550	55,022	55,572
Texas	3,045	26,025	29,070
Virginia	137	58,840	58,977
Washington	113,635	348,882	462,517
West Virginia	194	37,632	37,826
Totals	541,971	2,271,409	2,813,380 [1]

[1] Constitutes 97% of total acreage seeded.

sown has been with this species. Site preparation has involved prescribed burning, the use of tractors, either with rock rake blades or pulling shark-finned barrel scarifiers with anchor chains. A "torpedo seeder" has been used in conjunction with the barrel scarifier for spring and fall sowing. However, seed application is preferably done on the snow with snowmobiles (Fig. 1) on the larger areas (Larson and Jamrock, 1969) or with hand-operated Cyclone Seeders on smaller plots. Winter seeding presumably reduces losses of seeds to birds and rodents. Endrin is not used, only Arasan, latex and aluminum flakes being applied. The effectiveness of this treatment is in doubt.

Environmental restraints on severe site preparation for areas having much shrub and tree competition prevent direct seeding. These areas are treated with light site preparation and hand planted.

Other species seeded in Minnesota are red pine (*Pinus resinosa*), white spruce (*Picea glauca*) and black spruce (*Picea mariana*). Black spruce seeding on peatland following broadcast burning of slash has been successful and will probably be continued since two-thirds of the black spruce type in the Lake States is in Minnesota. Seeding of northern white-cedar (*Thuja occidentalis*) and tamarack (*Larix laricina*) may also become practical as interest in these forest types is increasing.

Economics of direct seeding in Minnesota are highly motivating. The U. S. Forest Service's costs on the Superior National Forest are less than one-sixth that of hand planting.

SEEDING IN THE WEST

Pacific Northwest

Of the other 19 states where 1000 acres or more have been seeded annually, six are in the West. Oregon and Washington, respectively, have been the two leaders in the country and their combined efforts equal over one million acres or nearly one-half of all the land seeded during the 11-year period 1961-1971 (Table 4). This constitutes nearly 40% of the land area

Figure 1. Snowmobile seeding in Minnesota (*Courtesy of John Benzie, U.S.F.S.*).

reforested by these two states. Probably 98% of all the seeding has been to Douglas-fir (*Pseudotsuga menziesii*). Helicopter seeding (Fig. 2) is most popular and site preparation has consisted largely of only prescribed burning or none at all. In those instances where more expensive treatment was required, tree planting replaced seeding. Earlier practices to prevent seed losses by rodents consisted of pre-baiting with 1080-treated wheat to reduce small mammal populations prior to seeding. When 1080 became unavailable a few years ago, treating seeds with Endrin became the standard practice as it had elsewhere in the country. A few hundred acres of spot seeding have been done each year but this method has generally been insignificant. The seeds were either treated with Endrin or covered with wire mesh screens to protect them from rodents.

Seeding in the Pacific Northwest has been only a partial success, because it usually has resulted in either over-stocking or a complete failure. Few successes have been experienced with Douglas-fir on hot, south-facing slopes in the southern section. Best results have been further north on the east and north-facing slopes or in coastal areas with fog drip or more adequate summer precipitation. Although the area seeded in this region has been very large over the past 15 years, chances of consistent success is considered remote by many foresters. Exceptions occur, such as in northern Washington, where climate is more amenable and less severe rodent problems tend to make seeding preferred over planting.

Washington and Oregon require landowners to attempt reforestation; one reason for direct seeding's popularity is because it represents the least costly way of meeting this requirement. One of my West coast correspondents feels that when landowners become more concerned over keeping their forests adequately stocked than merely attempting the cheapest method of reforestation, the popularity of seeding will decline.

A forest scientist with a large industrial landowner reports that their cost of tree planting is over 5 times that of direct seeding (no special site preparation measures taken) but that this increased expense is considered justified on their three highest site classes.

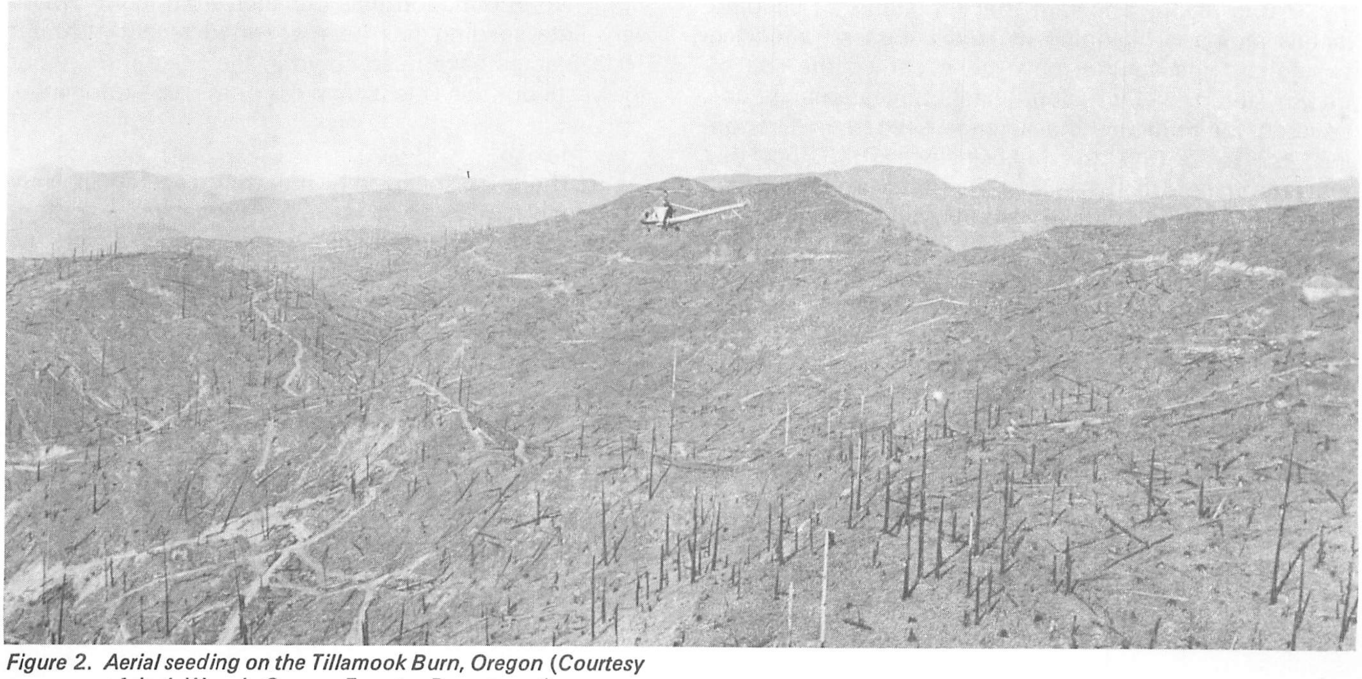

Figure 2. Aerial seeding on the Tillamook Burn, Oregon (Courtesy of Jack Wanek, Oregon Forestry Department).

Their acreage seeded has been proportional to the amount of harvesting on poor quality land, varying from 15 to 40% in recent years. He emphasized the importance of protecting seeds from deer mice and other enemies. Endrin is still in use by his company but a recent study showed that even with this protection, 20% of the seeds were lost to rodents, 25% to insects, 40% to fungi and 10% to unknown causes. Only 5% resulted in trees.

Another correspondent informed me that the U. S. Forest Service has greatly reduced the amount of direct seeding in both Oregon and Washington. Their reforestation efforts in the future will be 99% planting and 1% spot seeding. Major reasons given for this policy are: (1) restrictions on the use of 1080 and Endrin make rodent control nearly impossible; (2) site preparation costs plus seeding about equals the cost of planting; (3) an increasing proportion of reforestation is from genetically improved seed, which because of its scarcity is used exclusively in a planting program; and (4) results of aerial seeding are too erratic to achieve the desired regeneration within 1 year after harvesting.

It is readily apparent that the status of seeding in this region is changing markedly. Federal agencies throughout the country have been denied the use of Endrin and this fact alone has unquestionably accounted for reducing the acreage seeded in Oregon in 1972 to 29,000, the lowest since 1959. For the first time in more than a decade, Oregon has relinquished its position as the number 1 state in direct seeding.

California

California is the only other western state which has seeded more than 100,000 acres. Douglas-fir is the major species here also, but several other species have been seeded, such as: ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), Monterey pine (*Pinus radiata*), white fir (*Abies concolor*), red fir (*Abies magnifica*), sitka spruce (*Picea sitchensis*), Port-Orford-cedar (*Chamaecyparis lawsoniana*) and redwood (*Sequoia sempervirens*).

A recent survey (Conkle, 1972) indicated that 37% of the state's reforestation in 1969-70 was by seeding. U. S. Forest Service statistics show that seeding has averaged about 20% of the area reforested since 1960.

Seeding has been increasing, and one influential factor suggested had been a California law requiring guaranteed regeneration on clearcut lands (Conkle, 1972). High planting costs, scarcity of seedlings and the need to reforest inaccessible areas all combine to encourage the continuation of seeding in this State.

Major obstacles to success are seed losses to rodents, summer drought and scarcity of Douglas-fir seed. Baiting to reduce rodent populations plus treatment of seed with Endrin is considered mandatory to successful direct seeding in California.

Montana and Idaho

About 40,000 acres have been seeded in Montana, nearly 20% of the reforestation there in recent years. The seven species in order of use are: western larch (*Larix occidentalis*), Douglas-fir, Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), ponderosa pine, grand fir (*Abies grandis*), and western white pine (*Pinus monticola*). The major obstacle to success here seems to be seed losses to rodents. Without adequate protection from baiting and/or seed protectants, failures are eminent.

No information was obtained from Idaho where very little seeding has been reported recently. About 10,000 acres have been sown in the State throughout the years but this is less than 4% of the area reforested.

New Mexico

There has been very little reforestation in New Mexico but 62% of it is represented by the 21,000 acres which have been direct seeded, mostly on the Lincoln National Forest. Ponderosa pine accounts for 95% of the seed sown but Douglas-fir, white fir, and southwestern white pine (*Pinus flexilis* var. *reflexa*) are also used. Success here has been low, estimated at only 20%. Rodents are a major factor and without 1080 or Endrin as protectants, direct seeding has little chance to succeed.

SEEDING IN THE SOUTH

Most of the other 13 states, where seeding is important, are in the South where the concern, primarily, is with regenerating southern pines (Figs. 3, 4). Louisiana, Florida, Alabama, Mississippi and Georgia are the leaders. Louisiana ranks third in the country,

Figure 3. Aerial seeding in the South (Courtesy of Bill Mann, U.S.F.S.).

Figure 4. Row-seeded longleaf pine emerging from grass stage (Courtesy of Bill Mann, U.S.F.S.).

exceeded only by Oregon and Washington, and has sown nearly a quarter of a million acres since 1961. This approximates 29% of its reforestation. In Florida, where more acres have been reforested than in any other state in the country, the contribution of direct seeding has been about 7%. Georgia, second only to Florida in tree planting, moved into the 100,000-acre group of seeding states in 1972. Seeding here has represented about 6% of the State's reforestation effort. South Carolina ranks among the top 10 states in reforestation but its 55,000 acres of seedings equals less than 1% of its regeneration. In Texas, Alabama, Mississippi and North Carolina seeding ranges from about 5 to 12% of the land area reforested.

No reliable information is available on the acreage sown by species but it is probably conservative to state that over 90% has been with loblolly and slash pines. This of course does not apply to all states, especially some of those outside of the deep South. An outstanding example is West Virginia, where direct seeding of black locust (*Robinia pseudoacacia*) has been the most common method of reforesting surface-mined lands since the 1940's (Brown, 1973). Brown (1962) found that successful stands of trees were established on nearly 75% of these seeded spoil-banks. The increasing popularity of this practice is demonstrated by the fact that it accounted for 12% of the State's acreage reforested in 1967, 40% in 1968, and 62% in 1972.

Thanks to the efforts of Bill Mann and Harold Derr, the practices and problems associated with seeding the southern pines are so well described in U. S. Forest Service publications that an elaboration here would be quite redundant.

The banning of Endrin for use by federal agencies has, for obvious reasons, had less effect in the South than in the West as seeding here is largely on private lands. This is reflected in the 1972 statistics which show an increase in acreage seeded over previous years.

Mann believes that the greatest obstacle to expanded seeding of the southern pines will be the increased production of genetically improved seed. However, if aerial row seeding and seed encapsulation (on which he is currently conducting research) can be perfected, the efficiency of seeding can be increased sufficiently to make it competitive with planting. He further predicts that direct seeding's contribution will continue to be about 15% of the area reforested in the South even if these improvements are not achieved. Savings in labor costs and time are the factors given by him that should assure the continuation of direct seeding's status in southern pine silviculture.

I would like to add a few personal observations on seeding in the South based upon my visits there over a 3-month period during the spring of 1972. From conversations with foresters employed by several of the larger, industrial landowners, especially in Florida, Georgia, and the Carolinas, I found little enthusiasm for direct seeding. Their reforestation programs, which include very expensive site preparation measures, are based primarily on the planting of genetically improved seedlings. Within less than a decade, seed orchard production should be sufficient to supply seeds to meet all of the planting needs of these companies and the advantages of planting over seeding would, therefore, appear to be greater here than anywhere else in the country. In addition, new emphasis upon spacing, density control and future avoidance of thinnings of any type, commercial as well as pre-commercial, would seem to dictate against seeding.

There is, however, another more subtle aspect to the situation. The tasks of site preparation and planting thousands of acres of forest land each year are tremendous. Droughty periods, excessively wet seasons and other climatic vagaries occasionally curtail reforestation efforts so drastically that millions of seedlings lifted from the nursery go unplanted. This not only reduces the acreage reforested but also increases the cost of the stock that does get planted. The normal planting season is much too short to accomplish the task at hand and research efforts to extend the period of time when seedlings can be successfully planted are now being made.

Thus, because large areas can be seeded quickly or under conditions when planting is not feasible, and at a somewhat reduced cost, direct seeding should continue to serve as a valuable ally to planting in the South. This point is emphasized by the following statement in a letter received from a commercial helicopter seeding company: "The real activity for aerial seeding has been here in the Southeast from Arkansas on across to Georgia. Last year our company seeded 30,000 acres from our Georgia base alone. This market, for us, has been growing each year. With labor getting more and more expensive and clearcutting growing with each year, the foresters have found aerial seeding to be the only way of keeping up."

SUMMARY AND CONCLUSIONS

Approximately 210,000 acres, two-thirds on private lands, are direct seeded annually in the United States. This represents 14% of the land area being reforested. Although 49 of the 50 states have reported some seeding, the area sown is significant in only 20 states, and the more important ones are either in the West or South. The one exception is Minnesota, where the seeding of jack pine and black spruce is becoming increasingly important.

Most of the direct seeding in the West has been with Douglas-fir in Oregon, Washington, and California. Although this region leads the nation in area seeded, this practice is considered by many foresters to be only a qualified success and is declining, especially in Oregon. Seed losses to rodents, aggravated by recent restrictions on chemicals such as 1080 and Endrin, are primarily responsible for this decline, especially on federal lands. Lifting the ban on Endrin to permit resumption of its use by federal agencies, or finding a satisfactory substitute for it, seems essential to the continuation of seeding in the West as extensively as in the past.

Seeding in the South, led by Louisiana, Florida, Alabama, Mississippi and Georgia, is principally with loblolly and slash pines. Rodent problems here are less severe than in the West and the areas involved are largely under private ownership. Thus, recent restrictions on the use of chemicals for baiting and seed protection have been less inhibiting. Acreage sown continues to be at about 100,000 each year and no general decline is evidenced. If the use of Endrin on private lands is not banned, seeding in the South will probably continue at about 15% of the area reforested. However, the increased use of genetically improved seed and the emphasis on density control will give preference to planting wherever ecologic and economic factors will permit it.

In conclusion, it must be admitted that direct seeding has not achieved the status of a Utopian regeneration method that all silviculturists desire. The land area seeded is not a true measure of its usefulness and even under the most optimum conditions results have often been disappointing. Failures have been prevalent and successes plagued by excessive stocking. Nevertheless, its merits seem to overshadow its inadequacies, for it has made a valuable contribution, as a compromise technique, to the improvement of the composition and stocking on forest lands long neglected, such as the Tillamook Burn in Oregon and the cutover pineries of the South. It has also given us another means of aiding nature is replacing the coniferous forests which have been harvested or destroyed by fires during the past decade, especially on low quality or inaccessible sites.

I believe that some of the frailties of this forestry practice are due to our failure to perfect it. Surely we cannot fault the method because of our inability to protect tree seeds from rodents. Although there are many ways in which we could work to improve the efficiency of direct seeding, the development of an effective seed protectant, or other means of reducing seed losses to rodents should be our top research priority. There is no reason to believe that this cannot be achieved and if we do so, direct seeding should continue to make a significant contribution to reforestation in the United States.

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Direct seeding in Canada 1900-1972

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Between 1900 and 1972 approximately 337,000 acres were direct seeded in Canada; currently 42,000 acres are being treated annually at an estimated average cost of $27 per acre. These data compare with a 72 year total of 3,000,000 acres planted and a current annual program of 260,000 acres at $55 per acre (Haig and Scott 1972).

Stocking for all species and treatment combinations over the 72-year period averaged 26% on a milacre basis with 1,100 4-year-old seedlings per acre; comparable 'stocking' for current planting programs is approximately 45% or 450 surviving transplants per acre (Anon. 1970). The calculated cost of a stocked quadrat would be $1.04 for direct seeding and $1.22 for planting. At an average sowing rate of 50,000 seeds and a ratio of one seedling per 44 seeds sown, the cost of one 4-year-old seedling was 2 cents; the cost per transplant 12 cents.

To date, only jack pine has been successfully direct seeded. Although all other species sown have been failures, direct seeding of Douglas-fir, black spruce and lodgepole pine have yielded somewhat better results than those achieved for eastern white pine or white spruce.

The use of direct seeding as an operational technique has, in recent years, been increasing at a rapid rate:

Years	Acreage	%
1903–1912	10,020	3
1913–1922	180	* [1]
1923–1932	26,731	8
1933–1942	585	*
1943–1952	24,321	7
1953–1962	28,159	8
1963–1972	246,982	73

[1] Less than 1%.

This increased use appears to be based largely on the spiralling cost of planting bare-root stock, labor shortages, and inconsistent results being obtained with container-grown seedlings rather than on any significant degree of success achieved in the past using direct seeding, either on a research or operational basis. In 1972, 42,000 acres were direct seeded in Canada, almost double the average (25,000) of the previous 10 years.

Excluding a small number of operational scale direct seeding projects carried out by industry in the early 1900's and in the 1920's, the bulk of the direct seeding carried out between 1900-1955 was research orientated. It wasn't until the mid-1950's and early 1960's that the potential of direct seeding for regenerating burned-over and cut-over areas, for converting hardwood stands to conifers and, for afforesting grass and heathlands was taken seriously and large scale operational programs undertaken. Over the 72-year period 90% of the acreage seeded has been on an operational scale and 10% on research and development of methods, materials (repellents) and equipment. Over the past 5 years (1967-1971) research has been running at about 2%.

Most of the direct seeding in Canada has been carried out in Ontario and Alberta and to a lesser extent in Quebec and British Columbia:

The direct seeding programs have been carried out by the provincial agencies responsible for forest management and for forest research [2] (86%), by industry (13%) and the Canadian Forestry Service (1%).

Province	Acreage (1900–72)	% (1900–72)	Year of 1st recorded seeding	Estimated acreage direct seeded in 1972
Ontario	139,392	41	1905	20,700
Alberta	122,725	36	1911	15,600
Quebec	27,227	8	1908	2,600
British Columbia	15,558	5	1923	2,100
Nova Scotia	10,037	3	1904	0
Manitoba	8,573	3	1904	300
Newfoundland	5,203	2	1950	0
New Brunswick	4,734	1	1923	300
Saskatchewan	3,529	1	1909	200
Prince Edward Island	0	0	—	0

White spruce and jack pine account for most of the acreage direct seeded to date; less important species include lodgepole pine, Douglas-fir, eastern white pine and black spruce. A complete listing is as follows:

Species	Acreage (1900–1972)	% (1900–1972)
White spruce	141,623	42
Jack pine	114,171	34
Lodgepole pine	15,201	5
Douglas-fir	13,592	4
E. white pine	13,359	4
Black spruce	13,210	4
Norway spruce	10,114	3
Red pine	6,259	2
Scots pine	3,551	1
Sugar maple	1,234	*
Yellow birch	1,131	*
Balsam fir	903	*
Red spruce	770	*
Western hemlock	578	*
Engelmann spruce	435	*
E. white cedar	285	*
W. red cedar	219	*
Sitka spruce	194	*
Western larch	62	*
Ponderosa pine	47	*
Siberian larch	29	*
W. white pine	6	*
Oak	4	*
Eastern larch	1	*

[2] Principally the British Columbia and Ontario Research Divisions.

Current programs are principally white spruce in Alberta and jack pine in Ontario. As a result of high seed costs direct seeding of Douglas-fir in British Columbia on an operational basis is rare; MacMillan-Bloedel have completely abandoned direct seeding as an economical and effective reforestation technique.

Reliable information on the viability of seed used in direct seeding is lacking. Available information indicates that jack pine seed was of high quality – between 80-100% viable. Evidence indicates that the viability of white spruce seed was low (Johnson 1973) – probably closer to 50%. Viability of the other tree species was extremely variable.

Seed treatment to protect against rodents and birds was used as early as 1924 but it wasn't until the late 1940's that detailed research was undertaken. In the early years seed was treated with red lead and sown with farm drills or broadcast as untreated seed. Later a variety of rodenticides, fungicides and lubricants were introduced. Of the more important chemicals used, combinations of endrin, arasan and aluminium flakes were the most significant (72%):

Seed treatment	Acreage	%
	(1900–1972)	
Endrin-aluminium	111,373	33
Arasan-endrin-aluminium	72,213	21
Arasan	43,644	13
Arasan-endrin	10,495	3
Endrin	3,786	1
Aluminium	1,618	*
Sub total (A.E.A.)	243,129	72
Captan-50W	6,900	2
Poison baits (1080)	2,351	1
Tetramine	1,310	*
Red lead	1,071	*
Other	1,244	*
Total treated	256,005	76
Not treated	80,973	24

It is interesting to note that the use of untreated seed in recent years is on the increase, reflecting to some extent the fact that some of the chemicals developed have not proven entirely reliable and that some (endrin) are dangerous to man if not handled with adequate precautions (Scott 1970). In the case of Captan-50W, research proved that this fungicide was detrimental to seed when surface sown (i.e. reduced germination and increased germinate abnormality) but was insignificantly so when seed was sown as deep as in nursery seedbeds (Cayford and Waldron 1967). The use of tetramine and poison baits on the west coast has been halted; although currently used by New Brunswick, red lead is of historic interest only. In 1971, 68% of the seed sown was untreated or coated with lubricants (aluminium) only and 32% treated with repellents as compared to 2% and 98% respectively in 1967.

The majority of the direct seeding to date has been carried out in the autumn:

Season of sowing	Acreage	%
	(1900–72)	
Spring (Apr.-May)	55,324	16
Summer (June-Aug.)	15,244	5
Autumn (Sept.-Nov.)	222,550	66
Winter (Dec.-Mar.)	43,860	13

In recent years winter sowing has shown a slight increase due mainly to the development of a motorized tree seed broadcaster designed for use on snowmobiles (Brown 1969). Most summer seeding was carried out in early June; very little direct seeding has taken place in July and August.

Direct seeding has been carried out under a wide variety of vegetative conditions including areas devastated by wildfire, cut-overs, and in undisturbed forests (hardwood conversions):

In more recent years (1967-71) emphasis has been on cut-overs; better fire detection and suppression techniques have significantly reduced the acreage of wildfires requiring regeneration inputs. Johnson (1973) recently recommended that due to poor results conversion of hardwood sites should not be attempted until improved techniques can be applied.

Vegetative conditions	Acreage (1900–72)	% (1900–72)	% (1967–71)
Cut-overs	168,367	50	76
Wildfires (burned standing)	95,888	26	8
Undisturbed forests (conversion)	63,557	19	14
Cut-overs followed by wildfire	8,122	3	2
Barrens (grassland and heath)	880	*	*
Abandoned farmland	164	*	*

Excluding areas subjected to wildfires, mineral soil seedbeds were generally prepared – either mechanically or manually – prior to direct seeding. Bulldozer and blade (standard straight plus a variety of more recently developed blades including Young's teeth, and V) has been most often used, followed by the Ontario barrel scarifiers and anchor chains:

Scarification Equipment	Acreage (1900–72)	% (1900–72)	% (1967–71)
Bulldozer (plus a variety of blade designs)	134,049	40	54
Barrels and anchor chains (drags)	72,694	22	30
Prescribed burning	13,916	4	1
Hand implements	12,185	4	3
Athens disc, middlebuster plough	10,219	3	2
SFI, Imsett, Bracke.	8,029	2	4
Other	3,944	1	*
No site preparation	81,941	24	6

Presently the bulldozer, together with either blade or drag scarifiers, account for 84% of the scarification equipment in use. Ploughs and discs have never been too popular and reflect early attempts at scarification; prescribed burning has been used principally in B.C. although other provinces have used the techniques on an experimental basis. The SFI, Imsett and Brackekultivatorn are more recent innovations and require further field testing (Hall 1970).

Spot and aerial broadcast have been the two most common seeding techniques used; surprisingly ground broadcast has not been used very frequently while mechanical seeding using heavy equipment is still in the research and development stage:

Type of seeding	Acreage (1900–72)	% (1900–72)	% (1967–71)
Spot	154,262	46	41
Broadcast-aerial	131,383	39	48
-ground	46,450	14	8
Mechanical with heavy equipment	4,883	1	3

Spot seeding has largely been carried out using the Brohm, Swedish and M & B hand seeders, "walking sticks", home made shakers such as oil cans, or by hand. Helicopters and fixed wing aircraft have been used for aerial seeding; the latter appears to be gaining in popularity in more recent years (a 60-40 split between 1967-71). On-the-ground broadcast seeding has been carried out using the standard cyclone seeder or more recently with motorized seeders mounted on snowmobiles:

Seeding equipment	Acreage (1900–72)	% (1900–72)	% (1967–71)
Hand	88,894	26	13
Hand seeders & shakers	82,535	25	28
Helicopters	71,092	21	29
Fixed-wing aircraft	60,967	18	19
Cyclone seeder	21,661	6	4
Scarification and seeding equipment	8,527	3	5
Motorized seeders on snowmobiles	3,302	1	2

The use of aerial seeding is presently on the increase while spot seeding with its heavy reliance on manpower appears to be on the decline (51% 1900-72 compared to 41% 1967-71).

Between 1900 and 1972 a total of 116,000 lb. of seed were sown; the average rate of sowing for all species and treatment combinations was 50,000 seeds per acre:

Rate of sowing (seeds/acre)	Acreage (1900–72)	% (1900–72)
0– 10,000	90,705	27
10,001– 20,000	97,187	29
20,001– 30,000	29,753	9
30,001– 40,000	9,497	3
40,001– 50,000	25,047	7
50,001–100,000	29,272	9
100,001–200,000	19,467	6
200,001 +	36,050	10

However rate of sowing was variable depending principally on the seeding technique and the species, and to a lesser extent on seed size and seed viability. For spot seeding and for the larger seeded species such as Douglas-fir, eastern white and red pines, 5,000 to 30,000 seeds per acre have been used; most of the white spruce acreage was spot seeded at a rate of 50,000 seeds per acre. Aerial seeding of jack pine has been carried out with 20,000-40,000 and black spruce with 60,000-80,000 seeds per acre (Scott 1966a). Heavier rates, up to 200,000 + seeds per acre, have been used for the small-seeded species such as western hemlock and eastern white cedar.

It is extremely difficult to evaluate with any high degree of certainty the stocking results documented in this review (1) because data are available for only 40% of the total acreage treated, (2) because of the large number of species, factors and treatment combinations and, (3) the fact that the majority of the seeding has taken place in the past 5 (44%) to 10 (73%) years.

Nevertheless, from the information available it would appear that over the broad spectrum direct seeding has not been an unqualified success – rather the opposite would appear to be true. Only 26% of the direct seeded acreage for which data is available had milacre stockings exceeding 40% at an average seedling age of 4 years:

Stocking (% milacre)	Acreage (1900–72)	% (1900–72)
0– 20	203,999	61
21– 40	44,369	13
41– 60	47,527	14
61– 80	31,589	9
81–100	9,494	3

Similarly only 29% of the direct seeded acreage had 1,000 or more 4-year-old seedlings per acre:

Stocking (seedlings/acre)	Acreage (1900–72)	%
0– 500	204,826	61
501– 1,000	32,839	10
1,001– 2,000	46,416	14
2,001– 5,000	43,248	13
5,001–10,000	8,762	2
10,001 +	887	*

Smithers (1965) in his report "Direct seeding in eastern Canada" determined the success of both operational and research direct seeding projects carried out prior to 1963 using a rating system based on species, seedling age, and percent milacre stocking. That rating system, to which Douglas-fir has been added, is outlined here:

Success Category	Stocking: Jack, lodgepole and eastern white pine, Douglas-fir (% milacre)	Stocking: White and black spruce (% milacre)
Satisfactory		
1 year	60+	70+
2 years	50+	60+
3 years plus	40+	50+
4 years plus		40+
Moderate		
1 year	40–59	50–69
2 years	40–49	50–59
3 years plus	30–39	40–49
4 years plus		30–39
Failure		
1 year	<40	<50
2 years	<40	<50
3 years plus	<30	<40
4 years plus		<30

Using the above standards it becomes apparent that only jack pine has been successfully direct seeded (Table 1). Clearly direct seeding of white spruce and eastern white pine have been complete failures; stocking results for Douglas-fir, black spruce and lodgepole pine, while double that of the previous two species, fall below that required for even a success rating of "moderate".

An analyses of factors affecting the stocking success of jack pine and white spruce direct seeded between 1953 and 1972 reveals — ALTHOUGH THIS 'REVELATION' SHOULD NOT BE TAKEN AS CONCLUSIVE PROOF — that certain situations are more conducive to successful stocking than others (Table 2). It should be stressed that these data represent averages based on unequal sampling in which only one factor is examined at a time; an examination of comparable factor combinations would allow for more reliable conclusions to be drawn. Nevertheless, a number of observations can be made.

Table 1. Success of direct seeding programs between 1900 and 1972 for 6 selected species.

Species	Stocking Success[1] 1900 — 1972 Satisfactory (% of acreage treated)	Moderate	Failure	Average Stocking (% milacre)	Average Seedling Age (years)	Overall Success Rating[1]	Minimum % Stocking rq'd for Satisfactory Rating[2]	Basis No. Trials	No. Acres	Acres Treated (1900-72)
Jack pine[3]	39	13	48	40	2.5	Moderate	45	195	46,400	114,200
Douglas-fir	6	23	71	31	2	Failure	50	83	10,900	13,600
Lodgepole pine	22	14	64	25	3	Failure	40	46	4,000	15,200
Black spruce	5	10	85	23	3	Failure	50	35	2,200	13,200
E. white pine	2	2	97	13	4	Failure	40	22	3,800	13,300
White spruce[3]	2	*	98	12	4	Failure	40	79	19,500	141,600

[1] After Smithers (1965).
[2] Using age of seedlings (years) given in column 6.
[3] Data for jack pine and white spruce from 1963–1972 programs only.

Table 2. Factors affecting the stocking success of direct seeded jack pine and white spruce, 1953 – 1972.

Factor	Average Stocking[1] and Success Category[2] 1953-1972: Jack Pine % Stocking	Jack Pine Success Category	White Spruce % Stocking	White Spruce Success Category
Year:				
1900 – 1952 1953 – 1962	40	M	15	F
1963 – 1972	40	M	12	F
Seed Treatment:				
None	27	F	–	–
A.E.A. Arasan	48 42	S M	12	F
Captan-50W	25	F	15	F
Season of Sowing:				
Spring	55	S	37	M
Summer[3]	69	S	10	F
Autumn	41	M	11	F
Winter	23	F	20	F
Vegetative Conditions:				
Cut-overs	43	M	22	F
Wildfire	25	F	10	F
Cut-over-wildfire	25	F	–	
Undisturbed (conversion)	–	–	11	F
Scarification Equipment:				
Athen's disc	28	F	–	
Barrels, chains	36	M	–	
Bulldozer, blades	69	S	12	F
Imsett, SFI	41	M	–	
None	17	F	10	F

Factor	Jack Pine		White Spruce	
	% Stocking	Success Category	% Stocking	Success Category
Type of Seeding:				
Spot	44	M	10	F
Broadcast-ground	42	M	19	F
-aerial	39	M	10	F
Mechanical	36	M	–	
Seeding Equipment:				
Cyclone	38	M	19	F
Helicopters	36	M	10	F
Fixed wing	48	S	–	
Scarifiers and Seeders	48	S	–	
Hand or hand seeders	44	M	10	F
Rate of Sowing:				
0–10,000	26	F	10	F
10,001–20,000	44	M	12	F
20,001–30,000	52	S	–	
30,001–40,000	43	M	–	
40,001–50,000	33	F	10	F
50,001+	25	F	17	F

[1] Based on a minimum of 500 acres per factor.
[2] Based on Smither's (1965) stocking standards and an average seedling age of 2.5 years for jack pine and 4.0 years for white spruce.
[3] Generally seeded in early June or 'late spring'.

It is apparent that the degree of success achieved through direct seeding of jack pine has not changed over the past 72 years. However, it is apparent that seed treatment with the arasan-endrin-aluminium combination, or more recently with Arasan alone has been beneficial. Research has shown that the benefits of treating seed with repellents can be attributed to increased germination or reduced rodent and bird losses. The detrimental effects of Captan — 50W on seed have been previously reported (Cayford and Waldron 1967). The success of direct seeding is more related to the weather than to the season of the year. Nevertheless, over the long run (20 years), it would appear from this data that sowing in April, May or June has yielded, on the average, higher stocking than either autumn or winter seeding. As pointed out by many (Smithers 1965), direct seeding on burned seebeds is not normally successful; exposures of mineral soil on cut-over situations would appear to be more conducive to success. The bulldozer together with a wide variety of blade designs apparently produces the optimum seedbeds for jack pine germination and early survival; also suitable for seedbed preparation are the barrels and chains and the more recently developed Imsett and SFI scarifier — seeders; in the latter case further testing is warranted before wholesale application with this equipment.

There is little to choose between seeding techniques as apparently they have all been equally successful in distributing the seed on suitable seedbeds; fixed wing aircraft may provide better coverage than the helicopter, and the scarifier-seeders appear to be promising. Although the data are somewhat contradictory it would appear that on the average 20,000 — 30,000 jack pine seeds are adequate for obtaining satisfactory stocking [3].

It is difficult to analyze factors affecting success when results indicate a complete failure, and the analysis of the direct seeding of white spruce is no exception. Truthfully nothing can be said here that would prove useful although a case might be made for spring seeding.

In summary it can be stated that, with the exception of jack pine, direct seeding in Canada

[3] The success achieved by sowing so few seeds (1/5 lb./acre) can probably be attributed, in part, to the fact that a considerable number of seedlings are obtained from cone-bearing slash following site preparation for direct seeding. The use of barrels or anchor chains to obtain satisfactory stocking of jack pine regeneration from cone-bearing slash — without direct seeding — is a proven operational silvicultural technique in current practise in northwestern Ontario, northern Manitoba and Saskatchewan.

between 1900-1972 has on the average been a failure. It is believed that with perhaps some minor operational modifications and site selection, direct seeding of jack pine could be made more successful. For the other species it would appear that an indepth analysis of the reasons for failure is required. I personally believe that adequate information on the ecology and silviculture of direct seeding the principle conifers is available now. What is needed is not more research, but better application of existing knowledge.

With improved operational application, direct seeding could become a viable silviculture technique in reforestation programs.

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APPENDIX I

Table 1. Costs of direct seeding in 1972.

Site preparation ($ per acre):	
Bulldozer and blades	– 16.00
Barrels and chains	– 15.00
Prescribed burning	– 9.00
SFI, Imsett, Bracke.	– 8.00
Hand tools (grub hoe, etc.)	– 19.00
Seeding ($ per acre):	
Aerial	– 1.00
Cyclone (on ground)	– 6.00
Cyclone on snowmobile	– 2.00
Hand (Brohm, Shakers, etc.)	– 8.00
Seed ($ per lb.):	
Spruce, black	– 41.00
, Englemann	– 25.00
, Norway	– 10.00
, red	– 15.00
, Sitka	– 20.00
, white	– 15.00
Pine, eastern white	– 11.00
, jack	– 25.00
, lodgepole	– 45.00
, red	– 20.00
Fir, balsam	– 4.00
Douglas-fir	– 16.00
Seed treatment ($ per lb.):	
Arasan, endrin, aluminium flakes	– 0.50
Filler ($ per acre):	
Sol-speedi-dri	– 0.20

APPENDIX II

Smither's (1965) in his report "Direct Seeding in Eastern Canada" determined the success of direct seeding jack pine and white spruce based on the stocking standards outlined on page 11. Briefly his results showed that jack pine was successfully stocked on 53% of the trials undertaken; 23% were moderately stocked and 24% were failure. Comparable data for white spruce were 27%, 25% and 48% respectively.

The above results are based on data collected on eastern Canada (including Manitoba) prior to 1963. Pre 1963 data collected during this analysis for white spruce and jack pine seeding projects carried out in Saskatchewan, Alberta and British Columbia were incorporated with the data analyzed by Smithers. This additional data did not change Smithers' results by more than 1 or 2 per cent. This revised data is compared with results achieved since 1963 in the following table:

Assuming the differences revealed by this data to be significant then it could be concluded that the success of direct seeding has decreased somewhat over the past decade. Such a decrease could be expected since the extrapolation of techniques from small test trials or research plots to large scale operations inevitably leads to poorer results due to the difficulty of getting the seed on suitable micro site following site preparation on a macro scale. However, it is doubtful that the above data shows any real trends. The current success of direct seeding based on acreage treated is outlined in the main body of the report and indicates rather emphatically that the success of direct seeding of jack pine has improved (almost double) dramatically in recent years. Little change in the success of direct seeding white spruce was noted.

Success Category	% of Trials in Each Success Category			
	jack pine		white spruce	
	1900–62	1963–72	1900–62	1963–72
Satisfactory	55	53	32	29
Moderate	22	15	22	13
Failure	23	32	46	58
Basis: no. of trials	84	195	60	79

Direct seeding versus other regeneration techniques: Silvicultural aspects

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ABSTRACT

The relative cheapness of regenerating spruce and pine stands in Ontario by direct seeding has encouraged foresters to consider direct seeding projects as a part of their silviculture plans. Site in terms of topography, soil moisture and vegetative competition, and weather are basic elements in assessing the feasibility of direct seeding projects. Results are directly related to the extent of seedbed preparation, and less so to the coating, encapsulating or pelleting of the seed. The manner in which the seedbed is prepared (none, plow, etc.) and the seeding method used (aerial, spot seeding, etc.) directly affects the nature of the resultant stand, the degree of stocking, and to a lesser extent tree form and the amount of thinning required.

Direct seeding is a silvicultural technique that will become more popular and effective with increased experience and experimentation. It cannot replace hand or mechanical planting of nursery grown stock completely due to the unavailability of proper sites in such areas as parks, where relative precise placement and stocking of large seedlings is necessary.

RÉSUMÉ

Le fait que la régénération des peuplements d'épinettes et de pins en Ontario coûte relativement peu par ensemencement direct permet aux forestiers de considérer les projets d'ensemencement direct dans leurs plans sylviculturaux. Ces projets doivent comprendre l'étude des éléments essentiels suivants: les conditions météorologiques et la station en termes de topographie, humidité du sol et concurrence des plantes. Les bons résultats dépendent beaucoup d'une préparation poussée du sol, moins de l'enduit sur les graines ou l'encapsulage de celles-ci. La façon de préparer le sol (aucune préparation, labourer, etc.) et la méthode d'ensemencement (aérienne, semer depuis une motoneige, etc.) influent directement sur le futur peuplement et sa densité. Ils influent moins sur la forme future des arbres et la quantité d'élagage qui sera nécessaire.

L'ensemencement direct est une technique de sylviculture qui deviendra plus populaire et efficace avec l'expérience et l'expérimentation. Il ne peut

remplacer la plantation à la main ou mécanique d'arbres de pépinières transplantés par exemple dans des parcs où la position précise et telle densité de gros semis entrent en jeu.

INTRODUCTION

Direct seeding includes all methods whereby tree seed is applied directly to the seedbed by man or machine, the seedbed usually being prepared prior to seeding. Until recently, direct seeding seemed an untried and uncertain method for obtaining satisfactory levels of regeneration. However, as we gained more experience with various techniques for seeding under various conditions, our results and confidence have improved to where many include direct seeding in their silvicultural plans.

But why should you consider direct seeding over other regeneration methods to treat, silviculturally, cut-over ground? Several reasons are worth considering. Project time is much shorter and less supervisory staff is needed than, for example, planting bare-root stock. Seeding may be done during periods of the year when experienced, regular staff is generally more available, i.e., fall and winter; the main disadvantage of seeding in fall and winter is the time lost due to bad weather. Frequently, you can use direct seeding when adequate stocking was not obtained from an earlier seeding and still keep the total cost of the project down, provided there has not been a loss of seedbed preparation. From these advantages you can see the main attraction of direct seeding is, and will remain, its relative cheapness.

In the Chapleau District since 1967, and excluding site preparation, the average per acre costs for artificial regeneration have been $38.92 for hand-planted nursery stock, $21.90 for container stock, and $4.19 for direct seeding.

FACTORS AFFECTING SUCCESS

When should we consider direct seeding as the proper silvicultural technique? When, the site (seedbed), and the climatic conditions are right for germination, survival and growth. Failure to recognize these all important factors in the past has resulted in very poor stocking from direct seeding projects.

Site

Unfortunately seed cannot be applied successfull to all sites: Only the "better" sites for the species should be seeded. Given a "better" site, it must be possible to machinically prepare the site by exposing mineral soil. This is more important for direct seeding than for planting nursery stock when the planter's dibble or spade is driven through the humus before the seedling is set.

The objective of site preparation for direct seeding is to establish a favorable seedbed and to control vegetation that may compete with seedlings for space, moisture and light. Seeding trials in Ontario have verified the need to prepare a mineral soil seedbed for all three of the main boreal tree species – jack pine, black spruce and white spruce. Our ability to obtain the right seedbed conditions hinges to a certain extent on conditions affecting the capacity of site preparation equipment to mix and expose mineral soil.

The three main factors affecting the degree of exposing and mixing obtainable are; slash, stoniness and vegetation. The field man must rely upon his experience and common sense to tell him whether or not these three factors will prevent an adequate amount of ground disturbance.

There are three other site conditions which may influence direct seeding success – topography, soil moisture and vegetation. These conditions have less effect on planted nursery stock due to the latter's relatively advanced stage of growth when field-planted.

Topography

Terrain containing sudden steep changes in elevation is not a prime site for direct seeding. Seed sown on such ground is usually washed downslope or buried before germination can take place. If seed does germinate, it may be buried by soil movement in the initial years of growth. The amount of soil movement will depend upon steepness of slope, severity of scarification, soil particle size and occurrence of heavy rainfall or run-off. Soil movement on slopes may be reduced somewhat if scarification is only severe enough to cause a "mixing" of the organic and mineral soil components.

Soil Moisture

Adequate soil moisture is necessary for seed germination. Recognizing the soil moisture condition on a site is the easiest way to classify a site's potential for direct seeding. It is not enough to say that the previous stand of jack pine originated from seed and therefore seeding should work now. If the site is very dry in the first place, and a combination of other factors with abnormally dry weather should occur, germination success is uncertain. Planting nursery stock might be a better choice.

One of the best ways to classify a site's moisture capabilities is by the indicator plants. Using jack pine sites as our example, *very dry* jack pine sites are characterized by reindeer lichens (*Clodonia Spps.*); *moist sites* by the presence of Labrador Tea (*Ledum Groenlandicem* Oeder), Leatherleaf (*Chamaedaphne calyculata* (L.) Moench) and Raspberry (*Rubus ideaus* L.). Soil texture will indicate its capacity to retain moisture, color, its heat absorption or reflectivity characteristics. Vegetation will be a competitor to some degree but also may offer some initially beneficial shade.

Vegetative Competition

Vegetation was mentioned earlier in reference to its effect on site preparation and some possible benefit from shade. In addition to these considerations, the forester must be aware of the characteristics of the various kinds of vegetation present and how each could influence the site over subsequent years. For example, trembling aspen may rapidly overtop any conifer regeneration and spread itself by root suckering. Sweet Fern (*Comptonae peregrina*), which sheds its leaves in late fall, may cover sown seed and seedlings with a wet mat of leaves. Grass, present during site preparation, may spread under the right conditions and compete heavily for and intercept moisture. On moister sites, scarification may stimulate the prolific growth of herbaceous vegetation resulting in loss of light at the seedbed. Similarily, the forester must know the characteristics of the species to be sown such as its tolerance or intolerance to light competition. The presence of any potentially detrimental vegetation does not necessarily rule out direct seeding. However, the implications of its presence should be carefully assessed and be considered in the decision to seed.

Weather

In continuing our discussion of conditions or factors influencing seeding success, climatic influences must be given consideration before undertaking a large direct seeding program. Knowing the "normal" climatic conditions in your area will assist in choosing the best time of year to sow. How "normal" conditions affect germination and survival will influence the success of a direct seeding program. The details of this climatic influence on seed germination and survival will be covered in another paper.

For the sake of discussion, it will suffice to mention that in northern Ontario, seed is usually sown during early spring or late fall. Each season has its own advocates who will diligently argue the advantages of one season versus another. Until conclusive data is available favoring one season in your locality, choice will no doubt depend upon which time of year is most convenient to do the work. This is an advantage in itself, if your silviculture program includes planting.

Some districts have experimented with winter sowing with a cyclone seeder mounted on a snow-mobile. Regeneration results are not yet available to me but this appears to be a very useful way to extend annual silviculture programs beyond the normal 6 month field period. This method of sowing should give a more even (controlled) distribution of seed than aerial seeding. And it should be ideal for small, clear cut-overs.

Another point to consider in relation to time of sowing is whether or not the newly prepared seedbed should be left to settle for a year. Horton and Wang (1965) indicate that freshly scarified ground is equal to, or in the case of jack pine, better than a stabilized (year old) seedbed in terms of surface catch from broadcast sowing. My own opinion based upon observation is that soil settling may partially explain low seed germination on certain sites. If at all possible, I allow a site to settle for one complete year before seeding. However, there are times when sowing must be done on freshly scarified ground. The best precaution against the effects of soil settling is a heavier than normal seeding rate.

Soil settling does not usually affect total bare root or container stock planting survival to the same extent as seedlings from broadcast seeding. The effect of soil settling is proportional to the size of the seedling when the changes occur.

WHAT TO EXPECT IN STOCKING

Aerial Seeding

There is no concrete formula for determining the most suitable seed application rate. To date, most Ontario districts have been relying upon their own experience with local conditions in establishing rates of application of jack pine seed. The usual range is 10,000 to 20,000 viable seeds per acre with most operators settling on 15,000 seeds per acre. The expected stocking depends upon degree of site preparation, weather conditions during the regeneration period and existing potential for natural seeding. In Chapleau District, the stocking for direct seeded jack pine is quite variable, ranging from 50–80% (1000 trees/milacre quadrat basis) and 1500 to 3000 trees per acre in the second and third year after seeding. On the other hand, planted bare root nursery stock ranges between 800 and 1500 trees per acre, but with a higher average stocking. In general, the potential for extreme tree density levels with the aerial seeding is greater than with planting nursery stock or any of the other direct seeding methods. However, if a high density stand of trees should occur, you might look at it this way. The money saved in aerial seeding as compared to other silviculture methods may allow you to thin and still have a relatively low per acre regeneration cost.

I do not agree with the school of thought that we must control stocking from aerial seeding by confining the seedlings within prepared furrows and thereby have a row effect in the future stand. My feeling is that instead, more emphasis should be placed on obtaining a greater degree of seedbed preparation through increased scarification. This in turn would do much to ensure that minimum acceptable stocking levels are reached. It may be feasible to increase the amount of site preparation by covering the same ground twice using the same equipment; the extra cost would likely be justified by the improved regeneration results. Increased ground preparation should mean that more of the seed sown at present normal rates, would settle on a satisfactory seedbed. A slight downward adjustment of the application rate might be warranted on such sites to prevent too high a density occuring.

Mechanical Ground Equipment

The mechanical one-pass scarifier-seeders place the seed exactly on the prepared seedbed. Dispersal of seed is controlled by such machines to a certain spacing along each row; spacing between rows is usually governed by operating conditions. The row-spot seeding machines, such as the S.F.I. Scarifier-Seeder or the Bracke Cultivator, release from 4–15 seeds per scalp, which results in clumps of trees if germination is good. Many believe that in a short period of time one dominant tree will take over each scalp and, as the spacing between rows and scalps fills in due to tree growth, many of the slower growing or inferior trees will not survive the competition. If this is true, the initial number of trees per acre would be reduced substantially.

It is quite possible with this method of seeding, that the initial number of trees per acre (density) will be high but stocking could be somewhat low as compared to a nursery-stock plantation with the same relative density. Therefore, be certain to recognize that a high density-survey figure on this type of project does not always represent satisfactory stocking.

Another type of mechanical seeder is the single row seeding device that spaces the seed evenly along a furrow. This type of seeding, if it should prove successful, will result in a stocking effect very similar to a nursery stock plantation. A Canadian Forestry Service designed machine was tried in the Chapleau District with jack pine seed during 1972. A quick walk over the area in the spring of 1973 revealed a fairly consistent pattern of regeneration along the rows.

Cone Scattering

Seeding by scattering cone-bearing jack pine slash in a frequently used method of direct seeding in northwestern Ontario. The process consists of distributing the seed bearing cones evenly over a site during the preparation of the seedbed. We in northeastern Ontario have not had a great deal of success with the method as measured by stocking results. Poor stocking is inherent in this direct seeding technique, unless a suitable seedbed can be prepared and there is a substantial amount of unopened cones to distribute. Today, many tree harvesting systems do not facilitate the use of cone scattering as a direct seeding technique.

GENERAL STOCKING PROBLEMS

The results from planting bare root and container nursery stock usually do not create overstocking problems. A more frequent occurrence is understocking as a result of mortality after planting. If mortality is fairly consistent, it is easily compensated for by increasing the number of trees planted per acre (reduce tree spacing).

Direct seeding results can be at either extreme. We frequently hear of overstocking with direct seeding and perhaps many feel this shows its prowess as a technique. However, I believe that with aerial seeding, undesirably high number of trees per acre is the exception rather than the normal case. (Foresters do not advertise their more frequent boo-boos.) I would agree that as we become more familiar with seeding as a regeneration technique, overstocking may become a more serious problem than it is now. The answers to overstocking will no doubt come at the stage when we know more about the environmental factors influencing seeding success and how to control some of these factors.

As mentioned earlier, the mechanical one pass scarifier-seeders, such as the Bracke Cultivator, commonly produce scalps with more than one seedling per scalp. With jack pine as an example, this may result in bunches of seedlings along each treated row. If one strong "grower" takes over each scalp, then the others in the scalp eventually become suppressed as the plantation matures and closes to light. This holds true if there is consistently at least one dominant tree per scalp over the entire area and if the spacing between rows and the scalps within rows is 6 feet by 6 feet or less. If this is not the case, then stand closure takes much longer and suppression of the co-dominant trees in any scalp takes much longer. This means that although the dominant tree is seeking light by growing taller at the center of the bunch, the outside co-dominant trees are increasing their foliage by heavy branching and probably receiving about just as much light as the dominant tree. I am not certain what this all means to the resulting stand, but it is interesting to surmise what may eventually happen to stand development. However, I cannot help but think that overall growth may be somewhat slower (rotation lengthened) and wood quality lower (limbiness) than normal, in such stands.

JACK PINE SEEDING

Silviculture forecasts to 1985 indicate a marked increase in the total province-wide acreage to be direct seeded. To date, jack pine has been the most widely used species for direct seeding and should continue to be the program's largest component.

The predominant use of jack pine in Ontario's direct seeding program is due to a number of reasons:

1. site preparation is relatively easy.
2. jack pine roots rapidly and deeply during the first season which makes it resistant to frost heaving.
3. jack pine is more drought resistant than most other species.
4. the usually large clear cuts facilitate direct broadcast seeding by plane or helicopter.

In Ontario, the same type of site preparation equipment and procedures can and have been used for direct seeding as for hand planting trees. Possibility this factor initially facilitated direct seeding experimentation and its relatively smooth transition to a production basis.

Although jack pine seeding has not always been successful, results have obviously encouraged foresters to continue their efforts to determine and remedy conditions that prevent consistent results. There is still much to learn about the relative importance of the various factors influencing seeding success and how to control them. Regardless of what we do not know about these factors, the forester must recognize those factors he can influence and take the necessary steps to control them in the field. Here lies much of the reason for the lack of consistent and comparable successes on similar jack pine sites.

SPRUCE SEEDING

The direct seeding of white and black spruce is still relatively untried in Ontario, and few districts have gone into production-scale programs. Some experimentation has been done but lacked adequate control and/or proper follow-up assessment which would permit meaningful conclusions to be made.

White and black spruce sites relative to jack pine sites are not large, often only partially cut-over and usually containing residual trees, rapid growing ericaceous shrubs and grasses. This is especially true on white spruce sites and has generally prevented adequate seedbed preparation by standard methods for direct or natural seeding. If proper site preparation were possible, I see no reason why direct seeding would not be successful as there are many examples of natural spruce seeding success on sites disturbed only be timber harvesting operations.

However, the problem appears to be, *how* to prepare seedbeds on these spruce sites. To date not enough experimentation has been done with available equipment or the adoption of technology to develop a satisfactory method of preparing, in particular, lowland black spruce sites.

Modified Harvest Cutting

The factors or conditions effecting direct seeding success also influence the success of natural seeding. Therefore, modified harvest cutting is a technique that will no doubt receive more and more attention from foresters interested in all aspects of seeding, whether it be direct or natural.

Strip cutting in pure black spruce stands is the most commonly used method of modified harvest cutting in Ontario. On many of the wet, organic black spruce sites, this is the only practical means of getting regeneration. Some type of seedbed preparation is desirable but in most cases, such sites receive no more than that caused by logging. Now that we know some form of site disturbance is preferable (Johnston, 1972; Van Nostrand, 1971), practical research is needed to determine just how the seedbed may be prepared and what is the best form of disturbance, e.g. compaction, scalping, etc.

Modified harvest cutting to leave seed trees is practiced only in certain areas of Ontario. Most commonly, white pine is the species left. In the tolerant hardwood forests where white pine grows in association with hardwood species, basswood and maple are harvested in conjunction with pine. Here it is possible to leave pine seed trees and to prepare a seedbed around them as most of the hardwood understory has been removed by harvesting. On dry sand sites, where white pine grows with only a scattered softwood understory, the seed tree method can be used without seedbed preparation. Further north, in the boreal forest, site conditions have not been as favorable to using the system with white pine. An understory of balsam fir, poplar and birch that is not harvested with the pine plus the large quantity of culled material left on the ground, makes seedbed preparation impractical.

THE FUTURE

Looking to the future, it would appear that the cheapness of direct seeding relative to planting will cause many foresters to review their sites more closely to ensure that all potentially seedable ground will be sown and not planted. It is doubtful whether direct seeding could ever replace the nursery stock planting program completely. There will always be sites around that are unsuitable for seeding for one reason or another; sites that need seedlings at an advanced stage of development to ensure full stocking; areas, such as parks, where the risk of not obtaining satisfactory stocking immediately makes the use of direct seeding unaceptable.

Discussions on direct seeding at symposiums like this do much to dispel the pessimism often expressed about seeding in general. Foresters must do everything possible to improve their present knowledge and techniques. In this vein, the progress or the growth in importance of seeding in our regeneration programs will hinge on our ability to continue to learn and understand more about the conditions influencing seeding and how we may affect them. Once we have succeeded in interpreting and understanding many of the conditions that affect seeding, then problems such as over-stocking will receive the consideration they deserve.

The types of forests expected from seeding and the consequent possibilities for tending and harvesting will be discussed in a later paper.

Economics of direct seeding versus other regeneration techniques

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"Behold a sower went forth to sow;
And when he sowed . . .
Some fell upon stony places whereon they had not much earth . . .
And when the sun was up they were scorched;
And because they had no root they withered away.
And some fell among thorns;
And the thorns sprang up and choked them;
But others fell into good ground and brought forth fruit . . .
Who hath ears to hear, let him hear".

A national symposium on direct seeding is one indication of good listeners among foresters in Canada. Perhaps a draught of applied economics will help the process of converting words into deeds.

Any forester contemplating the use of direct seeding in his reforestation program must reconcile its two central contradictory features. The notion that seed can be distributed over large areas of cutover land with a minimum of manpower, whilst eliminating one phase of reforestation entirely, appeals to his economical senses; it is almost irresistible to the man who is sorely tried by the problem of acquiring and holding the manpower necessary to keep a planting program on schedule and within budget. Yet, the attractive force of seeding is counter-balanced by the long-held and deep-seated idea that seeding is an erratic and unreliable vehicle for reforestation campaigns, and that the liberal use of seed, so frequently in short supply, is wasteful.

In the history of North American silvicultural practice, the balance between the attractive and repellent features of seeding has fluctuated. It seems that here, in common with other parts of the world, seeding was the principal method of regeneration in the early days of forestry, but as organized forestry advanced, seeding gave way to planting (Toumey and Korstian 1942). This pattern has been duplicated quite recently in the Douglas-fir region of the Pacific Northwest States (Hagenstein 1969). In Canada, seeding has not progressed far beyond large-scale trials, except in Alberta (Smyth and Karaim 1972) and Ontario (Scott 1970). Nevertheless, the central theme of early preoccupation with seeding and subsequent replacement by planting remains.

Today it seems there may be a return to direct seeding. The exigencies of increased reforestation work loads and dwindling supplies of manpower for the arduous task of planting are forcing a reappraisal of seeding in addition to generating a search for new reforestation methods. Even without these factors the concentration of resources on planting ought to be viewed with concern. Toumey and Korstian (1942, p. 86) remarked that "... (planting) has often been carried to excess ... (and) ... foresters generally concede that the particular circumstances of each case should determine the form of artificial reproduction to practice." The value of this comment has been recently reaffirmed by the applied economic analyses of Teeguarden (1969). In his study of Douglas-fir reforestation alternatives in southwestern Oregon, broadcast seeding, when compared with planting, emerged as the best investment opportunity on a number of the best site classes despite its unreliability, but on the poorer sites it was found to be inferior. When the complexities of ecological, economic and administrative factors are considered, it is not at all surprising that the stereotyped application of planting cannot exploit all the opportunities or resolve all the problems of establishing forests on cut- and burned-over lands.

Well tried concepts of applied economics can help develop the argument that seeding has some potential for improving the efficiency of reforestation programs. Detailed investigation is required in three areas. First, reforestation objectives should be carefully examined; the choice of reforestation techniques is as much dependent on forestry goals as it is on environmental conditions. Second, the success of alternative techniques must be scrutinized in relation to the many factors which influence the levels of inputs required and outputs attained. Finally, the potential of research for improving the levels of success of the alternative techniques should be explored because technology cannot be assumed to stand still.

REFORESTATION OBJECTIVES

Before exploring the potential role of seeding in any forest region, it is necessary to examine why seeding or any other regeneration technique is to be used at all. To make forestry decisions without any clear impression of some final purpose is transparently bad practice: it is rather like the situation in which a man, by running very fast, catches the wrong train. On the other hand, to expect a single, unequivocal objective capable of expression in mathematic symbols, is unrealistic. Some degree of uncertainty, and confusion stemming from a multiplicity of aims, is to be expected.

Why then do we make deliberate efforts to restock cut- and burned-over forest lands or renew forest cover on lands long since converted to agricultural use? Among the objectives are the following:

1. to increase physical productivity of a private or public timber production unit;
2. to ensure long-term continuation of timber production and industries based on timber supplies (on private as well as public lands; see Fedkiw (1960));
3. to protect or renew non-timber values of forest land;
4. to reduce unemployment in rural areas;
5. to make a profitable investment (sometimes prompted by tax structure, e.g. in the U.K., see Price (1971)).

Added to this list of objectives must be the goal of economic efficiency. This goal is based on an appreciation that the resources available to society, private firm, or an individual are limited and that they should be employed in such a way that the net social or private value of a planned reforestation program is maximized. This goal can be applied to the values that will stem from pursuing any or all of the ends identified earlier[1].

How is the choice of reforestation technique molded by the existence of multiple objectives? Without detailed analysis it seems reasonable to expect that when maximizing the net value of increased timber production one technique may be superior, yet in efforts to protect a watershed after wildfire it may be relatively ineffective. Often, reforestation programs have more than one goal and thus compromises must be reached in selecting a technique to obtain a satisfactory, but often heterogeneous, mix of values. Under these circumstances there is no one dominant technique — no "method for all seasons".

[1] There is a danger associated with the use of the economic efficiency goal in analyses of past or future decisions. Analysts tend to be seduced by the possibilities of quantifying all benefits and costs and concentrate on the search for a single yardstick to measure success. Inevitably the analysis ends up employing real and imaginary dollar values and utilizing the by now familiar "Faustmann"-like procedures. In forestry investment decisions, it leads to the serious contemplation of a future one or two lifetimes away, a procedure labelled as trivial extrapolation by Kilander (1966). It has also led to wrangles over the use of discounting techniques and learned discussions about the most appropriate interest rate. Broussalian (1971) has pointed out that while it is certainly necessary to show clearly when costs are incurred and when benefits will be realized, economic rationality (or economic efficiency) is not assured by the use of elegant procedures, especially when investments decisions have non-marketable elements.

LIMITS TO REFORESTATION DECISIONS

When planning a reforestation program, a clear impression of objectives is not enough. The choice of project locations, regeneration techniques, and subsidiary items will be limited by many factors which, while beyond the forest manager's immediate control, must be recognized and planned for. Among the reforestation limits or constraints are the following:

- laws;
- government and company regulations;
- operational budgets;
- capital budgets;
- existing physical plant;
- nursery stock inventories;
- seed inventories;
- skilled manpower supply;
- unskilled manpower supply;
- logging decisions;
- environmental factors.

These constraints on choice are only rarely permanent in the long run. If they are shown to result in inefficient reforestation programs, the manager will have sufficient grounds for arranging or requesting their release. Whether their release will be effected will depend on the extent of the manager's control. For example, a change in seed inventories will emanate from the manager's own actions, but a change in law may require an unravelling of complex social, political and institutional problems. Before they are changed, however, the constraints act as a second level objective, and alternative actions must be judged against them as they must against the primary goals.

Success in Reforestation: The Need For Criteria

One popular method of gauging the success of reforestation activities is to measure the percentage of surviving seedlings one or more years after planting. But is this a satisfactory method? All too obviously it is limited to reforestation by planting, and if seeding is to be compared with other regeneration techniques, more universal criteria are required. But it has other faults which provide useful pointers to more desirable measures. Survival-percent gauges the ability of trees, grown under a certain regime, to withstand the physical and physiological stress imposed by environmental conditions at the planting site. It does not measure growth, which may be all important on a site with heavy vegetative competition. Nor does it give any indication of the distribution of mortality or the role of natural seedlings filling in gaps caused by mortality or faulty spacing during planting. To sum up, survival does not indicate whether the project has been a success in terms of reforestation program goals. Even when cost is added to the criterion in the form of cost per surviving tree, the measure is inadequate. It is possible to conceive of a technique with a very low cost per tree and poor survival which would surpass all other techniques but which would not achieve minimal stocking requirements unless planting density, and therefore the cost per acre, was increased. Obtaining good survival of planted stock is only one means to an end, whether that end is a highly productive timber stand or maintaining soil stability, and it should not become an end in itself.

An excellent clue to the correct method of defining success is the minimum stocking standard long ago adopted by the B.C. Forest Service, among others. With this measure an area is not considered satisfactorily reforested until the target is reached (in B.C. the standard declares that 31% of mil-acre quadrats must be stocked with one or more second-year seedlings (U.B.C. Forest Club 1971)). Once a target of this type has been matched to the forest manager's objectives, he can set out to minimize the cost of reaching it. Working with the inevitable limited budget, the manager must be concerned with success on both the project level (e.g. a clearcut area of 200 acres) and on the program level. He must be concerned with maximizing the total area reforested to meet the established standard. He can do this by planning to minimize the cost of completing each project, by ranking the projects in order of increasing cost, and working through the order until his budget is expended.

For programs where the sole, low key objective is to ensure the continuation of forest cover and to protect non-timber values, the reforestation target might be as follows:

- create a stand of mixed coniferous and deciduous species with a stocking of more than 100 trees per acre over 75% of the stand area within 7 years of logging.

Where the manager is concerned about future supplies of timber from company limits or publicly owned forests, the appropriate target might be to:

- create a stand with 90% of a favored species, and a stocking of between 400 and 600 trees per acre over 90% of the stand area within 5 years of logging, with height growth to exceed 110% of height of natural seedlings of equivalent age [2].

The other goals of reforestation will have their own distinct targets and in each case the aim will be to minimize the cost of reaching it.

In structuring reforestation decisions as a cost minimization problem, two problems of principle arise. First, by establishing a target stand as a proximate measure of success (McKean 1958) one assumes that it is in fact worth reaching, that it is a good representation of the reforestation objective. Thus, the establishment of targets places a heavy weight on the process of deciding upon objectives, a process which may prove to be a difficult and contentious task. There is also a tendency for such targets to be inflexible. As an example, when the suggested intensive timber production standard is used, one regeneration technique might be rejected continuously because of a failure to exceed the height growth requirement, although in other respects it is satisfactory and is cheaper than alternative techniques. The effect of loss in height growth on timber production might be quite inadequate to justify losing the advantage of reduced cost, and the phenomenon of sub-optimization occurs. McKean (1958) regards this as inevitable in any situation where the problems of choice (timber production choices) must be broken down into subproblems (reforestation, fertilization, tree breeding, etc.). One can only hope to ward off the likelihood of incorrect decisions by continuously appraising the relationship of the target to the original objectives.

Success in Reforestation: The Role of Uncertainty

Failure is the original sin of reforestation specialists. It is, and will continue to be, commonplace because we still do not know enough about the reasons for failure, nor are we sure, if we did, that measures could be taken to correct them. However, foresters are not alone in this predicament and the following words from an eminent decision theorist may add some perspective to the dilemma:

> "Everything we know about the future is an inference, the end of a reasoning process, whether the reasoning is sound or not . . . decision is wholly concerned with the future . . . Decision, then, is choice, but it is choice amongst thoughts . . . it is choice amongst the products of imagination". (G.L.S. Shackle quoted in Lundgren 1972).

Ways of coping with uncertainty in reforestation must be found. To some extent this has already occurred, albeit at the cost of losing seeding. Foresters invariably choose to plant rather than seed because failure with planting is only rarely as disastrous as with seeding. Planted stock can survive when and where germinants cannot. This decision is an example of the mini-max solution to uncertainty: the maximum loss is minimized. It is appropriate when nothing is known about the conditions which produce losses, but is it sensible after 75 years of silvicultural research?

We are only partially ignorant of the conditions of failure and success. The reforestation manager has a range of conditions under his partial or complete control (see Table 1) and can manipulate them at some cost to increase the probability of success. It is unnecessary, therefore, to cope with uncertainty by assuming the worst. Instead, the means exist for choosing the action which will produce the most favorable expected result, an amalgam of pessimistic and optimistic expectations. The techniques for decision-making under conditions of partial ignorance have been described by Thompson (1972).

A Comparison of Regeneration Techniques

Once the objectives of a reforestation program have been crystallized, the possible obstacles that complicate reforestation choices have been searched out and the standards of success have been established, the decision-making problem is more than half solved. We are left with the more mundane tasks of selecting appropriate and, hopefully, imaginative alternatives, collecting data concerning the expected results of using each alternative, and describing and applying a simple method of conveying the relevant information to the decision maker.

[2] The timber production objective has been represented by a cost minimization criterion rather than the maximization of wood yield per dollar expended criterion proposed by Teeguarden (1969) because early stocking control is considered one of the prime opportunities for maximizing yield (e.g. Smith 1971). Thus, even if reforestation efforts are unsuccessful at first, it is assumed that forest managers will take steps to ensure that the standard is eventually reached. At some point the additional effort will not be worth the extra yield gained, but the decision of how far to go in ensuring success must be left to another analysis and another criterion.

Table 1. Environmental factors which interact with regeneration technique to influence success on a reforestation project area.

Fixed	Partially Controllable	Varied by Manager
Climate:	Seedbed:	Species
precipitation (quantity)	moisture	Stocking
" (timing)	temperature	
temperature	nutrients	
humidity	microorganisms	
radiation	light	
wind	vegetation	
	organic matter	
Elevation		
Aspect	Insects	
Soil:	Disease	
depth		
texture	Animals	

(After Hughes and Post 1973).

For most forest areas in Canada, the reforestation manager has the choice of the following techniques:[3]

1. do nothing
2. site preparation
3. broadcast seeding by air or ground
4. planting bareroot stock by hand

Before launching into an analysis of these readily available reforestation techniques, it is well to be aware that reality is about to be represented in a very limited way. This has been done deliberately in an effort to increase the instructive value of the analysis. As a result, a number of assumptions have been made which may not be justified in actual practice. These assumptions are as follows:

- the reforestation manager is attempting to establish a stand with:
  90% preferred species;
  at least 400 trees per acre 5 years after logging;
  400-600 trees per acre 10 years after logging;
  rapid early growth not essential.
- the manager is not limited by supplies of seed, manpower or seedlings.
- the costs of the available techniques and stand treatment necessary to reach the target stand are those shown in Table 2.
- natural regeneration, when it is assumed to occur, is possible in any of first 5 years after logging and results in at least 600 trees per acre.
- site preparation requirements are the same for seeding or planting.

[3] A range of other techniques, which are now in limited use (spot seeding, machine planting, silvicultural treatment of mature stands, container planting), or are still in the development stage, are also available.

To begin the analysis let us imagine that on a given site natural regeneration is not expected, seedbed conditions are not conductive to successful seeding, but planting on the basis of experience is not very likely to fail. Each of these statements is represented by a probability estimate shown in Table 3. The estimates can be interpreted as the reforestation expert's answer to the question "if seeding (or planting) were to be attempted on this site on 100 separate occasions, what would be the frequency of results with stocking less than 400 stems per acre (spa), between 400 and 600 spa and greater than 600 spa?" (Teeguarden 1969). These estimates can be combined with the costs of seeding, planting, replanting and spacing to calculate the expected cost per acre of each technique when using the decision-tree techniques illustrated in Figure 1. The first set of costs used (see case A, Table 2) are based on high seed costs, and low bareroot planting costs due to a productive, experienced crew working under good site and weather conditions and paid at going eastern Canadian rates.

Table 2. Standard costs for a comparison of regeneration techniques.

Cost Item	$ Per Acre	Remarks
CASE A – unfavorable for seeding		
Broadcast seeding:		
seed	13	seed $40/lb, 1/3 lb/acre distributed
distribution of seed	1	aerial or snowmobile and marking.
Total	14	
Planting–bareroot:		
nursery, storage, transport	10	stock $20/M at Forest H.Q. 500 trees per acre
planting	17	crew $25 per day per man, 750 trees per man per day.
Total	27	
Replanting after planting	19	100 trees per acre, 750 trees per man
Planting after seeding	32	350 trees per acre, 500 trees per man
Replanting after seeding or second replanting after planting	27	100 trees per acre, 500 trees per man
Spacing after seeding	20	3000 stems per acre removed at age 10.
CASE B – lower seed costs, higher planting costs		
Broadcast seeding:	6	seed $15/lb.
Planting	35	500 trees per acre
Replanting after planting	27	100 trees per acre
Planting after seeding	45	350 trees per acre
Replanting after seeding or second replanting after planting	40	100 trees per acre.
CASE C – with natural regeneration		
Spacing after planting	15	2000 stems per acre.
Spacing after seeding	30	5000 stems per acre.

Table 3. Estimated probability of Regeneration success by regeneration technique. (percent of 100 trials).

Regeneration Technique	Probability of reaching stocking target < Target	Target	> Target
Broadcast seeding	70	–	30
Planting	10	90	–
Planting after seeding or replanting	5	95	–
Replanting after seeding or 2nd planting	1	99	–

Table 4. A sample calculation of the expected cost of achieving a highly productive stand – Case A (without natural regeneration).

Cost Item	Probability of reaching target	Cost per acre	Expected cost per acre
	%	$	$
Broadcast seeding:			
Seeding plus spacing	30	34	10.20
Seeding plus replanting	66	46	30.36
Seeding plus planting plus replanting	4	73	2.92
Total			43.48
Planting:			
Planting	90	27	24.30
Planting plus replanting	9	46	4.14
Planting plus replanting plus replanting	1	73	.73
Total			29.17

The costs of spacing are relatively low by coastal British Columbian conditions, due to lower labor costs, but not as low as those reported by Riley (1973).

The analysis shows that the expected cost of achieving the target stand by broadcast seeding is $43.50 and by planting $29.20 per acre. This substantial cost differential in favor of planting is due to the need for replanting and spacing after seeding, cost factors which outweigh the initial cost advantage.

If the cost of planting (and replanting) increases either as a result of increased manpower costs or reduced productivity, or both, and the cost of seed falls in comparison to those costs assumed in Case A, how is the comparison influenced? The gap between planting and seeding is narrowed but planting is still less costly with $38.10 compared to $45.10. This is because the expected cost of seeding is tied to the cost of planting when the probability of seeding success is low.

Seeding only becomes the superior alternative under the cost conditions of Case B when the probability of seeding success climbs to over 50%, as Figure 2 shows. If the manager chooses to reseed before contemplating planting, the expected costs of seeding are reduced and the break-even point between planting and seeding declines to a little over 40%.

The condition of planting dominance is changed when the likelihood of some natural regeneration occurring is considered. Stocking expected from natural seed sources must be accounted for in both seeding and planting options. With the former alternative, the probability of less than adequate stocking is reduced; in the latter case, the probability that spacing must be carried out in some planted stands must be added to the decision analysis.

On most sites some natural regeneration can be expected in the form of a one-time event from cones left on site after logging, and advanced reproduction, or as a multiple event in the case where the logged area is surrounded by cone bearing trees over the period of years that seed beds are receptive. The latter circumstance is assumed for the purpose of the analysis.

The effect of increasing the probability of stocking (400 spa) from natural regeneration on the expected cost of the planting and seeding options (with their success rates held constant at the rates given in Table 3) is shown in Figure 3.

In Zone I on the diagram, the relatively low probability of seeding reaching more than 600 spa (30%) means that the expected cost of seeding is closely tied to the cost of replanting. Since replanting is usually more expensive than planting, planting is the superior alternative. Once the probability of natural regeneration success exceeds 30% (Zone II), the dominance of planting depends largely on the relative costs of seeding and first-time planting. In Zone III,

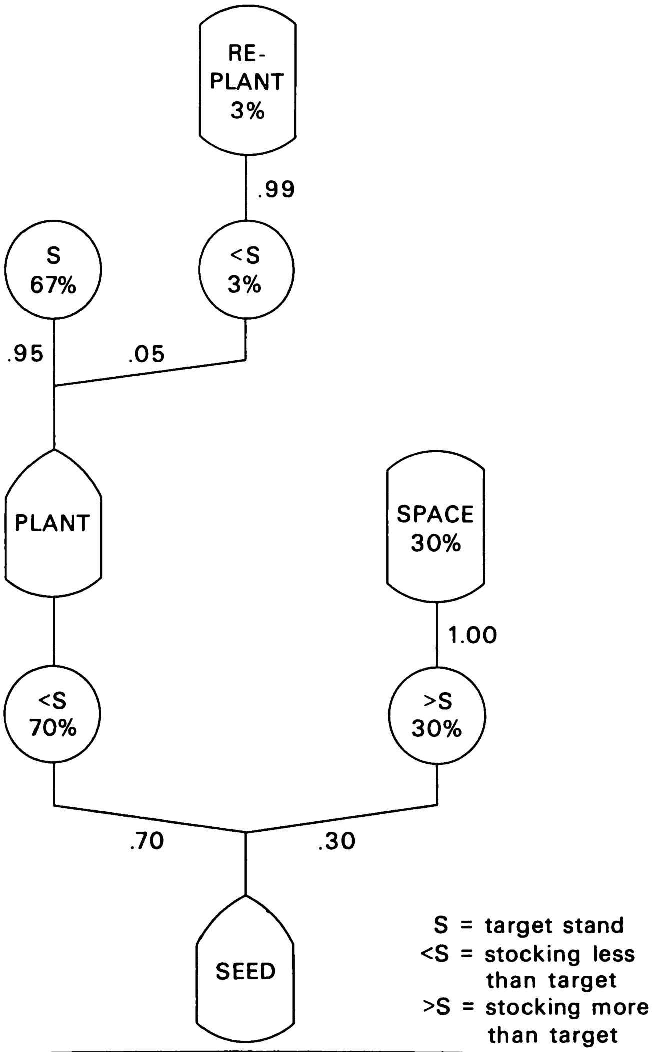

Figure 1. An example of a decision tree.

the probability of natural regeneration stocking is high enough to ensure very few seeding or planting failures and the expected cost of each is the sum of first-time application and spacing costs.

The analysis so far has some transparent flaws:

1. the representation of probabilities of success in terms of three levels of stocking (Table 3) and the assumed levels of stocking after seeding, seeding plus natural regeneration, and planting plus natural regeneration (see comments in Table 2) are gross over-simplifications.
2. the probabilities of success for seeding, planting, and natural regeneration are not independent and to vary one holding the others constant may be misleading.
3. when the probability of success for natural regeneration is high (Zone III), the forester may plan on natural regeneration without recourse to artificial regeneration techniques. The distribution of relatively small quantities of seed might be undertaken as an insurance measure against failure.
4. the yield at rotation age for seeded stands and planted stands, with varying components of naturally regenerated stock, may not be the same despite spacing efforts. Accurate predictions of any difference will require special mensurational efforts over a wide range of conditions. In the meantime, managers must decide whether any expected cost saving resulting from seeding is worth the possible loss in yield.

Despite these drawbacks it is possible to draw two important conclusions about the choice of regeneration technique when the forest manager wishes to create a highly productive stand of timber. First, if the probability of seeding achieving a stocking of greater than 600 spa is high, it will be a good competitor with planting, always supposing seed is available at relatively low costs. Second, when natural regeneration is expected to disrupt the careful spacing of planted stands, the relative cost position of seeding is improved.

A Minimum Stocking Standard

How is the situation changed when the objective of reforestation is directed from timber production

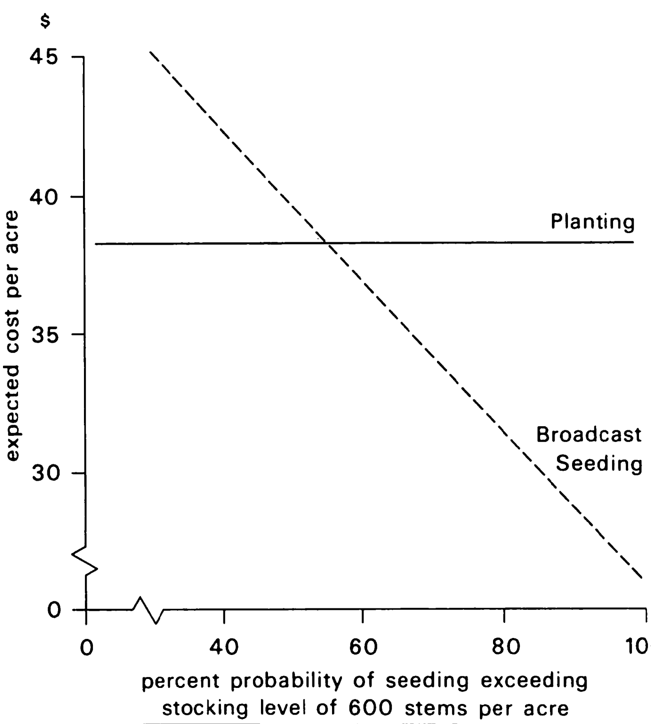

Figure 2. Expected cost of creating high yield stand in absence of natural regeneration.

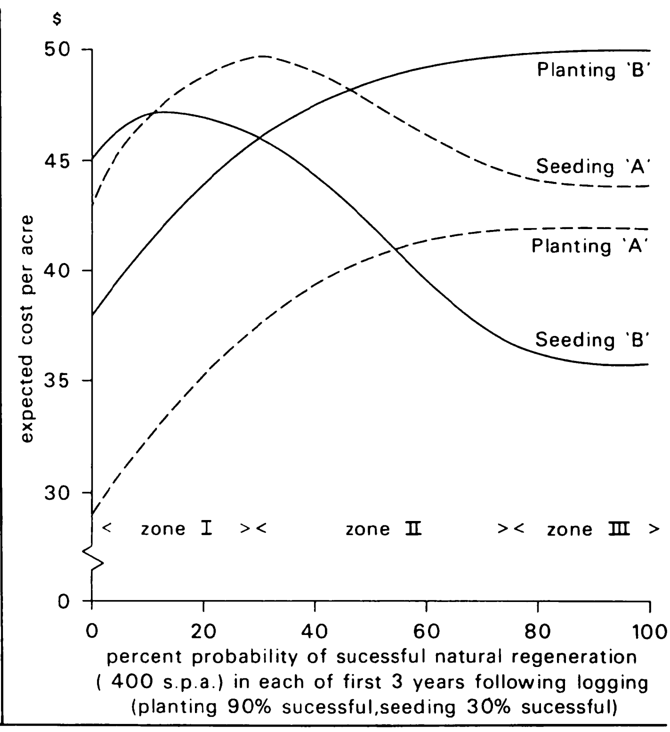

Figure 3. Effect of natural regeneration on choice of artificial regeneration technique.

to a less demanding concern for the renewal of forest cover and nothing more? First the framework and data of the previous section must be applied to a new stand target and, as an example, the requirement that logging areas must reach a minimum of 31% stocked quadrats within 7 years has been chosen. With this less stringent target, the probability of reaching the target using either planting or broadcast seeding is increased, and substantially so in the latter case. The absence of an upper limit means that spacing can be dispensed with, and the occurrence of expensive replanting is reduced.

A few rapid calculations using the decision-tree technique show that with relatively expensive seed ($14/acre) and cheap planting ($27/acre) the probability of successful seeding has only to exceed 40% to be superior. This break-even point is further reduced by increasing the probability of natural regeneration and reducing seed cost.

Factors That Limit Choice of Technique

Operation budgets are the most common form of reforestation program constraint. Their prevalence has led to the adoption of the cost minimization criterion used in the foregoing analysis. However, if the major constraint was available land, and not budget, the criterion would change and with it the results of the analysis. The assumption of a budget constraint thus has a pivotal role in program planning.

Among other factors that can limit the choice of technique are logging decisions, seed and seedling supply, manpower availability, capital budgets, administrative problems, laws and regulations and environmental factors. Some of these limiting factors are linked to the operational budget because they can be changed only if it is expanded.

LOGGING DECISIONS. Natural regeneration is strongly influenced by the method and timing of logging. Thus logging decisions may limit the courses of action open to the reforestation manager.

SEED SUPPLY. The production of nursery stock of certain species and provenances may be limited by the quantities of seed on hand in storage, but broadcast seeding is the principal victim. Seed shortages have been offered as the principal reason for the absence of broadcast seeding from British Columbia's large reforestation program (Robinson 1970).

Arguments against seeding on the grounds of its high rate of seed consumption are complicated by the notion of waste; thus when seed is in relatively short supply, it is thought to be wasteful to apply relatively large quantities of seed per acre when the same seed used to grow seedlings could restock a much larger area. This position is erroneous because it assumes that the management objective is to maximize the acres stocked per pound of seed. If planting is the superior alternative on minimum cost grounds, the error will not be serious. However, if seeding is superior, and there is every reason to suppose that it may be, the extra resources expended by not seeding could have been spent on relieving the seed shortage [4].

SEEDLINGS. Planting programs may be limited by the current output of bareroot seedlings from forest nurseries. Increases in the output will take at least 3 years to take effect, may involve substantial capital expenditures, and may be limited by skilled and unskilled manpower problems.

CAPITAL BUDGET AND PHYSICAL PLANT. The expansion of seeding projects may require additional seed processing and storage facilities. The cost of the plant and equipment could be substantial and capital budgets could block the expansion plans. However, if an expansion in overall reforestation programs is planned, the capital investment required to establish a seeding capability is less than that required to expand planting projects (see Table 5).

MANPOWER. Shortages of manpower afflict planting projects more severely than seeding projects (see Table 5), although seeding is, surprisingly perhaps, a labor intensive operation. The large increases in seed consumption created by seeding projects may create difficulties in the organization and supervision of cone collection crews.

The shortage of unskilled labor appears to be general in northern regions. Solutions are not immediately at hand although automation and mechanization provide a partial answer in solving reforestation difficulties as in other activities. That it is only a partial answer has been emphasized by Sundberg (1969), who warns that excessive mechanization may conflict with social development and employment policies in hinterland areas.

[4] If the average expected cost of seeding is $10/acre less than planting for an annual reforestation program of 20,000 acres, up to $200,000 per year could be spent on ensuring the availability of 7,000 lb. of seed in addition to normal seed requirements. Seed costs could be doubled from $15 to $30 and seeding would remain the superior option. It is important to note that in addition to the problems of cone crop periodicity, manpower and capital shortages could frustrate any short-run effort to increase seed supplies.

Table 5. Estimated labor and capital inputs required for a 20,000 acre expansion in an artificial regeneration program.

Regeneration Operation	Labor input			Capital input	
	% total cost	man-hrs per acre	man-days	M$	Comment
Broadcast seeding	85	2	5000	0–80	seed processing plant.
Row Seeding site preparation and seeding combined	60	3	7500	100	machine rental row seeders, seed plant not required.
Planting bareroot seedling hand planted	95	10	25000	200	10 million seedling nursery.
Planting bareroot seedlings machine planted	75	6	15000	350	nursery plus planting machines.
Planting container grown seedling, hand planted	80	4	10000	200–400	nursery with varying degrees of environmental control.
Site preparation scarification	10	.4	800	0	machine rental.
Spacing	95	10	—	—	only part of total area will need treatment.

ADMINISTRATION. The selection of any particular regeneration technique may be limited by the capability of the reforestation agency, which is expressed in terms of skills, workloads and imagination. The acquisition of new and perhaps scarce skills and drastic reorganization may be required to implement a change in planned programs. Large changes of this nature are frequently unacceptable to administrators.

LAWS AND REGULATIONS. When a stocking standard is established by government, foresters often argue that only techniques with a high probability of success should be used. Decision theory and decision-tree analyses show that this reasoning is inadequate.

Regulations concerning the use of herbicides or pesticides may also influence regeneration technique. For example, Endrin, which is a persistent chlorinated hydrocarbon and which is used to protect seeds from rodents, has been banned by some government agencies in the United States; this action has jeopardized seeding programs where rodent protection is required.

ENVIRONMENTAL FACTORS. The majority of environmental factors that influence the choice of regeneration technique are incorporated in the assessments of cost and success for a given site. Sometimes, however, site limitations are so clear that program restrictions can be formulated (e.g. no seeding on good sites with high probability of severe vegetative competition).

Other environmental constraints are associated with seasonal weather patterns. Planting in the Boreal forest, for example, is restricted to a total of 4 or 5 months in spring and fall. When these seasonal constraints combine with manpower or equipment shortages, they have a substantial impact on the shape of the reforestation program.

In summary, there are a range of factors that can limit the choice of regeneration technique. On balance, they favor planting in spite of high manpower requirements because existing programs are already planned and planting is the accepted alternative. To become accepted, seeding programs should follow the Ontario example (Scott 1970), beginning on a limited scale and using species which have few seed supply problems.

THE EFFECT OF TECHNOLOGICAL INNOVATIONS

A variety of technological innovations, which are now under development, will have a major effect on the regeneration techniques used in future. Some of the more important of these developments are listed in Table 6. Their precise impact on the choice of technique cannot be forecast with accuracy because there is no clear pattern of development favoring one technique or another. Container grown trees will reduce the cost of nursery stock and planting, but this seems likely to be balanced by aerial row seeding of encapsulated seed, which will reduce the cost of seeding and improve its stocking capabilities. Row seeding by ground machines that also prepare the site is a promising technique. However, new machines that prepare a site at the same time as planting are under development.

Seeding will be favored by one development. Row seeding, which cuts down seed consumption while maintaining the advantage of highly productive distribution systems, will reduce the effect of seed shortages now limiting the application of broadcast seeding.

Exploiting the Potential of Direct Seeding

Decisive conclusions about the economics of seeding versus other regeneration techniques are beyond the capabilities of a single technical paper. The real decisions, after all, must be made by the forester on the spot, and preferably in the field. Herein lie the problems of exploiting the evident potential of seeding as one means of contending with the difficulties of regenerating Canada's northern forests. Generally speaking, foresters seem disinclined to gamble and they reject direct seeding as an uncertain route to the successful achievement of their goals. (Natural regeneration has suffered a similar fate although it has been tolerated due to the impossibllity of artificially regenerating every acre).

To correct this situation, foresters should:

1. improve the definition of reforestation goals and adopt a probabilistic attitude toward the achievement of those goals rather than adopt the "mini-max" approach;
2. recognize that failures are as important as successes in learning how to improve reforestation practice;

Table 6. The impact of technological innovations on reforestation operations.

Operation	Operational Cost	Achieving Success: Adequate stocking	Achieving Success: Precise stocking	Constraints	Reference
SEEDING					
1. Encapsulation of seed	reduced	increased	greatly increased	greatly reduced seed consumption	Schrieber and LaCroix (1967), Union Carbide Co., Germains Inc.
2. Row seeding					
a. air	reduced		greatly increased	"	Mann and Taylor (1969).
b. ground					Scott (1970).
3. Seed squares	increased	increased	greatly increased	"	Anon (1969)
4. Protection from rodents	–	increased	–	reduced seed consumption	Crouch and Radwan (1971 Radvanyi (1970)
5. Cone production research	–			increased availability of seed	Puritch (1972)
PLANTING					
1. Containers	reduced	increased	increased	possible increase in capital cost	Kinghorn (1970)
2. Mechanization of planting	reduced	–	–	increased in capital cost	Haig (1970)
3. Aerial planting	reduced?	reduced	reduced	–	Walters (1971)
SPACING					
1. Aerial application of herbicides	reduced	–	–	–	Newton (1971)

3. encourage development of technological innovations that improve the acceptability of direct seeding;
4. examine the cone production–seed supply problem and act on the most promising short-run and long-run methods of relieving this serious constraint on seeding programs;
5. improve communications between operational forester and researcher to avoid a repetition of the situation in which seeding is rejected as an operational technique because of insufficient seed, yet research is not undertaken to increase seed supplies because of little current pressure on seed supplies.

Returning to the parable that began this paper, direct seeding has the potential for bearing fruit in Canada but foresters must hear, and act.

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The genetic considerations of direct seeding

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ABSTRACT

When artificially regenerating by direct seeding, genetic principles should be considered. Seeding the proper provenance reduces loss to frost, insect and disease. In some species, introduced provenances are preferable as increased growth can be obtained. Seed collection and seed production areas provide some genetic gain at minimal costs. Until problems in direct seeding are overcome, most of the improved seed should come from seed collection and production areas. Greatest genetic gains result from selected plus trees established in seed orchards. At present any seed from orchards should be used for planting stock, but eventually as greater amounts of orchard seed are available, some may be available for seeding programs. Mention is made of the present and anticipated regeneration program for Ontario, and Ontario's approach to producing improved seed for the Province's needs.

RÉSUMÉ

Les principes de la Génétique devraient être pris en considération dans la régénération artificielle par ensemencement. L'emploi de graines de provenance adéquate réduit les pertes dues au gel, aux insectes et à la maladie. Pour certaines espèces les provenances exotiques sont préférables, vu qu'on peut en obtenir une meilleure croissance. Les aires de production et de récolte de graines procurent certains avantages génétiques à peu de frais. Jusqu'à solution des problèmes posés par l'ensemencement, les graines améliorées devraient surtout provenir d'aires de production et de récolte. On obtient les plus grands avantages génétiques des arbres plus sélectionnés et établis dans des vergers à graines. À présent toute graine de verger devrait être utilisée pour la production de plants, mais advenant une plus grande disponibilité de telles graines, quelques unes pourront éventuellement être affectées à des programmes d'ensemencement. L'auteur fait mention du programme de régénération actuelle et anticipée pour l'Ontario, ainsi que de la méthode prospective de production de graines améliorées pour les besoins de cette province.

INTRODUCTION

With greater and greater forest areas being cut, we are forced to be more aware of the need to regenerate our stands faster, cheaper and better. To do this faster and cheaper, one of the techniques to apply is direct seeding; to do this better one logical means to try is the application of genetic principles. When restocking an area, we must take several factors into account such as method of harvesting, species selection, regeneration technique, silvicultural treatment before and after regeneration – and genetic considerations. In the artificially regenerated forest, great gains can be made by practising genetics: great failures can result from neglecting genetics.

Following is a synopsis of the types of approaches to genetic improvement that can be taken in an artificial regeneration program. In seed source selection and seed collection and production areas, it is the genetic variability in the natural stand that determines the genetic gains or losses which can be obtained. Only in the seed orchard approach does actual breeding play a role in attaining genetic improvement.

SELECTION OF SEED SOURCE

Considerable genetic gain can be obtained by the establishment of seed zones on the basis of species variation and climatic conditions. These zones define the outer limits of seed transfer. When seed is grown in seed zones from which it was collected, we take advantage of the natural selection pressure that species have undergone for numerous generations prior to mans' intervention. Introduced sources or provenances are often more susceptible to disease, insect and frost damage than the local provenance. Morgenstern and Roche (1969) claim that movements of 3 degrees latitude and 300 meters in elevation can lead to growth losses of 6 – 17% from the mean. Thus, if specific information is not available, it is best to use a local seed source to regenerate an area.

Provenance tests of most of the major species in North America are underway and some results are already available. With some species we have to maintain stringent seed transfer rules, with others quite broad transfers are not only permissible, but desirable. In a jack pine provenance test in Ontario, increased height growth to a maximum of 10% was obtained (Morgenstern and Teich 1969), but the risk of frost in these provenances was much higher, thus the local seed source was still recommended (Yeatman and Teich 1969). A seed source study of white spruce in Wisconsin showed that after 29 years a southeastern Ontario source outperformed the plantation average by 22% and the local source by 16% (Nienstaedt 1969) with no offsetting, detrimental effects. In contrast to the experience in jack pine, here is an instance where the foreign provenance was actually desirable. The Lake States presently have an intensive program underway to establish this Ontario material in seed orchards (Anonymous 1973).

Insect and disease resistance can also be affected by choice of provenance. In another Ontario jack pine seed source study, seed collected from three sources in Quebec were more resistant to *Scleroderris lagerbergii* than the two Ontario sources (Yeatman 1971). Further observations are being made to see if this resistance can be effectively utilized in Ontario. A provenance experiment established in southern Ontario for white pine showed no apparent geographic difference in the resistance of the species to blister rust (*Cronartium ribicola*), but did indicate that when southern provenances were moved northward they were more susceptible to the weevil (*Pissodes strobi*) (Fowler and Heimburger 1969).

SEED COLLECTION AREAS

These are areas within the selected seed zone and consist of mature above-average stands that are ready to harvest. No silvicultural improvement is applied to these stands. Cone collections are made from the felled trees at or shortly after the time of cutting. Ideally the areas would be regenerated with the seed from these stands and this regeneration would then be treated, tested and rogued to upgrade the genetic potential of the stand so as superior seed could be produced for ensuing generations.

The selection intensity of these stands is very low, thus the amount of genetic improvement of the seed is also low. But, it is only logical to take seed from the best stands, as the offspring at least have the potential to produce stands as good as the original. Without selection and testing of individual trees within the stands, it is unlikely that future stands would be better than the original. But some of the gain can be obtained when the seed from these above-average stands is used on sites that had produced low quality stands.

SEED PRODUCTION AREAS

The next level of potential improvement is the establishment of seed production areas. The stands within the seed zones are evaluated and the young above-average stands are selected as possible seed production areas. The age of the stands selected in the Lake States are one-half to three-quarters of their rotation age (Rudolf 1959), but if possible I feel that the stands should be much younger. If we are trying to get improved growth and shorter rotations we should be looking at stands which are vigorous in their early years, rather than stands which appear superior when approaching full maturity. Seed from these young vigorous stands is particularly important in a direct seeding program because fast, early growth is crucial in the establishment stage to overcome grass and shrub competition.

The original seed production area produces little genetic gain, but when the stand is silviculturally managed, rogued and fertilized, the gain improves and the cone crop increases. In most species we should be able to obtain a 5 – 10% genetic gain after roguing. Experience in the Lake States indicates that the cost of collecting seed from a seed production area in comparison to a general collection is 50 – 100% greater, but the better yields and improved stock offset the costs (Rudolf 1969). In Ontario, the costs for red pine and white spruce are approximately 100% greater. The gains from this type of approach are obtained in a relatively short period of time and the increased cost is minimal in relation to the gains obtained. The seed production area is used only as an interim measure until seed orchards are in production and able to supply the seed requirements.

SEED ORCHARD

One of the highest levels of genetic improvement results from the establishment of seed orchards consisting of the best material available within the seed zone. Plus trees, which are phenotypically superior to the surrounding trees in the stand, are selected and cuttings or scions are taken from these trees. The collected material is then rooted or grafted and established in a clonal bank or seed orchard. Each individual clone is then evaluated on the basis of control or open pollinated progeny tests. If the offspring produced are superior then the clone is maintained in the seed orchard. If the offspring are inferior, the clone is eliminated from the seed production program. With a high selection intensity in the field to select the plus trees and through progeny testing, 15 – 25% increases in genetic gain for growth and volume should be possible. If selecting for a highly inherited characteristic such as form, the genetic gains would be much greater still. To obtain these improvements, the time and expense in selecting these plus trees in the field, vegetatively reproducing them, establishing orchards, and evaluating field tests of the offspring is considerable.

ONTARIO'S REGENERATION PROGRAM

As Ontario is presently involved in a direct seeding program and we anticipate that this program will grow considerably in the future, I have used the regeneration targets of Ontario as the basis for my description of tree improvement research through genetics in this Province. I will relate to the major species of Ontario, namely red, white, and jack pine and white and black spruce. These species also play important roles in the Northeast and Lake States, and in eastern and western Canada.

Table 1 indicates the present and predicted acreages annually cut in Ontario and the area that requires some form of treatment to obtain satisfactory regeneration. Of the 266,000 acres presently requiring some form of treatment (Table 1), 111,000 acres are artificially restocked (Table 2). By 1987, of the 369,000 acres requiring treatment (Table 1), 223,000 acres will be restocked (Table 2). Although the area to be regenerated with nursery material is to increase by about 50%, the area to be regenerated by direct seeding is to increase by nearly 300% (Table 2). This is the major reason why genetics cannot be ignored in Ontario's direct seeding program. Table 3 indicates the present and predicted amounts of seed needed annually to supply the Province with the seed and stock required. This table also shows that red pine and white spruce will not be considered in a direct seeding program, although some white spruce is presently being utilized. The major emphasis will be directed to jack pine because the greatest success in Ontario is with this species. A secondary effort will be devoted to black spruce, but some problems are evident and if these are not overcome, then seeding will be discontinued for this species. Minimum emphasis will be given white pine. Currently, North Bay is the only area where direct seeding of white pine is an apparent success.

ONTARIO'S APPROACH TO GENETICALLY IMPROVED SEED

In the 1950's, Ontario established seed zones for the Province based on climatic conditions. These have worked quite effectively with available data. Presently these seed zones are under review and it is likely that some of the boundaries may be changed as a result of information accumulated over the past 20 years. Thus, we have crossed the first hurdle as we already have source identified seed.

One of the problems in Ontario is that the area covered by each seed zone is so extensive that there is considerable geographic and genetic variation of the species within a zone. Plans are underway to identify each large seed collection by township, thus effectively identifying the different genetic entities of each species. Some problems are anticipated in maintaining the identity of small seed lots from time of collection, through seed extraction to nursery and/or field establishment. These problems will have to be overcome with time and experience.

Efforts are also being made to select seed collection areas within the seed zone, so that the seed being collected is at least coming from the best available stands rather than from uncontrolled collections. This approach is relatively easy to follow with jack pine and black spruce since these species grow in pure or relatively pure stands. The problem is somewhat more difficult with white pine and white spruce since these species tend towards mixed stands and they may or may not be dominant in the stand.

The selection of good seed production areas is difficult because the entire area within a seed zone must be known, the species classified and the age and site classes identified. Table 4 indicates the number

Table 1. Present and predicted acreages cut and requiring regeneration treatment in Ontario. (Internal Report, Ministry of Natural Resources. 1973).

	1970-71	1987
	acres	
Area cut	396,000	499,000
Natural regeneration	130,000	130,000
Area requiring treatment	266,000	369,000

Table 2. Present and predicted acreages artificially regenerated in Ontario. (Internal Report, Ministry of Natural Resources, 1973).

	1970-71	1987
	acres	
Planting of nursery stock	81,500	127,000
Planting of container stock	8,100	36,000
Direct seeding	21,300	60,500
Total	110,900	223,500

Table 3. Number of present and predicted viable seeds required in Ontario. (Internal Report, Ministry of Natural Resources, 1972).

	1970-71			2000		
	Direct seeded	Nursery stock	Total	Direct seeded	Nursery stock	Total
			(millions of seeds)			
White pine	4.5	20.3	24.8	28.5	48.0	76.5
Red pine	—	144.4	144.4	—	100.0	100.0
Jack pine	254.4	34.0	288.4	713.2	72.0	785.2
White spruce	11.6	98.3	109.9	—	425.0	425.0
Black spruce	116.0	117.3	233.3	332.0	294.0	626.0
Total	386.5	414.3	800.8	1073.7	939.0	2012.7

Table 4. Proposed acreages for seed collection to be established within the next 25 years in Ontario — (Internal Report, Ministry of Natural Resources, 1972).

	Seed collection areas	Seed production areas	Seed orchards
White pine	—	100	50
Red pine	—	500	40
Jack pine	5000	30	—
White spruce	—	520	350
Black spruce	—	200	300

of acres required for seed production areas within the next 25 years. When possible these areas must be natural stands and not plantations. This will present little problem in the northern part of the province. In the southern and central part we will likely have to resort to some plantations as most of the good natural stands have been eliminated. We must also select the young vigorous stands in preference to the mature established stands.

The proposed areas will be tested on a broad scale to determine the merits of one stand relative to the others. As some poorer stands are eliminated, others will be added in attempts to constantly upgrade the genetic constitution of the production areas.

Plus trees have and will continue to be selected for seed orchard programs. This program is expanding and receiving greater emphasis, particularly in the spruces. Several hundred plus trees have been selected in both black and white spruce and some already are established in seed orchards. Table 4 does not include any figures for jack pine seed orchards, but this aspect of the program will undoubtedly get underway in the near future owing to the increasing importance of the species and its natural variability. A major problem to overcome in jack pine is picking cones without damaging the branches.

These orchards will be intensively tested with control pollinated progeny tests. The results of the tests will not only allow us to select the best clones within the established orchard, but also will allow us to select material from the offspring that can be used for a second generation orchard.

Future plus tree selections will not be put directly into the orchard, but will be evaluated on the basis of individual cone collections from the trees in the field. The trees which produce the best progeny will then be incorporated into the controlled pollination program for more detailed information.

Presently the greatest proportion of seed in Ontario comes from general collections within the confines of the various seed zones. Beginning in 1973, the collections will be further identified according to township. Some seed is being collected from seed production areas. Within the next few years, much larger percentages will be collected from these areas. It will be another 5 – 10 years before an appreciable amount of seed is collected from the seed orchards. Some of the orchards are presently flowering, but the crops are quite small and most of the seed collected is utilized in testing programs.

It is anticipated that the amount of jack pine seed required will triple over the next 25 years (Table 4). Within 5 years all of the seed should be coming from modified seed collection areas. These areas would be felled and then regenerated with seed from the same area, thus the genetic constitution of these stands can be maintained in perpetuity. Since jack pine flowers at an early age, we can establish both clonal seed orchards and seedling seed orchards for this species. By the year 2000, 90% of the jack pine seed will be utilized for direct seeding, and most of the seed used will be genetically improved.

Black spruce seed collection areas will provide the greatest proportion of seed for the next few years. The present acreage, 100, of seed production area is to be doubled and the bulk of the seed will come from these areas until the seed orchards come into production. Twenty-three acres of seed orchard have been established and this will be increased to 300 acres as soon as plus trees can be selected and grafts established.

The present 11 acres of white pine seed production area will be increased to 100. Many areas presently producing natural white pine will be maintained and regenerated with the same seed to maintain the gene pool reserves, which are seriously depleted in this province. The seed orchard area will be enlarged to 50 acres.

GENETIC CONSIDERATIONS OF DIRECT SEEDING

The genetic considerations cannot be ignored in a direct seeding program, especially with the anticipated acreages to be seeded in Ontario and other parts of the country. But, due to problems in the direct seeding techniques and to the present shortage of genetically improved seed, direct seeding is not at the top of my list of priorities for improved seed. Only if techniques are perfected will there be justification in spending greater amounts of money in breeding and progeny testing for direct seeding. As a result, I would advocate that the improved seed from a tree improvement and breeding program be directed first to planting stock where the ratio of seed produced to seedling established is much higher than in the direct seeding program. For the immediate future, we should concentrate on selecting enough good seed collection and production areas to supply the required amounts of seed for the entire artificial regeneration program. This seed would provide a considerable amount of genetic improvement for the areas seeded. Until the tested seed orchards come into production, the seed collected from the plus tree selections could be sown for seedling seed orchards. This phase would require a minimum number of years for both black spruce and jack pine because of the early flowering tendencies of these species. These orchards would be untested and would be used only as a stop-gap until better material became available. With the proposed improvement program for Ontario, it is hoped that there will eventually be sufficient quantities of improved seed for all phases of artificial regeneration. The major factor we have to contend with is time.

The genetics program is an ongoing selection and breeding method that constantly attempts to upgrade the quality of the seed being used. The gains we can make through a good genetics program will cut several years from the rotation ages we are accustomed to.

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Germination and seedling establishment

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ABSTRACT

Reviews the literature pertaining to factors which can affect the establishment of direct-sown spruce and pine. The three stages in the establishment of a seedling — germination, succulent and juvenile — are discussed in detail as success of any direct seeding project can be adversely affected by failure at any of these stages.

RÉSUMÉ

Revue de la littérature scientifique sur les facteurs qui peuvent affecter la première pousse de jeunes Pins et Épinettes semés directement. L'auteur discute en détail les trois stades de la première pousse d'un semis — germination, plante succulente et juvénile — vu que le succès d'un projet d'ensemencement direct peut être affecté par toute défaillance à l'un ou l'autre de ces stades.

INTRODUCTION

Three phases in the establishment of a seedling are defined by Baker (1950), as follows: (i) the germination phase ending with the appearance of the seedling above the ground; (ii) the succulent stage ending with the hardening of the hypocotyl, and (iii) the juvenile stage which lasts for an indefinite period until the seedling has become well established. As the success of any direct seeding project can be adversely affected by failure at any of these stages, my presentation will deal with each in turn.

GERMINATION

Moisture of the Seedbed

The moisture retention capacity of the seedbed is of paramount importance in direct seeding. Although there are usually adequate supplies of moisture in early spring, rising temperatures and increased evaporation rates often lead to moisture deficits as the growing season progresses. Deficiencies of surface moisture are cited as one of the principal causes of poor germination (Cayford and Dobbs 1967; Clark 1958; Farrar and Fraser 1953; Fraser 1954; Sims 1968, 1970).

One of the most important factors governing the moisture level of the seedbed, hence the ultimate success of direct seeding, is the amount and distribution of rainfall (Smith 1964). Rainfall in spring and early summer (May – July) of the first growing season had a strong influence on the success of direct seeding experiments of white spruce, Engelmann spruce and lodgepole pine in the central Interior of British Columbia (Illingworth 1964; Prochnau 1963).

Notwithstanding the need for adequate moisture supply (Clark 1958, 1960; Fraser and Farrar 1953b; Horton and McCormack 1961) heavy precipitation can have an adverse effect by washing seeds from scarified plots (Clements 1964). This can be particularly severe on bare soils and on steep slopes. On the other hand, rainfall can be beneficial by covering up the seed through soil splashing, thus reducing potential losses to birds and rodents (Clements 1964).

Although many references link the success or failure of direct seeding to inadequate precipitation, the total amount of rainfall is probably much less important than its distribution. Smith (1964) set the critical limit as the number of days elapsing between rainfalls of 0.25 inches or more. He also noted that, in the crucial uppermost layers of mineral soil, a heavy rain is hardly more beneficial than a moderate one and, as pointed out above, a particularly heavy rainfall can have detrimental effects. Working with Engelmann spruce in greenhouse experiments, Alexander and Nobel (1971) found that total germination on field soil increased with the amount of water applied between 1 and 1.5 inches per month. There was no appreciable survival (after 24 weeks) unless the seedlings received a total of 1 inch of rain at regular intervals throughout the month.

Other conditions that favor good seed germination are shading, fine-textured soil and seed covering (Fraser and Farrar 1953b). The need for some degree of shade for successful germination is cited by several authors (Clark 1969a, 1969b; Fraser 1954; Fraser & Farrar 1953a; Graber 1968; Smith 1951). Sowing techniques that bury or cover seeds are often deemed preferable to those in which seeds are broadcast on the soil surface (Clark 1969c; Horton and Wang 1969; Jarret 1964; McLeod 1953; Tinsley 1939). Covering affords improved moisture conditions and added protection from small mammals (Graber 1969). However, the maximum depth to which seeds can be sown varies with their size. Although large pine seeds may successfully germinate at depths of 3 inches, small seeds such as spruce may not germinate at depths of more than half an inch (Baker 1950). Germination below this depth may be technically possible but the hypocotyl loop may never reach the soil surface. Since small seeds can only be covered by a thin layer of soil, they are subject to high evaporative stress, large fluctuations in soil moisture content and extreme surface temperatures with adverse effects on germination.

Seedbed moisture and temperature conditions are likely to be optimum in the spring, so it is not surprising that a preponderance of authors cite this season as preferable for sowing spruce and pine (Armit 1969; Cayford 1961; Gilmour 1966; Roe 1949; Strothmann and Conover 1960; Tinsley 1939; Veness 1927). Dickson (1956) noted that sowing on the snow was essential for satisfactory stocking of black spruce in Newfoundland, while Clark (1958), in British Columbia, stated that the exact time of spring sowing for Engelmann spruce and ponderosa pine is immaterial, provided it is not later than 3-4 weeks after the snow has melted.

All sources are not unanimous in their choice of sowing date. Although Horton and McCormack (1961) found no significant differences between spring and autumn trials for jack pine, Scott (1966), in his extensive review of direct seeding work in Ontario, pointed out that best stocking for this species was obtained with fall seeding. Fall sowing may be desirable for eastern white pine (Smithers 1964). An interaction between site type and sowing date was noted by Cayford and Dobbs (1967), who found that better results were obtained with fall sowing of jack pine on drier sites; spring sowing was best on fresh and moist sites. Illingworth (1966) found that the best season for sowing western white pine and Engelmann spruce in the Columbia Forest Zone varied widely with species, site factors and weather patterns.

Temperature and Germination

The average optimal temperature for germination of coniferous species is approximately 75 F, the range being 60–85 F (Baker 1950). Recent work by Fraser (1971) indicates that the temperature range within which maximum germination of white spruce will occur varies with the environment at the latitude of the seed source. Thus the optimum cardinal temperature for white spruce from British Columbia (54°32′N) was 55–60 F, whereas seed from New Brunswick (46°00′N) had an optimal range of 65–75 F. For most coniferous species, germination is slow below 50 F and temperatures in excess of 100 F will probably prevent germination occurring (Baker 1950; Fraser 1971). Carmichael (1958) delineated the absolute maximum air temperatures that both red and jack pine and white and black spruce seeds can tolerate at low relative humidity (Table 1). For germination of certain species, such as jack and lodgepole pine, there is a strong interaction between temperature and light (Ackerman and Farrar 1965). Engelmann spruce germination at low temperatures will also be increased by exposure to light (Patten 1963).

Seedbeds

MINERAL SOIL. Mineral soil is an excellent seedbed for the germination of Canadian spruces and pines (Alexander 1966; Anon. 1953; Armit 1968, 1969; Beaufait 1960; Clark 1968, 1969a, 1969c; Clements 1964; Davis and Hart 1961; Eis 1965; Fisher 1935; Haig 1959; Illingworth 1964; Jameson 1961; Jarvis 1966; Lees 1970; Logan 1951a, 1951b; Parker 1952; Prochnau 1960, 1963; Quaite 1956; Roe and Squillace 1950; Rowe 1955; Smith 1955; Smith and Clark 1960; Sutton 1964; Thomson 1949; Wagg 1964 and Waldron 1966). The reasons why this should be so are well defined by Baker (1950): "The infiltration capacity and aeration is good, yet the soil packs well around the seed, which thus secures close contact with films of moisture. The soil has good heat-conducting capacity and will warm up faster than the loose organic horizons. There is no great resistance to the process of germination. Harmful microorganisms are less likely to be present in large numbers than they are in highly organic soils. The capillary is well enough developed so that as the moisture is drawn from the nearest soil by imbibition of the seed, new moisture moves in to take its place, at least until the level of the water content falls below field capacity of the soil."

As previously discussed, moisture of the seedbed is of primary importance in successfully obtaining germination. Thus microenvironments, such as at the bottom of a cultivated furrow, are more conductive to germination than adjacent, open areas on dry sandy soils (Jameson 1961). Seedlings in the furrow bottoms may be subject to high mortality through burying by soil washing in from the sides (Cayford 1961). Cultivation of exposed mineral soil also tends to conserve moisture and thus improve germination. On sandy loam soils in Alberta, Crossley (1949, 1952) found that scarification improved germination of white spruce. Best stocking with spruce in Alberta's sub-alpine region was obtained when the ground was well prepared (Blyth 1955). Scarification of a cutover, either with a bulldozer blade, disking or anchor chains, is considered by many as a prerequisite for success of direct seeding in spruce and pine (Arlidge 1967; Cayford 1961; M. W. Day 1964; Hocker 1961; Horton and Wang 1969; Roe 1963; Sims 1970).

Seedbeds favorable to germination of spruce and pine can also be created through an alternative technique of seed spotting, where small mineral soil patches are created by screefing (Abbott 1964; Arnott *et al.* 1971; Clark 1969a; Dickson 1956; Franklin and Hoffman 1968; Horton 1966; Robertson

Table 1. Safe limits of exposure (hours) for pine and spruce at low relative humidities [1].

Temperature	120 F			150 F			180 F		
Rel. Humidity	10%	20%	30%	10%	20%	30%	10%	20%	30%
Red pine	70+	70+	70+	70+	70+	70+	30	30	10
Jack pine	70+	70+	70+	70+	70+	50	30	30	10
Black spruce	70+	50	50	50	50	50	30	30	10
White spruce	50-70	50-70	50-70	Conditions too severe			Conditions too severe		

[1] Carmichael, 1958.

1926; Roe and Boe 1952; Tinsley 1939). Seed spotting on exposed, windswept areas reduces loss of seed from the area by wind (Cayford 1966) although depressions created by seed spots are more subject to flooding with attendant loss of seed or germinants (McLeod 1953).

However, bare mineral soil is not necessarily the best seedbed for all species and on all sites. Cayford and Waldron (1962) found highest white spruce germination from sowing on mineral soil and covering the seed with a thin layer of aspen leaf litter, while jack pine germinated best on bare mineral soil.

The soil horizons exposed by scarification or screefing are not particularly rich in nutrients. Thus, bare mineral soil, although suitable for good germination, is often much less suitable for seedling growth (Place 1955). Working with red pine, Mader (1971) demonstrated that mixing humus and topsoil in seed spots promoted better and more uniform growth of seedlings.

LITTER, DUFF AND HUMUS. "Most of the writers who comment on the excellence of germination on mineral soil, contrast it to the poorness of germination on litter, duff and raw humus. ." (Place 1955). This is not surprising when one considers the physical characteristics of these materials. The major seedbed type left after logging is duff, the accumulation of partially decomposed organic debris and litter. The litter consists of a criss-crossed pattern of hard conifer needles and twigs, through which rainfall passes rapidly. Although it may have a high moisture content by weight, the moisture. . . "is mainly imbibed within the cellulose walls of the needles and does not exist in surface films as it does among the many impermeable grains of mineral soil" (Baker 1950). In addition, upward movement of moisture through this material is poor so that it is not rapidly replenished from below as it is removed from the surface by evaporation. As a result of this, plus a low thermal conductivity, temperatures and moisture content fluctuate over a wide range. With such physical properties, undisturbed duff constitutes a poor seedbed for directly sown spruce and pine seeds (Anon. 1953; Arnott *et al.* 1971; Fisher 1935; Jameson 1961; Jarvis 1966; Strothman and Conover 1960; Wagg and Hermann 1962).

MOSSES. There are few references to moss seedbeds in the direct seeding literature pertaining to pine and spruce in Canada. Exposure of the forest floor resulting from clear-cutting either destroys much of the moss cover or creates conditions unfavorable for moss growth, particularly on the drier upland sites. Furthermore, most areas designated for direct seeding are subject to slash burning and/or mechanical site preparation.

The two moss types most commonly found are the *sphagna*, characteristic of wet habitats, and the upland mosses, such as the feather moss group and the genus *Polytrichum* (Place 1955). On cutover fresh upland sites, the feather mosses tend to become dry, making a poor seedbed for germination. However, Richardson (1970) concluded that direct sowing of black spruce is a suitable technique for regenerating fresh to very moist burned, cutover upland sites with a moss and herbaceous ground cover. Because of the thin humus layer on such sites, seedling root systems are able to reach the mineral soil before the organic horizons dry out.

The *sphagna*, because of the large amount of water that they retain, are an excellent germination medium for most species. However, most germinants soon become engulfed in this fast-growing moss type (Arnott 1968; Le Barron 1948; Place 1955; Roe 1949).

ROTTEN WOOD. Rotten wood makes an excellent seedbed in the undisturbed stand (Place 1950; Rowe 1955) because it retains adequate supplies of moisture. In logged spruce stands, it is also deemed favorable for germination (Lees 1970; Smith 1955), although Prochnau (1960) noted that it was not as favorable as mineral soil or burned humus. Fisher (1935) found that this substrate formed a good seedbed for germination of lodgepole pine, western white pine and Engelmann spruce.

SUCCULENT STAGE

Temperature Effects and Heat Injury

Heat is a very important limiting factor for seedlings, having greatest impact through drying out the surface of the seedbed (Place 1955). According to Place (1955), most seedlings die from drought on hot seedbeds because of high transpirational stresses and rapid dessication of the seedbed surface. There is a strong interrelationship between temperature and inherent moisture of the seedbed, which makes it difficult to ascertain which of the two parameters caused the death of the seedling (Scott 1966).

Nevertheless, seedlings in the succulent stage are particularly susceptible to direct heat injury, the degree and amount of damage depending more on the exposure of the seedbed to direct sunlight than upon any other factor (Baker 1950). Although 120–130 F appears to be the thermal death point for all species, they vary in their capacity to maintain hypocotyl temperatures which are lower than the surface temperature of the seedbed. Baker (1929) found temperatures of the hypocotyl 12–30 F below the temperature of the surrounding soil surfaces. Such differences are accountable to the diameter of the hypocotyl, the degree of shade afforded by the cotyledons and the cooling effect of the transpirational stream. According to Baker (1950), to develop a lethal tissue temperature of 120–130 F, the surrounding soil surface must rise as high as 140–150 F.

Working with white spruce in the central interior of British Columbia, Eis (1965) found seedling mortality in mineral soil confined to periods of summer drought when maximum air temperatures approached 100 F. Corresponding mineral soil and humus surface temperatures were 120 and 135 F, respectively.

The soil surface temperature can rise considerably above that of the surrounding air. The principal controlling factor is the thermal conductivity of the seedbed, which determines the efficiency with which seedbed materials dissipate heat from the sun (Smith 1951). Seedbeds such as duffs, with poor thermal conductivity, heat up more than mineral soil (Baker 1950; Cochran 1969). Baker (1950) demonstrated that temperatures in excess of 130 F were observed 62 days out of the season on duff, only 18 days on mineral soil and 34 days on burned mineral soil. Maximum temperatures on duff (161 F) were also higher than on the mineral soils (150 and 152 F, respectively). Working with jack pine on prepared cutovers, Sims (1970) reported similar results from work in Manitoba. Practices that increase the surface temperature on mineral soils are cultivation, which increases the soil air space and thereby reduces thermal conductivity, and covering with dry organic mulches that have lower thermal conductivities than the soil (Cochran 1969). Conversely, practices that decrease surface temperature variation are soil compaction, mulching with organic materials which have higher thermal diffusivity (index to rate of temperature change with time and depth.) than the soil, and removing the litter to expose mineral soil. An example of this was demonstrated by Fraser (1968) where, on a clear day, seedbed temperature was 30 F cooler under an algin mulch and 10 F warmer under one of petroleum than on exposed soil. There are several other references in the literature that relate direct seeding success to the practice of mulching the seedbed (Anon. 1956; McLeod 1953, 1963; Tinsley 1939). However, these sources do not indicate specifically whether the improved germination resulted from temperature or moisture modifications caused by the mulching.

The presence of moist soil just below a dry surface soil will prevent surface temperature extremes that would occur if the entire soil profile was dry (Cochran 1969). Nevertheless, Day (1963) pointed out that temperatures in excess of 122 F caused severe seedling mortality even when the soil was moist at a depth of 1 inch. Eis (1965) also reported that, in periods of summer drought in the central interior of British Columbia, with air temperatures approaching 100 F, moisture content of the upper 20-40 mm of mineral soil was reduced below the wilting point, resulting in death of 45% of white spruce seedlings.

Cochran (1969) stated that the influence of color on the surface temperature of the seedbed has probably been overemphasized and that other thermal properties of the seedbed influence temperature fluctuations much more than color alone.

Precipitation effects

Scott (1966) pointed out that rainfall can have a harmful effect where heavy rains wash out or bury the germinating seedling. On the other hand, Clements (1964) noted that splashing can produce columns of soil around the stems of young seedlings which can adhere for as long as 7 – 10 days, thus affording some protection against lethal temperatures created by direct sunlight on scarified seedbeds.

JUVENILE STAGE

Drought

To a great degree, survival and growth of young seedlings is dependent upon the precipitation regime of the area, a subject already dealt with under germination. However, mortality from drought for pine (Cayford 1963; Horton and McCormack 1961; Sims 1970; Wagg and Hermann 1962) and spruce (Alexander and Noble 1971; Clark 1958, 1960; Rowe 1955) can result from factors other than long, dry periods; namely, slow root development, rapid evaporation from duff, and root competition (Baker 1950).

Root development following germination is critical to seedling establishment, particularly for small seeded conifers with their relatively slow root growth. Unless the root system can keep ahead of soil dessication, which advances deeper into the soil as the growing season progresses, the seedling is likely to die from drought. Eis (1965) found that the main cause of seedling mortality in both undisturbed and disturbed mineral soil seedbeds was water deficit in the root zone. Naturally, the degree of dependence on soil moisture regimes will vary with the species. The greater abundance of fir on dry habitats suggests that fir, which has heavier seed and a longer radicle, is less dependent on surface soil moisture during its establishment (Day 1964). Place (1952) found that fir had the advantage over spruce of greater root elongation in the critical period immediately after germination. Although spruce root development improves later, it is often too late to save the seedling. The importance of root penetration was emphasized by Eis (1965), who found that the mean root length of white spruce seedlings that died on mineral soil was 18 mm while surviving seedlings had an average root length of 37 mm. Depth of root penetration depends to a degree on the ease with which the radicle can penetrate the surface soil or organic layers. Eis (1965) found that the depth of root penetration was greatest on sandy soils and Muri (1955) noted that Engelmann spruce seedlings died because their radicles had difficulty penetrating burned seedbed surfaces.

Rate of soil dessication depends on the type of soil, depth of duff, the amount of rain, the rate of evaporation and the depth of the water table. Where duff remains intact, if the seedling roots do not rapidly penetrate to mineral soil, chances of survival are minimal. Eis (1965) found that raw humus reached the wilting point a few days after rain, and few white spruce seedlings survived on this seedbed type to the end of the growing season.

Few young seedlings will survive drought conditions where soil moisture falls below the wilting point for any extended period of time. Under conditions of low soil moisture availability, the ability of the seedling to survive depends on the degree of evaporative stress under which it is growing. Thus any factor, such as shade, which will reduce this stress will improve its probability of survival (Day 1963; Graber 1968; Wagg and Hermann 1962).

Shade/Light Requirements

Although Wagg and Hermann (1962) stated that shading had little effect on the germination of ponderosa pine, it did increase survival. Smith and Clark (1960) found that Engelmann spruce survived best on seedbeds receiving approximately 30% of full sunlight. Logan (1951b) also surmised that poor survival of red and white pine on seedspots indicated that these species benefitted from shading in their early years. Shade requirements for the survival of white spruce in New Brunswick are reported by Veness (1927), and for hybrid (white x Engelmann) spruce in Alberta by Day (1963). Cayford (1959) also suggested that jack and red pine survival might be increased by providing shade.

Although shade is usually beneficial or essential for seedling survival, it can have a negative effect on growth of the juvenile seedling. Smith and Clark (1960) indicated that height of Engelmann spruce increased as insolation rose from 30 to 70% full sunlight at noon. Smith (1951) also noted that once white pine seedlings are established, they grow satisfactorily only in full sunlight.

In spot-seeding research work, small conical screens are commonly used to protect the seeds from predators. However, the screens have the added advantage of partially shading the juvenile seedling. In addition to providing shade, screens cause appreciable differences in light intensity, soil temperature and other factors. In California, Fowells and Arnold (1939) found that screens reduced the average maximum ambient temperature by 12.2 F. Another advantage in screening the seed spots is that the juvenile seedlings are initially protected from smothering by hardwood leaves (Baldwin 1960).

Competition

Young seedlings must compete with surrounding vegetation for light, moisture and nutrients. Lack of nutrients may be overcome through fertilization. This will result in increased growth rate of the seedling and reduce the time during which it must compete with herbaceous vegetation, although Alban (1971) discovered that such treatment, on 1-year-old direct-sown red pine seedlings, increased mortality by salt injury to the plants. In Saskatchewan, Jameson (1961) found that competition tended to prevent jack pine seedling survival on the more productive sites. On intermediate sites, moderate stocking was obtained without seedbed treatment to reduce competition. On poor sites, competition was unimportant. Similar site type/competition interactions have been noted for both jack and red pine and white and black spruce by Sims and Mueller-Dombois (1968). An aerial seeding of jack pine on a poor quality site in Ontario probably owed its success to the lack of vigorous competition from ground vegetation (Kokocinski 1965). Often, however, direct competition from other vegetation has been cited as a principal cause of failure of direct sowing and natural seeding on cutover areas (Baldwin 1960; Cayford and Waldron 1963; Roe 1963; Tackle 1956). Spot-sown conifers under a thinned stand of mixed hardwoods are particularly subject to competition (Fraser 1952). Although scarification initially reduces herbaceous competition (Phelps 1949; Rowe 1955), it can stimulate its regrowth and thereby create conditions that are even more detrimental to seedling survival (Crossley 1955). An alternative treatment is to release the seedlings between the third and fifth years, as Benzie (1968) recommends for jack pine regeneration in cutover stands.

The effective life of a prepared seedbed will depend, among other factors, on the rate of reinvasion of competing vegetation. Working with spruce in British Columbia, Arlidge (1967) found that, with sowing 1, 2, 3, and 4 years after scarification, regeneration decreased with increase in seedbed age. Clark (1970) found that sowing of grass seed prevented the reestablishment of herbaceous cover on prepared seedbeds, although the grass itself had an inhibiting effect on conifer seedling survival.

Frost Heaving

Although scarification creates conditions conducive to germination, the removal of litter may render such seedbeds prone to frost heaving. The danger is increased on wet sites (Parker 1952). Revel (1969) noted heavy frost heaving of lodgepole pine seedlings because early disappearance of snow during January and February exposed the soils to freezing conditions. Tinsley (1939) found that western white pine and ponderosa pine seedlings on seed spots protected by screens were less subject to frost heaving than unprotected spots. He suggested removing the protective screens at the beginning of the second growing season after danger of frost has passed. Not all instances of frost heaving are harmful. Crossley (1952) found that frost heaving of white spruce seedlings had a beneficial result because the initial reproduction was so dense.

Seedling losses may occur directly from frost injury, although there is little reference to this phenomenon in the direct seeding literature. Pines as a class are generally hardier than spruces, which often suffer from frosts that kill the new growth in the spring (Baker 1950).

SUMMARY

Germination

1. The moisture retention capacity of the seedbed is of paramount importance in direct seeding; soil moisture deficits are cited as one of the principal causes of poor germination.
2. Variables having an influence on the above are (a) the amount and distribution of rainfall, (b) presence of shade, (c) rate of evaporation, (d) depth of water table, (e) texture of the soil, (f) degree of seed covering, (g) season of sowing, and (h) type of seedbed.
3. Mineral soil seedbeds, created by spot screefing or by scarification with bulldozer blade, disking or anchor chains are considered by many as a prerequisite for successful germination in direct seeding of spruce and pine. Moss cover with a thin humus layer, such as is found on fresh upland sites, can be a suitable seedbed if seedling root systems are able to reach the mineral soil before the organic horizons dry out. However, feather mosses tend to become dry on cutover upland sites, making a poor

seedbed for germination. *Sphagna* form excellent moist seedbeds for spruce but, through their rapid growth, soon engulf young germinants. Rotten wood is also deemed favorable for germination. Litter, duff and humus are considered poor seedbeds by most authors.

4. The average optimal temperature for germination of coniferous species is approximately 75 F, germination being too slow below 50 F and very poor in excess of 100 F.

Succulent Stage

1. Young seedlings in this stage are particularly susceptible to direct heat injury, the degree and amount of damage depending more on exposure to direct sunlight than any other factor.
2. To develop a lethal tissue temperature of 120–130 F, the surrounding soil surface must rise as high as 140–150 F. The principal factor controlling the soil surface temperature is its thermal conductivity, which determines how efficiently it can dissipate heat from the sun. Duffs, with low thermal conductivity, make poor seedbeds as they heat up much more than mineral soil.
3. Presence of moist soil below the surface will prevent surface temperature extremes that would occur if the entire profile was dry.

Juvenile Stage

1. Mortality from drought can result from factors other than long, dry periods; namely, slow root development, rapid evaporation from duff and root competition.
2. Most juvenile spruce and pine seedlings benefit from some degree of shade.
3. Herbaceous competition has a negative influence on survival and growth as young seedlings must compete with it for light, moisture and nutrients. Effective life of the prepared seedbed also depends on the rate of reinvasion by competing vegetation.
4. Although scarification creates conditions conducive to germination, the removal of litter may render such seedbeds prone to frost heaving, with the danger increasing on wet sites.

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Seed losses to small mammals and birds

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ABSTRACT

The ever increasing demands on forest resources by industry, and increasing labor costs encountered in planting, have revitalized an interest in direct seeding as a rapid and economical means of forest regeneration in North America. The paper reviews the difficulties encountered by research workers who have studied major seed losses in the field ascribed to a variety of small mammals, birds, and insects. In earlier studies the difficulties in relocating for examination the individual seeds planted into the forest environment have usually made statistical evaluation of seed fate a matter of conjecture. The use of radio-tagging methods in one of the three studies reviewed has enabled the retrieval of a large percentage of planted coniferous seeds as small as 2.5 to 3.0 mm in size. The radio-tracer method has indicated the inadequacy of past seed coating procedures and the requirement for further research in this field.

RÉSUMÉ

La demande toujours accrue de bois par l'industrie forestière, outre les coûts plus élevés de la main d'oeuvre employée pour les transplantations, ont popularisé à nouveau l'ensemencement direct qui est devenu un moyen rapide et économique de reboiser en Amérique du Nord. Le présent rapport fait la revue des difficultés éprouvées par les agents de recherche qui ont étudié les pertes importantes de graines sur le terrain, pertes dues à des petits mammifères, aux oiseaux et aux insectes. Lors d'études plus anciennes, on procédait par conjectures pour savoir ce qui était advenu aux graines semées en forêt, vu que l'on pouvait difficilement retrouver chaque graine. Plus récemment, la localisation par radio (rapportée dans l'un des trois articles passés en revue) a permis de trouver un fort pourcentage des graines de Conifères semées, graines mesurant aussi peu que 2.5 à 3 mm. de long. Cette nouvelle méthode a permis de savoir que les méthodes d'enduire les graines étaient inadéquates et que dans ce domaine, il fallait de plus amples recherches.

INTRODUCTION

With an increasing global demand for wood products and progressively less land upon which to grow their crop, foresters must give more attention to factors that influence regeneration on existing forest lands. A forest is more than a collection of trees of various sizes, shapes, or species. Many plants and animals are components of the system and their diversity and abundance change as forests become established. Numerical fluctuations in wildlife populations and the resulting patterns of damage to trees at various stages of development are frequently a direct result of the changes in habitat that occur coincident with the cycle of harvest and reestablishment of forests. While many factors may endanger forest regeneration, a variety of animals from shrews to moose can be particularly important when they come into conflict with industrial interests.

A pulpmill in operation in Alberta since 1955 had been clear cutting 10,000 acres of white spruce and lodgepole pine annually. Approximately 5,500 acres of the yearly cut required scarification and artificial seeding at the rate of 1 lb of seed per acre, or about 220,000 seeds per acre to produce 300 to 400 trees per acre. Several years of seeding at 1 lb/acre with seed treated with a bird repellent, an insecticide, and a fungicide (the aluminum powder-endrin-arasan latex treatment) failed to produce this level of stocking and a research study was initiated to answer the question – What happens to seeds which are broadcast into the field to start the new crop of trees?

In this paper I propose to refer first to work done by others in their attemps to reestablish forests by employing direct seeding methods and then to review those studies which I conducted during the past 13 years.

ENVIRONMENTAL FACTORS

Direct seeding methods have several advantages over the planting of seedlings. Because seeds can be used in the locality from which they originated, there is little adjustment imposed by soil and climatic conditions. By use of aircraft, areas difficult to reach can be replenished with a new seed supply. Basically, the requirement for a rapid and economic means of regenerating large cut-over areas has maintained an interest in the direct seeding method since the early years of the twentieth century.

But direct seeding has had its drawbacks. Much published literature describes small mammals and birds as important consumers of coniferous seeds. Dearborn (1912), in describing the role of small mammals on a seeded area, stated: "The rodent population of the Warren Gap seeding area amounts to one or two chipmunks and at least 24 white-footed mice per acre — enough to destroy not less than 80% of any seed sown before it could germinate."

Krauch (1936), in describing attempts at direct seeding over a 4-year period, concluded "The consistently poor results obtained on the areas open to rodents indicated the futility of direct seeding unless rodents (chiefly mice) were controlled."

Garman and Orr-Ewing (1949), in summarizing direct seeding experiments in British Columbia from 1923 to 1949, concluded that no success in the direct seeding of Douglas-fir could be expected until the seed was protected from deer mice.

Abbott (1961) concluded that three species of mice and voles in northeastern United States could destroy quantities of eastern white pine seed far in excess of the amounts that could be sown economically.

A wide variety of small mammals and birds found in forested areas feed to some degree upon coniferous seeds. The small mammals most frequently cited in this respect, because of their ubiquitous occurrence and insatiable appetites, were deer mice (*Peromyscus* spp.), red-backed voles (*Clethrionomys* spp.), chipmunks (*Eutamias* spp.), and meadow voles (*Microtus* spp.). Even the classical insectivores of our early biology courses, the shrews (*Sorex* spp.), supplement their diets with varying amounts of valuable seed.

Changes in the forest habitat, whether by natural or human means, alter greatly the availability of shelter and food for small mammals. These changes are reflected in the species and numbers of animals to be found there. As pointed out by Tevis (1956) and Gashwiler (1970), a closed canopy of mature coniferous timber shades out the herbs and shrubs that are a major source of food for many small mammals with the result that many rodent species are relatively scarce therein. Forest removal, too, has a profound effect on small mammals, at least temporarily. Such a marked alteration in the habitat affects sunlight, temperature, and humidity of microsites as well as vegetation species and food sources with the result that small mammals are exposed to predators and to the elements. During the first year on a clear-cut area vegetation, and hence shelter and food, may be sparse. Thereafter the proliferation of pioneer seed producing plants, which dominate the area within a year or two, allow seed eating small mammals to increase both in species and number. A newly clear-cut area is a particularly favorable habitat for the highly adaptable and ubiquitous deer mice. With continued reestablishment of ground cover, red-backed voles and chipmunks may appear, and with the increasing prevalence of grasses, the habitat becomes more and more favorable for red-backed and meadow voles (Dalquest 1948).

Factors such as food supply, weather, and cover affect small mammal numbers. Populations fluctuate widely between seasons and between years. A 3- or 4-year cycle in animal numbers has been propounded by such authors as Rowan (1954), Lack (1954), and Krebs (1966). Gashwiler (1965) suggested that there is a relationship between the abundance of tree seeds and the size of the deer mouse population during the succeeding autumn.

Prescribed burning of cutover forests has been used to reduce the hazard from wildlife and to prepare the land for regeneration by natural seed fall, aerial seeding, or planting. Many foresters have considered fire as a means of eliminating seed eating small mammals. Several workers have studied the influence of fire on resident small mammals (Horn 1938, Pruitt 1953, Tevis 1956, Gashwiler 1959, Lawrence 1966) and most agree that while fire produces a drastic change in the habitat, it does not eliminate populations of small mammals. Even within a hot burn, small pockets of unburned vegetation serve as islands of safety to which small mammals can retreat. Rodent burrows may enable some animals to retreat to depths where temperatures are well within their range of tolerance. The studies of Lawrence (1966) and Ahlgren (1966) both suggest that fire does not reduce the small mammal seed depredation problem, but on the contrary, it creates habitat and food conditions which are even more favorable to an increase in seed eaters in the following years. This is particularly true for deer mice, which subsist largely on a diet of seeds. Red-backed voles, on the other hand, feed on sprouting vegetation and fruit as well as seeds. These, together with chipmunks, begin to increase in numbers 2 to 3 years after a fire, when food and cover conditions become more suitable. Hooven (1969) suggests that many small mammals such as shrews cannot adapt adequately or readily to post-fire environmental conditions due to exposure of surface runways and tunnels.

DETERMINING SEEDING SUCCESS

The adequacy of surviving seedlings as determined by stocking surveys, usually carried out within a year or two after seeding, has been the principal method for gauging the success of direct seeding. Only when stocking was inadequate have foresters sought to determine, through a multitude of procedures, the possible causes for the regeneration failures. These methods have included repeated seeding at different rates, seeking the remains of seeds on the soil surface, painting seeds, marking the spots where seeds had been placed, or screening seeds with a variety of barriers that selectively exclude such destructive agents as birds, rodents, insects, or soil organisms. Most of these procedures have inherent limitations. For example, screening creates an artificial environment favoring germination while tending to restrict the movement of seeds and to limit their exposure to one or more types of destructive agent. The more adventurous of investigators have sought to determine the feeding habits of seed eating small mammals and birds and have sought to infer a relationship between seed germination success and abundance and composition of small mammal and bird populations.

Seeds placed into the natural environment are subject to repeated disturbance and may become relocated inches, or many feet, from the original points of placement. Largely because of such relocations and the small size of coniferous seeds, researchers have seldom been able to determine what fate befell a very large percentage of the seeds sown. Thus, a large percentage are "lost" and much of the data on the fate of specific seeds has been but conjecture. A means of recovering seeds from the natural environment is now available. Radio-tagging enables the investigator to relocate a specific seed, or what remains of it, at any time.

FATE OF RADIO-TAGGED SEED STUDIES

Only those researchers who have sought to account for the location and fate of very carefully placed seeds in the natural habitat have experienced the frustration of not being able to find these seeds a short while after placement. The radio-tagging procedure developed by Lawrence and Rediske (1959, 1962) greatly reduced this difficulty. While the radio-tagging method has proven a very valuable tool in ascertaining the fate of individual unrestrained seeds, thus providing data which cannot be obtained by any other means, this approach has been used in only three studies.

Lawrence and Rediske used the radiotracer technique in studying the fate of 440 Douglas-fir seeds tagged with Scandium 46 and placed into a field in northern California. After 22 weeks the losses were as follows: moulds (20%), insects and other soil invertebrates (11%), rodents (8%), birds (3%), lost and unaccounted for (4%); in total a loss of 46%.

Black (1969) conducted a somewhat similar Douglas-fir seed study in Oregon during 1966 and 1967. One half of 4,800 tagged seeds placed out in December 1966 were treated with 1% concentration of endrin, the other half was untreated. Of the untreated seeds, 70% were destroyed, principally by deer mice within 4 weeks of placement. Losses of endrin treated, seeds during the same period were significantly less, but totalled 52% by June 1967. Black reported that prebaiting of the study area at a rate of ½ lb of 1080 treated wheat per acre, or removal of the small mammals by trapping before placement of the seeds, did not reduce later seed losses. During the following year Black established that 44% of tagged endrin-treated seeds were destroyed within 1 month when these seeds were placed in the field 1 week prior to aerial seeding with untagged endrin-treated seed, but only 0-2% of tagged seeds were lost to small mammals if the seeds were placed during or 1 week after the aerial seeding.

I was interested in whether or not the radio-tagging technique would work if applied to seeds as small as those of white spruce (2.5 — 3.0 mm) and placed into the field under more severe Canadian climatic conditions. Seed size becomes an important factor because the proximity of the radiation source to the embryo may have a delaying effect on germination.

In 1960 the Canadian Wildlife Service undertook a study to determine the influence of small mammals on forest regeneration in Alberta. Our initial approach involved an extensive program of live trapping and tagging of small mammals on newly-cut areas, to determine what small mammal species were present, how the population built up, how it varied from year to year, and over what area individual animals travelled. Examination of stomach contents indicated whether or not coniferous seeds were being consumed and when. To-date over 5,000 small mammals have been handled in over 15,000 captures and recaptures. Usually 300 live traps distributed at 50 foot intervals on a grid covering 18.3 acres were used in the study. The traps were checked twice daily for 10 consecutive days in the spring and again in the fall. Newly captured animals were identified as to species, sex, age group, and trap location, then ear-tagged and released at the point of capture.

Small mammal populations varied with the season, type of habitat and time since the area was clear cut. In general, an area formerly in white spruce and cut in early spring was found to support between 3 and 4 small mammals per acre, primarily white-footed mice, red-backed voles, and shrews. By September, increased ground vegetation provided improved habitat and small mammal populations more than doubled to between 8 and 10 animals per acre as a result of reproduction and immigration. By a year later 12 to 15 animals per acre were present. By the fifth year after cutting, 15 to 18 animals per acre frequented the dense grassy vegetation.

In 1962, while continuing the small mammal aspect of the study, we directed our studies towards determining the fate of individual coniferous seeds placed into the natural environnmet.

Two thousand white spruce seeds tagged with Scandium 46 radioisotope were placed into the field during early June when seeding operations were being carried out. Each seed carried a tag of 3μ Ci strength or less and was subsequently coated with the aluminum powder-endrin-arasan-latex preparation. The location of the seeds was checked several times during the summer using a sensitive scintillometer. Although individual seeds had been placed 6 inches from marker stakes, 28% of them were found to have been moved an average of 15 inches from the point of placement.

Recoveries of the seeds were made during the second half of September by which time germination should have occurred. While most seeds were retrieved within the top 3 inches of soil, some were relocated in small mammal runways, others from under logs, from anthills, spider webs, hornet nests, from within open pine cones, within curled deciduous leaves, from as deep as 15 inches in the soil, and as far as 49 inches from the point of placement. (In subsequent years, radio-tagged spruce seeds have been recovered up to 200 feet from the points of placement.)

A total of 1,819 seeds (90.9% of the original 2,000 seeds set out) were recovered in whole or in part during the initial white spruce radio-tagged seed fate study. Of the seeds recovered, 20.6% had remained unchanged, 24.3% had dried up and 49.3% had been destroyed during the 17 weeks the seeds had been in the field. Only 5.8% had germinated. Of the seeds destroyed, 71.4% had been destroyed by mice and voles (*Peromyscus, Clethrionomys, Microtus, Zapus*), 19.2% by chipmunks (*Eutamias*), 5.9% by shrews (*Sorex*) and 3.5% by insects (unidentified).

A total of 386 small mammals was handled on the 2 areas studied in 1962 in 1,273 captures and recaptures. The data indicated the presence of 5.6 and 6.1 small mammals per acre in the spring and 4.0 and 4.8 per acre respectively in the fall (Radvanyi 1966).

Prior to this study most direct seeding in Alberta was carried out in late May or early June and employed the aluminum powder-endrin-arasan-latex seed coating procedure. The peak of natural seed fall in white spruce occurs in late September. Why seeding was being carried out in June and in what manner the fate of seeds placed out at another time of year might differ from those placed out in June was unknown. To ascertain these factors, seeds tagged with Zinc 65 and Cobalt 60 were placed into the field in two over-winter studies (1963-1964). Small mammal populations on these two study areas were 4.0 and 2.8 animals per acre in the spring and 6.9 animals per acre on each area in the fall during the first year; 5.6 and 10.3 (spring) and 7.1 and 9.8 (fall) animals per acre during the second year. Of the radio-tagged seeds recovered in September following mid-winter placement, only 1/3 as many (19.1% and 16.2% on the two areas respectively) were destroyed (compared to 49.3% following the initial spring seeding trial). Five to six times more seeds germinated (36.1 and 28.2% compared to 5.8% in the spring seeding). Natural stratification of the seed and protection provided by the snow cover may have accounted in part for the difference in seed fate resulting from the two seeding times. Ample soil moisture from melting snow may enable seeds to be carried passively but nonetheless more rapidly to subsurface locations than if disseminated into the environnement under later and more arid conditions. Graber (1969) noted that seed losses to small mammals could total 82% but were measurably less when seeds were covered with soil at the time of sowing.

To determine whether seeding of white spruce could be successful if carried out during a year when small mammal populations were at a low level, an additional 2,000 radio-tagged white spruce seeds were set out on two new study areas in June 1966. The seed eating small mammal populations were 3.7 and 3.1 animals per acre or 44% fewer animals per acre than were found on the study areas used in 1962. Yet despite the presence of fewer small mammals, recoveries of tagged seeds made in September indicated that an even greater number of seeds had been destroyed (50.4% in 1966 vs 49.3% in 1962).

Another 2,000 white spruce seeds set out in June 1966 were allowed to remain in the field until June 1967. In these, germination was only 4.4% higher than in those recovered in September 1966 and an additional 5.1% were destroyed during the winter.

Since 1968 our investigations have concentrated on a critical examination of seed coating procedures and in searching for a better form of protection for the valuable seed supply. Dissatisfied with the former, widely accepted seed coating formulation, we conducted over two hundred tests on 30 or more candidate ingredients for use in providing an effective coating for white spruce seeds. As a result of these tests we discarded the aluminum powder, endrin, and arasan and modified the latex. In our current studies black graphite powder replaces the bright shiny aluminum powder and a potent rodent repellent, R-55, replaces both the endrin and the arasan. In addition we acidified the Dow latex to change the pH from 9.6 to 4.5. While the salient features of the coating formulation were published (Radvanyi 1970), we do not yet consider the formulation to be entirely satisfactory and are continuing experiments to improve its effectiveness and retention.

Under laboratory conditions we found the new coating to be better than 95% effective in preventing seed depredation by the most common seed-eater, *Peromyscus*. White spruce seeds treated with R-55 and exposed to the elements for 244 days from November to July continued to show a very high degree of effectiveness in repelling animals of this species. Germination trials of white spruce seeds coated with the new coating yielded better results than with the old treatment. The limited field trials have not yielded consistently satisfactory results, which suggests that the adhesive being used on the seeds may be a weak link in our procedure. We are currently investigating the possibility of incorporating the repellent into a pelletizing procedure.

The radio-tagging technique has provided a means of determining the fate of individual seeds of a very small size (our recovery success on 21,800 white spruce seeds placed into the field has averaged 90.0%). While census methods may provide an index of animal species and numbers to be found upon a study area, what this means in terms of impact upon forest regeneration practices, and in particular upon direct seeding, is not clearly understood. Our knowledge in this area is fragmentary and frequently borders on conjecture.

Many factors influence small mammal numbers throughout the year and throughout the successional changes that occur in the microenvironment in which they live. Few studies have attempted to relate animal numbers and species to potential seed losses and to determine the ability of these animals to locate coniferous seeds. The most frequently quoted study has been Hooven (1958), who suggested that a population level of only two *Peromyscus* per acre, each animal consuming 300 Douglas-fir seeds per night, can destroy within a period of 35 nights, the ½ lb of seed usually sown in seeding programs. Spencer (1954) was slightly more conservative in suggesting that as few as six deer mice per acre could largely mullify a Douglas-fir seeding programm in which the seed was broadcast at a rate of ¼-pound per acre. Howard and Cole (1967) have reported the capabilities of *Peromyscus* in detecting, retrieving and consuming individual buried seeds of several coniferous, grain and vegetable species. As indicated earlier in reference to our small mammal studies in Alberta, the presence of two mice per acre is indeed a very low population level. In 10 years of field studies, on only one occasion – in early spring – did we encounter a population of only two animals per acre. If two animals per acre can destroy the seeds placed into the field by foresters, then what chances for survival do seeds have when small mammal populations reach levels of 12 to 15 or more per acre? The suggestion – or hopeful wish – so often made, that seeding should be done when small mammals are at a low point in their population cycle, is more often than not just a hopeful wish, for I do not know of one pulpwood operation or governmental agency responsible for forest regeneration that has taken the time and effort to determine the small mammal population. In the areas where we have conducted our studies with radio-tagged seeds in western Alberta, I do not believe that small mammal populations ever become naturally low enough for one to say, "Now it is safe to seed."

Hamilton (1941) reported that under natural conditions adult deer mice, jumping mice, and red-backed voles eat food equivalent to 30% of their weight daily, about 6 grams; short-tailed shrews about 50% of their weight or 9 grams, and long-tailed shrews from 2 to 4 grams of food daily. Thus, a mixed population of 60 — 100 animals per acre, which can occur in northeastern American forested regions, could consume from 0.85 to 1.2 pounds of food daily.

The numbers of coniferous seeds which small mammals are capable of consuming have most frequently been determined in the laboratory, or under outdoor conditions using enclosures and feeding stations. Data on seed destroying capabilities of small mammals derived from feeding experiments using caged animals may not be directly applicable to field situations due to the reduced amount of exercise required by caged animals to obtain an adequate quantity of food. On the other hand, the much greater amount of effort required to search for food in the natural environment could necessitate the consumption of a corresponsingly greater number of seeds. For example, Abbott (1961) determined that the average daily consumption of white pine seeds by individual caged white-footed mice and red-backed voles was 109 and 97 seeds respectively. Under field conditions he estimated 232 and 260 seeds per day were being destroyed by red-backed voles and white-footed mice respectively.

Studies by Wagg (1961) in Alberta on red-backed voles and deer mice and our laboratory studies

(Radvanyi 1971b) on seed consumption by *Peromyscus* both suggest that individuals of this species can consume approximately 1,000 lodgepole pine seeds, or 2,000 white spruce seeds nightly. Nightly consumption of Douglas-fir seeds by the same species occasionally exceeded 450 seeds, while consumption of black spruce seeds was almost 2,100 per night. These figures corroborate Abbott's (1961) suggestion that the smaller the seed, the greater the number which will be destroyed.

The classical insectivore — the lowly shrew — has received increasing attention in forest regeneration studies. Of nine subspecies of shrews occurring in the Douglas-fir region, Moore (1940) reported five were known to eat Douglas-fir seeds. Kangur (1954) reported that the overall average Douglas-fir seed consumption by 30 caged shrews in a 24-hour period was 180 seeds. Buckner (personal communication) reported that white spruce seeds which he presented to cinereus shrews during early phases of our studies, consumed the seeds in preference to their traditional diet of meal worms. Shrews accounted for 5.9% of the radio-tagged spruce seeds destroyed in our original field study.

While the radio-tagging technique enables recovery of seeds in the field, it does not indicate what happened to the seeds during the period they were in the field. This was ascertained by feeding seeds to animals of every species that occurred on the study area and determining, by microscopic examination of the discarded hulls, the manner in which each species opens the seeds.

Patterns of seed destruction in Douglas-fir by a variety of small mammals, birds and insects have been described by Moore (1940), Garman and Orr-Ewing (1949), Kangur (1954), Derr and Mann (1959), Yeatman (1960), and Lawrence and Rediske (1962). Our studies (Radvanyi 1966, 1971a,b) have determined seed destruction patterns by several small mammal species for white spruce and lodgepole pine seeds.

The effect of seed eating birds has been less thoroughly investigated. Gashwiler (1967) reported that combined seed losses to birds and mammals from seed traps and ground sample comparisons was 62% of the 69% total loss in Douglas-fir and 15% of the 40% loss in hemlock. He listed juncos, song sparrows, and white-crowned sparrows as the most common ground-frequenting summer residents on a clear-cut area in Oregon. Siskins, golden-crowned sparrows and red crossbills were also abundant in the fall and spring migrations. Krauch (1936) and Hagar (1960) considered juncos as the most important seed-eating birds in the American southwest and northwestern California respectively. Eastman (1960) listed 18 bird species that fed on ponderosa pine seeds in central Oregon. Mann (1968) considered seed losses to birds in direct seeding operations to have been of major proportions in the American south prior to the introduction of arasan bird repellent in the mid-'50's. In none of the radio-tagging studies described were seed losses to birds considered to be of major consequence.

CONCLUSION

Small mammals are very much a part of the forest regeneration scene. After some 13 years on the problem, I am no longer surprised at seed losses on cut-over areas. On the contrary, I am surprised that any regeneration occurs at all. Surely what encouraging regeneration results from direct seeding attempts in the past occurred because one or more small mammals did not do their homework or were away on holidays.

With ever spiralling labor costs and the increasing demands being made upon our forest resources, it will become increasingly important to regenerate cut-over forest lands shortly after harvesting. I believe that direct seeding, with effectively coated seed combined with proper seedbed preparation and time of sowing can be more economical than other reforestation methods. More research is needed, however, in perfecting the techniques and in evaluating all factors affecting seed fate. The problems of forest regeneration are not the responsibilities of a select few. Delays in solving them will affect not only this generation but perhaps even more so those yet to come. I do not believe forestry in North America can comfort itself much longer with the illusion that our forest resources are limitless and that we can ignore the wee beasties in the field. They are a part of the environment that must be dealt with, whether by annihilation (which I do not recommend) or by peaceful co-existence through the use of repellents. Experience has taught us they cannot be ignored — for to do so will surely place us all, and soon, beside the sage who, in speaking of our forested lands is said to have remarked, "I looked around me and there it was — gone!"

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Seed treatments (including repellents)

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ABSTRACT

Contradictory reports concerning the influence on germination of arasan-endrin repellent treatments are reviewed briefly but dismissed as irrelevant so far as Canadian pines and spruces are concerned because of the legal ban on the use of endrin in Canada. Interim results, subject to confirmation by statistical analyses, are presented on the influence of arasan, and of R-55 (Tertiary-butylsulfenyldimethyldithiocarbamate, a potential alternative to endrin) on germination of seeds of two major species for regeneration by direct seeding in the boreal forest region, namely black spruce (*Picea mariana* (Mill.) B.S.P.) and jack pine (*Pinus banksiana* Lamb.), arasan appears to have no effect on germination of black spruce seed, even after prolonged storage of coated seed, but may lower germination of jack pine seed at low temperature, i.e., 50 F (10.0 C). In one study R-55 seriously reduced germination of black spruce seed, the effect increasing to the point of failure with increased storage of coated seed. In a second series no such adverse effects were evident.

A similarly brief review reveals conflicting conclusions about the effect of pelleting on germination of tree seeds. In current laboratory tests pelleting had no harmful effect on germination of black spruce seeds. Encapsulation, which reportedly does not reduce germination of vegetable seed, reduced germination of black spruce seeds, and prevented germination of jack pine seeds. Field trials of all coating, pelleting, and encapsulating techniques are recommended before laboratory or greenhouse results are either rejected or adopted for operational seeding.

RÉSUMÉ

L'auteur passe brièvement en revue les rapports contradictoires sur l'influence de l'Arasan-Endrin sur la germination des graines de Pins et d'Épinettes canadiens bien qu'en ce pays, l'usage de l'Endrin soit illégal. Selon des résultats provisoires, qui doivent être confirmés par des analyses statistiques, sur l'influence de l'Arasan et de R-55 (Tertiary-butylsulfenyldimethyldithiocarbamate, qui peut remplacer l'Endrin) sur la germination des graines de deux espèces importantes à régénérer par ensemencement direct dans la Région forestière boréale, en l'occurence l'Épinette noire (*Picea mariana* (Mill.) B.S.P.) et le Pin gris

(*Pinus banksiana* Lamb.). L'Arasan semble ne pas affecter la germination des graines d'Épinette noire, même après un emmagasinage prolongé des graines enduites, mais il peut diminuer la germination des graines de Pin gris à basse température, i.e. 50 F (10.0 C). Lors d'une étude, R-55 diminua fortement la germination de graines d'Épinette noire, et son mauvais effet fit faillir leur germination lorsque les graines enduites furent emmagasinées plus longtemps. Par contre, lors d'une seconde étude, ces mauvais effets ne se produisirent pas.

Une autre brève revue permet de constater des rapports contradictoires sur l'effet du boulettage sur la germination des graines d'arbres. Selon des tests de laboratoire récents, ce procédé ne réduisit pas la germination des graines d'Épinette noire. Les capsules de graines qui, selon certains rapports, ne réduisent pas la germination, réduisirent de fait la germination des graines d'Épinette noire et empêchèrent la germination des graines de Pin gris. L'auteur recommende de faire des essais sur le terrain de toutes les techniques d'enduits, de boulettage, de mise en capsules avant que les résultats de laboratoire ou de serre soient rejetés ou adoptés pour les fins d'ensemencement pratique.

INTRODUCTION

For the purpose of this paper direct seeding is defined as the manual or mechanical seeding of tree seed on harvested forest areas to secure regeneration of desired species. The discussion is confined to jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.), not to denigrate white, or red pine (*Pinus strobus* L., *P. resinosa* Ait.) or white spruce (*Picea glauca* (Moench) Voss), but because direct seeding in the boreal forest is confined almost exclusively to jack pine and black spruce. According to Scott (1970) direct seeding jack pine is (already) an approved regeneration technique in Ontario, hence jack pine probably receives less consideration in this paper than does black spruce for which the results of direct seeding are still as erratic as those reported by Smithers (1965) at the Amherst Symposium.

Tree seeds may be treated in a variety of ways for a variety of reasons related to germination. These include (i) treatments to promote earlier germination relative to that of untreated seed, i.e., stratification of one kind or another to break dormancy, soaking treatments so the seeds have imbibed water fully before sowing; (ii) treatments to protect seeds from destruction by fungi, and from destruction or loss by insects, birds, and rodents, i.e., dusting, or coating with chemicals, adhesives, and lubricants, and (iii) treatments (usually pelleting, and encapsulation) to assist or improve mechanical seed dispersal or to facilitate precision sowing.

In this paper "coating" is the application of additives such as fungicides, repellents, etc., to the seed coat without markedly altering the shape of the seed; "pelleting" is the accretion of an artificial medium around the seed to produce a uniformly-shaped (usually spherical) and uniformly-sized seeding unit to facilitate seeding; "encapsulation" is the enclosure of seed in preformed shapes and sizes of capsules for the same purpose as "pelleting".

REVIEW OF LITERATURE

Treatments to Promote Germination

STRATIFICATION. Whether stratification is practical in direct seeding depends on the extent to which stratified seeds are damaged by the mechanical action of seed hoppers or slingers. Such damage is related to the size of seed, thickness of the seed coat, stratification technique, etc. Also, as seed treatment with rodent repellents is considered central to any direct-seeding operation (Mann 1968) seeds requiring stratification must be coated either before or after stratification. McLemore and Barnett (1966) found that stratifying repellent-coated southern pine (*Pinus palustris* Mill.) seeds had no adverse effect on germination; Belcher (1968) reported that it was necessary to stratify repellent-coated loblolly pine (*Pinus taeda* L.) seeds in order to get maximum germination, and Williston and Cox (1969) direct seeded loblolly pine most successfully where they stratified repellent-treated seed. However, Harrington (1960) reported that germination of short-leaf pine (*Pinus echinata* Mill.), loblolly pine, and Virginia pine (*Pinus virginiana* Mill.) seeds was seriously reduced if fresh seeds were repellent-coated and then stratified.

Bloomberg and Trelawny (1970) found that germination of Douglas-fir (*Pseudotsuga menziesii*

(Mirb.) Franco) seeds was delayed and also lower when the seeds were coated after stratification. Further consideration of conflicting results such as these is academic and it is doubtful that even the beneficial effects are sufficient to offset the potential damage which may result from mechanical sowing of stratified seed because neither jack pine nor black spruce, the species of major importance in the boreal forest, normally requires stratification (Anon. 1948).

COLD SOAKING. Cold soaking seeds which do not require stratification, and thereby allowing them to imbibe moisture before sowing them, may result in somewhat earlier or more rapid germination under controlled conditions, although unpublished results (J. W. Fraser, Great Lakes Forest Research Centre) indicate that the effectiveness of the treatment is related to germination temperature, at least for black spruce. Cold soaking might have similar beneficial effects even in direct seeding, provided that there was sufficient control over the operation to ensure (i) that the seeds were so treated immediately before sowing, (ii) that they were sown at the most opportune time and into a favorable environment where the germination process initiated by the soaking procedure would not be interrupted, and (iii) that the inbibed seeds were not damaged by handling or by the mechanical seeding devices. As direct seeding in Ontario is not sufficiently advanced to ensure these provisos, such treatments have received little if any consideration in practical field trials.

IONIZING RADIATION. Yim (1963), Sweaney (1967), Clark *et al.* (1967), are a few of many who have explored the effects of ionizing radiation on tree seeds under controlled laboratory conditions. They found that low dosages of ionizing radiation may stimulate germination of jack pine, pitch pine (*Pinus rigida* Mill.) and black spruce, but dosages above critical levels, which vary by species, tend to depress germination and affect survival and growth adversely.

MICROWAVES, AND LASER BEAMS. The Faculty of Forestry and the Electrical Engineering Department of the University of New Brunswick are cooperating in an exploratory study of microwave treatment of seed as a practical, rapid method of enhancing germination (G. R. Powell, University of New Brunswick, personal communication) but no results are available yet.

The use of a pulsed laser beam on seed of white, and black spruce, red, white, and jack pine seemed to accelerate germination and increase germination capacity but the technique is impracticable at present (D. A. Skeates, Ontario Ministry of Natural Resources, Maple, Ontario, personal communication).

TRACE ELEMENTS AND SURFACTANTS. Markova (1968) noted that most researchers found an increase in weight of seedlings grown from seeds soaked in solutions of trace elements [such as boron, copper, cobalt, manganese, and molybdenum] but that the effect of trace elements on germination and sprouting of conifer seeds was insufficiently clarified.

Burridge and Jorgensen (1972), exploring the effects of nonionic surfactants on germination of tree seed, including jack pine and black spruce, and on radicle growth in order to provide for their practical use in forestry, recommended against their use until further information is obtained. Edwards (1973), however, found only negligible side effects of one surfactant, Soil Wet,[1] when used as prescribed, on germination of Douglas fir, lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), white spruce, and Sitka spruce (*Picea sitchensis* (Bong.) Carr.).

MISCELLANEOUS. Waldron and Cayford (1967) suggested that germination of field-sown seed may be increased by treatment with baby powder in a methyl cellulose sticker, but the application of their experimental results to operational conditions was never confirmed.

Intense, short-duration infrared radiation to promote germination has been explored (Works and Boyd 1971). Although it promoted germination of western white pine (*Pinus monticola* Dougl.) the optimum exposure varied from one seed lot to another, overexposure was destructive, and they recommended further research to clarify conditions for achieving maximum results.

In 1972 the Ontario Ministry of Natural Resources explored the effectiveness of field seeding a hydromulch seed mixture but no meaningful results are as yet available (N. F. Lyon, Ontario Ministry of Natural Resources, Thunder Bay, Ontario, personal communication).

[1] Mention of companies and/or products in this manuscript does not constitute endorsement of either by the Great Lakes Forest Research Centre.

This will give some indication of the diversity of treatments being explored to promote or enhance germination. Much of such work is done under controlled or semicontrolled environmental conditions in growth chambers, greenhouses, etc., and the results are not necessarily applicable to conditions and techniques encountered in actual direct seeding operations.

Treatments to Protect Seeds

ENDRIN-ARASAN. According to Garman and Orr-Ewing (1949), "many small forest-mammals feed on tree seed, but under natural forest conditions this loss of seed is insignificant. The balance of nature is maintained and the numbers are controlled both by predators and environment. However, when the ecological association is abruptly changed, as by large-scale clear cutting of the forest, this balance is upset". In such conditions rodent-repellent treatments are considered central to any direct seeding (Smith and Aldous 1947; Russel 1964; Mann 1968; Gashwiler 1970; Radvanyi 1970b; Derr and Mann 1971).

Scott (1970) pointed out that the use of repellents was said to be one of the main factors contributing to the success of direct seeding in the southern United States, and reported that practically all seed used for direct seeding in Ontario was treated with chemicals to reduce losses to insects, diseases, birds and rodents. However, he also drew attention to the fact that it had never been established that there was the same need to treat seed used in Ontario forests, a controversial point we are now attempting to resolve in cooperative field trials with the Ontario Ministry of Natural Resources and Canadian Wildlife Service. Until it is resolved, most–if not all–jack pine and black spruce seed used for direct seeding in Ontario is treated as a precautionary measure against loss and destruction by small mammals.

The ideal repellent must be one which effectively protects the seed without inhibiting germination. The arasan-endrin treatment has been used extensively in the United States since the mid 1950's (Mann 1972). Its effectiveness as a repellent to birds and rodents is beyond the scope of this paper and has been dealt with by Dr. Radvanyi, but it is interesting to note that there is no universal agreement as to its effectiveness. It is generally agreed that arasan alone is effective as a fungicide and as a bird repellent (King 1958, Kingsley 1958; Derr 1961, 1964; Jorgensen 1968) but there is also some evidence that it does not have rodent-repellent properties (Anon. 1966).

Endrin, and arasan-endrin treatments are usually considered to be effective against rodents (Dimock 1957; Hooven 1957; Kverno and Hartwell 1957; Anon. 1958; Dick 1958; Seidel 1963; Stoeckler 1964; Mann 1968; Russel 1968; Graber 1969) but there have been instances where they were less effective in field tests than in laboratory tests (Engle and Clark 1959; Klawitter, Stubbs, and Johnson 1963; Jarrett 1964; Anon. 1966; Hooven 1966; Merritt and Adams 1967).

A few references will indicate similar contradictions about the influence of arasan-endrin treatments on germination. Cayford and Waldron (1966) found that arasan-endrin did not have any adverse effect on germination of jack pine seeds but noticed a greater proportion of abnormal germinates from coated seed. McDermid and Branton (1959) and Sanderson and McIntosh (1961), among others, noted no adverse effect of arasan-endrin on germination, but Harrington (1961), Seidel (1963), Merritt and Adams (1967), Demeritt and Hocker (1970), and Radvanyi (1970a) found that such treatments reduced germination or delayed it.

Conflicting as such results may be they are undoubtedly valid for particular species, particular formulations of arasan and endrin and the several adhesives and lubricants used, particular techniques of application, techniques of testing, and interpretation of results. In any case they may become irrelevant even in the United States where, according to Radwan and Ellis (1971), concern over "hard" pesticides may dictate that endrin be eliminated as a seed protectant. According to the Annual Reforestation and Timber Stand Improvement Report published by the United States Department of Agriculture in 1972, a decrease in acreage seeded was caused primarily by restrictions on the use of toxic rodent repellents. Mann (1972) points out that endrin is one of the chlorinated hydrocarbons under close scrutiny by Federal and State agencies and indicates the need to eliminate all chemical repellents either by encapsulating, [or by pelleting] seed.

ARASAN. In 1968 the use of endrin was discontinued in Ontario because of its harmful effects on humans and, subsequently, seeds used in direct seeding were coated only with arasan, latex and aluminum powder (Appendix B). Today the use of endrin in Canada is illegal; hence, its effectiveness as a repellent and its influence on germination of Canadian pines and spruces are no longer relevant.

The resurgent interest in direct seeding in Ontario in 1969 prompted questions about the effectiveness of the arasan-latex-aluminum coating as a rodent repellent and about its influence on germination. Scott (1970) noted that arasan was an effective bird repellent and fungicide, but its rodent-repellent qualities were questionable at best. According to his earlier review (Scott 1966) the arasan-endrin coating had no appreciable effect on germination, and in 1972 Lane (C. Lane, Ontario Ministry of Natural Resources, Toronto, Ontario, personal communication) confirmed the arasan-latex-aluminum coating neither decreased germination of jack pine and black spruce seeds nor had any [observable] adverse effects on survival or growth of germinates from treated seed. This agrees with Derr's (1964) results with southern pines, but Jones (1963) found that arasan not only reduced germination but also contaminated radicles of southern pine germinates from coated seeds, and Crouch and Radwan (1972) found that arasan caused a significant reduction in germination of Douglas-fir seed.

R-55. Experiments with R-55, the new rodent-repellent formulation suggested as an alternative to the arasan-endrin formulation (Radvanyi 1970a), have been limited in number, but the results insofar as germination is concerned are almost as controversial and contradictory as those concerning arasan-endrin.

Radvanyi (A. Radvanyi, Canadian Wildlife Service, personal communication) indicated good germination from R-55-coated black spruce (86%) but Edwards and Olsen (1972) found that R-55 seriously reduced germination of Douglas-fir seeds and that stratification, and dry storage of R-55-coated seeds increased germination losses.

(iii) Treatments to Improve Mechanical Seed Dispersal

PELLETING. Pelleting of a variety of seeds, primarily to facilitate precision planting, is widely practised, particularly with vegetable crops.

In 1968 Asgrow Seed Company introduced a technique called "Lite-Coat" by which small, irregularly-shaped seeds are pelleted with a specially-formulated substance to make them larger, rounder, and more uniform to facilitate precision seeding. Recently released results of company studies show favorable results in every vegetable crop studied (Anon. 1973), particularly in increased yields per acre and in decreased costs of labor for tending and thinning.

Schreiber and LaCroix (1967) reported a technique for pelleting wheat seed for fall sowing to get early spring germination and emergence. This technique may have a forestry application but there is no indication that it has been tried with tree seed.

Although precision seeding may never have any widespread application in forestry practice, particularly on boreal forest sites, attention has been drawn to the potential advantages of using pelleted seed for mechanical seeding (Anon, 1946; Grinnell 1968). Stoleson and Hallman (1972) showed that helicopter seeding damaged conifer seed and although they do not say so, it is possible that pelleted seed would not have been damaged by any of the three systems tested in the helicopter seeding trials.

Berbee, Berbee, and Brenner (1953) and Kozlowski (1960) reported favorable effects of pelleting coniferous seed with methyl cellulose or latex, and some fungicide to control damping-off of resultant germinates; Kozlowski (1960) found that the pelleting inhibited early germination but had no significant effect on germination 30 days after seeding. Hedderwick (1968) found that pelleting actually improved germination of pine seed on exposed, infertile soil.

Vaartaja (1955) reported that heavy pelleting with cellulose may reduce germination but this effect was mitigated by the addition of the fungicide Orthocide. Others found that pelleting had a generally unfavorable effect for one reason or another (Rudolph 1950, Hall and Richmond 1961, Chadwick and Turner 1969). Arnborg and Norden (1962) discussed advantages of pelleting but stressed that results were inconclusive, and Beuschel (1968), reviewing experience with pelleted forest seed, said that use of pelleted seed in forestry could not be recommended.

Nevertheless there is continued—even increasing—interest in pelleting of forest tree seed not only as a technique for facilitating mechanical seeding and as a carrier for fungicides, but also as a potential carrier for repellents of various kinds. If repellents can be applied successfully to the outside of pellets or incorporated into the pelleting medium and retain their effectiveness as such, the controversial adverse effects reported when the repellents are applied directly to the seed coats may be avoided. Pellets of one kind or another may also be acceptable carriers for herbicides to alleviate competition immediately around new germinates, or for fertilizers to promote early survival and growth.

In greenhouse trials in 1970, Haavisto (V. F. Haavisto, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario, personal communication) tested germination and survival of non-treated black spruce seed and seeds in compressed circular, flat pellets of peat moss. Both treatments were seeded on three different seedbeds and the pellets were seeded in three attitudes. The results were inconclusive but there was some indication that seedlings from pelleted seeds grew better than those from non-treated seeds, and that the small mound of raw peat moss left when the pellet collapsed precluded development and encroachment of *Sphagnum* spp. or of *Carex* spp. around the germinate which usually occurred and engulfed germinates from non-pelleted seeds.

ENCAPSULATION. Encapsulation, like pelleting, was developed primarily to facilitate precision sowing of vegetable crops. Comparative tests of non-coated lettuce seed, seed encapsulated in a flat, vermiculite tablet, and seed "mini-coated" in clay (Robinson and Johnston 1970) revealed that the non-coated seeds always emerged first, whereas clay-coated seeds emerged next in some tests but in others the vermiculite-encapsulated seeds emerged second. However, the final emergence from all treatments was high enough to be commercially acceptable and was not significantly different. Plants emerging from the vermiculite tablets were visibly smaller than those from the other two treatments, and it was noted that when the vermiculite tablets were insufficiently softened or eroded, emergence of seedling root systems was inhibited.

Tests of the efficiency of plastic capsules in protecting seed against destruction by rodents began in 1971 and are continuing (J. Walters, University of British Columbia, Research Forest, Haney, B.C., personal communication). Walters hopes that the plastic capsule will provide (i) mechanical protection against mice and birds, (ii) protection to the germinate from climatic factors during and soon after germination, (iii) a column of moist, rich, growing medium to speed the growth of the radicle, and (iv) a precise and uniform dimension to facilitate mechanical metering and precision distribution. So far, no adverse effects of encapsulation have been noticed, probably, according to Walters, because the capsule is a modified "bullet" which does not completely enclose the seed. This work is continuing.

STUDIES AT THE GREAT LAKES FOREST RESEARCH CENTRE

Radvanyi's (1970) timely report of a new rodent-repellent coating treatment for coniferous seeds prompted a cooperative study (Great Lakes Forest Research Centre, the Ontario Ministry of Natural Resources and the Western Region of the Canadian Wildlife Service) to determine (i) the relative effectiveness of the Ontario arasan-latex-aluminum treatment and of Radvanyi's R-55 treatment as rodent repellents, and (ii) their influence on germination. These studies, on completion, will be reported by Fraser and Radvanyi. However, some general indications of the germination studies are worth noting now.

Reported instances of abnormal germination and abnormal development of germinates from R-55-coated seeds, (D. G. W. Edwards, Pacific Forest Research Centre, Victoria, B.C., personal communication) (Edwards and Olsen 1972) and of arasan having contaminated radicles of germinates from arasan-coated seeds (Jones 1963) prompted exploratory survival and growth studies with jack pine and black spruce.

The Ontario Ministry of Natural Resources provided all seed used in these tests and also applied the arasan treatments (Appendix B). The Canadian Wildlife Service (Western Region) provided and applied the R-55 coatings (Appendix A).

Germination Tests

METHODS. Germination was tested under optimum moisture conditions in controlled temperature cabinets at constant temperatures (±1 F) of 50 F (10.0 C), 70 F (21.1 C), and 90 F (32.2 C) for 28 days. Initial temperatures of 45 F (7.2 C) for both species, and of 95 F (35.0 C) for spruce and 105 F (40.6 C) for jack pine were too close to the lower and upper cardinal germination temperatures for these species (Fraser 1970a, 1970b) to provide enough germinates for valid comparisons and were replaced by 50 F (10.0 C) and 90 F (32.2 C) for both species after the 0-month-storage tests. Non-treated black spruce and jack pine seeds, seed of both species coated with arasan, and black spruce seeds coated with R-55, previously stored at 35 F (1.6 C) to 40 F (4.4 C), were sown on saturated, short-grain, black germination paper over saturate, unbleached "Kimpak"[1] in covered, sterile petri dishes. There were four dishes of 100 seeds each for each seed-coat treatment per temperature. Allocation of seeded dishes to temperature cabinet, to shelf position within each cabinet, and to position on each shelf was completely randomized; cabinet/temperature combinations were also randomized for each test. Germination was tallied daily for the entire 28 days and the data transferred to IBM punch cards; seeds were tallied as germinates when radicles were at least 2 mm (.08 in. approx) long.

RESULTS AND DISCUSSION. Percent germination of non-treated and R-55-coated black spruce seeds 0, 6, 12, and 18 months after they were treated and stored at 35 F (1.6 C) to 40 F (4.4 C) (Table 1) indicate that R-55 reduced germination from freshly coated seeds (20-25%) and that germination from the coated seeds worsened with increased storage, particularly at the lower temperatures. These results agree in part with those reported by Edwards and Olsen (1972) working with Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Considering only the R-55 treatments, 4 and 5 had relatively less adverse effect on germination of stored seed than did 1, 2, and 3. However, the obvious anomalies in these data prompted a second series of identical germination tests with freshly coated seeds and with seeds that were coated and then stored for 2, 4, 6, 12, and 18 months. This series provided data for analyzing the influence of R-55 on germination and rates of germination, but neither the tests nor analyses are finished; hence, only the final 28-day germination results at 4-month intervals for the first year of storage are presented in Table 2.

Aside from an apparent, slightly adverse influence of treatments 2 and 3 on germination of stored seed (at the high temperature only!) there is no evidence from this test that R-55 has any deleterious effect on germination of black spruce seed.

As the experimental procedures were identical for both series of tests no satisfactory explanation has been advanced as to why the results of the second test conflict with those of the first series and those reported by Edwards and Olsen (1972).

Non-treated and arasan-coated black spruce and jack pine seeds were incorporated in the second series of germination tests with R-55-coated black spruce seeds. The 28-day germination data in Table 3 indicate that the arasan-latex-aluminum coating does not affect germination of black spruce seed. The coating may have some adverse influence on germination of jack pine seed, particularly at the lower temperature (50 F) (10.0 C), but there is no evidence that it seriously

Table 1. Percent laboratory germination (after 28 days at 50 F (10.0 C) and 70 F (21.1 C)) of untreated black spruce seed and black spruce seed treated with R-55[a] and stored at 35 F (1.6 C) – 40 F (4.4 C).

Months of storage	Control		R-55-1		R-55-2		R-55-3		R-55-4		R-55-5	
	Fahrenheit											
	50	70	50	70	50	70	50	70	50	70	50	70
0	91	98	77	74	74	83	84	86	70	73	95	86
6	63	94	4	45	23	45	5	63	32	84	29	76
12	83	94	0	15	7	15	0	10	15	70	21	67
18	73	96	0	4	1	4	0	0	4	60	7	70

[a] See Appendix A for R-55 treatments 1–5.

Table 2. Percent laboratory germination (after 28 days at 50 F (10.0 C), 70 F (21.1 C), and 90 F (32.2 C)) of untreated black spruce seed and black spruce seed treated with R-55[a] and stored at 35 F (1.1 C) – 40 F (4.4 C).

Months of storage	Control			R-55-1			R-55-2			R-55-3			R-55-4			R-55-5		
	Fahrenheit																	
	50	70	90	50	70	90	50	70	90	50	70	90	50	70	90	50	70	90
0[b]	4	94	12	1	88	11	3	89	3	2	88	2	6	88	15	1	94	12
4	88	90	80	84	90	82	86	89	76	85	92	43	84	90	77	59	90	80
8	83	91	82	75	90	84	70	88	62	77	89	31	76	87	72	76	91	82
12	85	91	87	74	91	80	74	88	62	76	90	34	72	91	80	68	91	87

a See Appendix A for R-55 treatments 1–5.
b Treatment temperatures for 0 storage only were 45 F and 95 F rather than 50 F and 90 F.

Table 3. Percent laboratory germination (after 28 days at 50 F (10.0 C), 70 F (21.1 C), and 90 F (32.2 C)) of untreated jack pine and black spruce seeds and of seeds of both species coated with arasan[a].

Months of storage	Jack pine						Black spruce					
	Control			Arasan			Control			Arasan		
	Fahrenheit											
	50	70	90	50	70	90	50	70	90	50	70	90
0	86	91	0[b]	80	89	0[b]	29[c]	99	29[d]	15[c]	99	37[d]
4	62	87	78	34	80	69	100	100	96	100	99	96
8	54	87	81	28	78	78	100	100	96	96	98	97
12	65	90	82	46	90	78	96	98	98	96	99	98

a See Appendix B for arasan treatments.
b 105 F for 0 storage only.
c 45 F for 0 storage only.
d 95 F for 0 storage only.

affects germination of jack pine seed at the optimum temperature 70 F (21.1 C) or even at 90 F (32.2 C). These results seem to confirm others (Derr 1964; Anon. 1966).

Bloomberg and Trelawny (1970) found that although germination of high-viability Douglas-fir seed was not affected by arasan it was delayed as the concentration of arasan was increased. One should bear in mind that analyses of the data summarized here may reveal statistically significant effects of some of the treatments, particularly at temperatures either side of the 70 F (21.1 C) optimum, which are not apparent at this point or are not considered to have any practical significance. Such analyses may also indicate statistically significant differences in rates of germination which could well be equally significant in direct-seeding operations where rate of germination may decide whether seeding succeeds or fails.

Survival and Growth Tests

METHODS. Germinates used in these studies were from seeds germinated at 70 F (21.1 C). They were needle-planted into a moist medium of fine gravel and sandy loam, 1 :5, top dressed with course sand; the medium was maintained adequately moist throughout the 12-week growing period by watering from above.

In the greenhouse test the seedlings were grown in 2-inch (5.08-cm) peat pots and were watered at least twice daily with a mist nozzle. The seedlings in the growth-chamber test were grown in "Cell-Paks"[1] and watered only as required, from an automatic pipette. Seedlings were tallied daily to determine at what stage of development mortality occurred, and 12 weeks from the planting date they were washed out of the soil for determination of oven-dry weight.

RESULTS AND DISCUSSION. Arasan had no adverse effect on survival of either black spruce or jack pine germinates from coated seeds in the greenhouse trial (Table 4). In the growth-chamber trial it seems to have had a slightly beneficial effect on survival of black spruce germinates from coated seeds, but was obviously detrimental to survival of jack pine germinates from coated seeds.

There is no evidence in the greenhouse trial of any deleterious effect of R-55 on survival of black spruce germinates, but in the growth-chamber trials treatments 1, 2, and 3 appear to have caused mortality which is probably statistically higher than that in the controls and in treatments 4 and 5.

These conflicting results are attributed to the necessity of more frequent watering, the system of watering required in the greenhouse, and resultant washing away of any arasan or R-55 residue before any possible contamination of germinates could occur. As this probably approximates more closely what occurs when coated seeds are direct seeded in the field than when they are seeded in greenhouse and laboratory trials the results of the two trials should be interpreted accordingly.

As ranked in Table 4, jack pine and black spruce germinates from control seeds were heavier than those from arasan-coated seeds, and black spruce germinates from R-55-coated seeds were heavier than those from either control seeds or seeds coated with arasan. Here again analyses may reveal statistically significant differences in root, shoot, or total weights between the several treatments but there were few if any observable differences between them in growth or vigor of the seedlings.

Pelleted, and Encapsulated Seed Tests

At the Great Lakes Forest Research Centre, black spruce and jack pine seeds provided by the Ontario Ministry of Natural Resources and pelleted by Moran Seeds, Inc., Salinas, California, (black spruce) or encapsulated by the Niagara Chemical Division, FMC Export Corporation, Modesto, California, (black spruce and jack pine) are being tested to determine if the pelleting or encapsulating techniques or mediums have any adverse effect on germination, before tackling the problem of chemical additives for different purposes.

METHODS. The laboratory germination tests at 70 F (21.1 C) were duplications of the 28-day germi-

Table 4. Percent survival and rank of growth of 12-week-old germinates from untreated jack pine and black spruce seeds and from seeds treated with R-55 [a], and with arasan [a].

Species	Treatment	% Survival		Weights (ranked)		
		Greenhouse [b]	Growth Chamber [c]	Shoots	Roots	Total [c]
Black spruce	Control	99	88	6	6	6
	R-55-1	97	67	1	1	1
	R-55-2	92	74	4	2	3
	R-55-3	98	62	3	4	4
	R-55-4	96	86	2	3	2
	R-55-5	99	88	5	5	5
	Arasan	96	95	7	7	7
Jack pine	Control	100	98	2	1	1
	Arasan	100	76	1	2	2

[a] See Appendices A and B for R-55 and arasan treatments.
[b] 100 needle-planted germinates.
[c] 42 needle-planted germinates.

nation tests described for R-55-coated and for arasan-coated seed, with the following exception: two methods of watering were employed to water the encapsulated seeds, i.e., watering from below, where the water was added at the side of the petri dishes and reached the tablets by absorption via the germination paper, and watering from above where the water was added freely on top of the germination paper and soaked directly into the tablets.

RESULTS AND DISCUSSION. The uniformly-sized, approximately spherical pellets (black spruce) absorbed moisture readily and 28-day germination of pelleted seeds was as high as possible and equal to germination from non-pelleted seed, i.e., 100%!

Germination of encapsulated black spruce seed was less than 50% compared with 100% from control seed, but there was little to choose between germination from encapsulated seed watered from below (42%) and from those watered from above (48%). None of the encapsulated jack pine seeds germinated, compared with 84% germination from non-treated control seeds.

Following the discouraging results with encapsulated jack pine seeds, 100 tablets from each watering treatment were carefully dissected and the recovered seeds were subjected to the same germination test at 70 F (21.1 C) whereupon 87% of them germinated! This indication that there was nothing toxic to jack pine seed in either the encapsulating medium or the adhesive used to cement the tablet halves together was substantiated by the results of two additional germination tests of non-treated jack pine seeds using (i) gravity, and (ii) vacuum filtrates in water of separate tablet halves (i.e., no adhesive) and of completely encapsulated seeds (i.e., tablet halves + adhesive + enclosed seeds) as the sole moistening mediums throughout the tests.

In the first test germination from seeds moistened with the gravity filtrates only was 86% (complete tablets) and 88% (tablet halves) compared with 92% germination from seeds moistened with distilled water. In the second test, with vacuum filtrates only, the germination was 89% (complete tablets) and 84% (tablet halves) compared with 89% from seeds moistened with distilled water.

No completely acceptable hypothesis has yet been advanced to account for these startling negative results with encapsulated jack pine seed, but explanations are being sought with a view to solving the problem to the mutual satisfaction of ourselves and the company concerned.

Meanwhile, cooperative arrangements have been made whereby black spruce seed provided by the Ontario Ministry of Natural Resources has been pelleted by the "Lite-Coat" process by Asgrow Seed Company, Kalamazoo, Michigan, for precision seeding trials at one of the Ministry's nurseries, and a sufficient quantity has been provided for testing the effect of this process on germination of black spruce seeds.

In our germination tests of pelleted seed we have dealt only with laboratory germination, but the question has arisen whether germinates from pellets can and do survive long enough under field conditions for their radicles to reach and penetrate the soil. Rudolph (1950) noted that many did not, but Liddell (W. A. Liddell, Asgrow Seed Company, Kalamazoo, Michigan, personal communication) thought there was no need for concern on this point. Field experiments with non-treated seed, and with pelleted, and encapsulated black spruce seed have been initiated to resolve this question.

SUMMARY

Whether arasan-endrin seed coatings were as effective for repelling rodents from small-seeded conifers under boreal forest conditions as they were reputed to be on larger-seeded southern pine seeds in the southern United States not only was never satisfactorily tested and resolved, but also became irrelevant when the use of endrin was legally banned in Canada. Although final statistical analyses may indicate otherwise and support the reported adverse effect of R-55—an alternative to arasan-endrin as a repellent—on Douglas-fir and western hemlock, the influence of R-55 on germination, survival and growth of black spruce seed is less well defined. The results reported here showed little if any ill effect of R-55 on germination or on survival under conditions simulating field conditions, i.e., in well-watered greenhouse trials.

The effectiveness of arasan other than as a fungicide is also somewhat controversial, but recent experiments at the Great Lakes Forest Research Centre indicate that arasan has no adverse effect on germination of black spruce seed, or on germination of jack pine seed except, perhaps, at low temperature.

The effect of seed pelleting some species seems to be as varied as the mediums and techniques used and almost as controversial as the effect of repellent treatments, but there has not been a great deal of pelleting of either black spruce or jack pine seed. Recent results from one method of pelleting black spruce seed, and of encapsulating both black spruce and jack pine seeds, indicated no harmful effect of the pelleting medium or technique, but did indicate an as yet unexplained adverse influence of the encapsulation medium or process on germination, particularly of jack pine seed.

Additional studies are required to explore other pelleting techniques, to resolve the problems related to encapsulation, and to explore the feasibility and effectiveness of chemical additives as repellents, herbicides, etc., when they are incorporated into the pelleting medium or added to the exterior of the pellet.

Seed coating and pelleting treatments that show promise in controlled laboratory or manipulated greenhouse environments should be field tested before any widespread application to direct seeding, and then only when it has been demonstrated that the technique or process also protects the seed against damage from mechanical seeding devices. Failures and contradictory results to date should not lessen the determination to develop satisfactory combinations of coating and pelleting coniferous seeds as an aid to increasing the success of direct seeding operations on our boreal forest sites.

ACKNOWLEDGEMENTS

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Particular thanks are due my technician, J. M. Shoup, for his conduct of the experiments, the results of which are reported here, and for his assistance in reviewing relevant literature.

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APPENDIX A

R-55 Seed-Coating Treatments (Black Spruce)

Seeds coated with R-55 were treated by the Canadian Wildlife Service, Western Region, as follows (A. Radvanyi, Canadian Wildlife Service, Edmonton, Alberta, personal communication) : coatings contained (a) a 4 : 1 R-55 : graphite mixture, (b) Dow latex 612, diluted 1 : 9 latex : water, acidified with HCl to bring the pH from 8.2 to 4.8.

Coating 1.
- 25cc latex solution applied in one lot
- gallon-sized mixer rotated 2-3 min before R-55/graphite applied
- 75gm R-55/graphite powder applied in three small portions
- seeds tumbled approximately 3 min more, then emptied and shaken in fine mesh sieve to remove

surplus powder
- coating was irregular under microscope.

Coating 2. – same as 1 except for 4 min tumbling after seeds wetted with latex and before powder added
- coating was still somewhat irregular.

Coating 3. – latex increased to 30cc
- 75gm R-55/graphite powder
- coating was still patchy.

Coating 4. – latex decreased to 20cc
- 75gm R-55/graphite powder
- coating improved but some lumping of powder still occurred.

Coating 5. – 20cc latex
- 75gm R-55/graphite powder
- 4 min between latex and powder application; latex added using a pipette, giving a very fine stream applied while mixer in motion
- coating more uniform.

APPENDIX B

Arasan Seed-Coating Treatments (Black Spruce, Jack Pine)

Seeds coated with arasan were treated by the Ontario Ministry of Natural Resources, Tree Seed Plant, (C.H. Lane, Ontario Ministry of Natural Resources, Toronto, Ontario, personal communication) using the following formulation for 10-lb seed lots

Arasan 42S	6.6 fl oz
Dow latex 512R	1.0 fl oz
Distilled water	9.0 fl oz
Aluminum flakes	1.0 oz

Seed procurement and handling: spruce and pine

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ABSTRACT

A survey of the procurement and handling of pine and spruce seed in Canada was conducted. Information from a questionnaire is combined with that from selected references.

There generally seems to be a desire to mechanize the cone procurement operation. Certain advances which have been made in this respect are described. The methods of handling cones once harvested are relatively uniform across the country and probably will not change to any degree in the near future. An area where more work is required is in forecasting cone crops. Estimates based on actual bud or fruit counts is a preferable method to those based on subjective appraisals; an example of a sequential sampling method which warrants consideration is given.

RÉSUMÉ

L'auteur inventoria les méthodes de récolte et de manutention des graines de Pin et d'Épinette au Canada. Il fournit des informations provenant d'un questionnaire et de références bibliographiques choisies.

On désire généralement mécaniser les opérations de récolte des cônes. L'auteur décrit certains progrès accomplis dans ce domaine. Les méthodes de manutention des cônes après la récolte sont plutôt uniformes d'un bout à l'autre du pays et elles ne changeront probablement pas à l'avenir. Un domaine où plus de travail s'impose est la prévision des récoltes de cônes. Les estimations fondées sur des comptages de bourgeons et de fruits sont à préférer aux estimations subjectives; à ce sujet l'auteur fournit un exemple de méthode d'échantillonnage séquentiel qui vaut la peine d'être examiné.

INTRODUCTION

The procurement and handling of seed is one of the most important steps in reforestation programs. Seed must come from the proper sources to be of the proper genetic make up for intented purposes. The question of seed source will not be discussed here but its importance cannot be overstressed. All provinces recognize the importance of identifying and developing quality seed sources for their particular region and efforts in this direction should be followed by the very best procurement and handling practices. Variation in these practices exist across Canada and many are changing. The driving force for the changes, at least in Manitoba, is the desire to obtain quality seed from known sources in a manner which is not destructive to the parent tree and then to handle the seed in a manner to assure maximum viability when it is removed from storage for use.

This paper summarizes the results of a questionnaire on the procurement and handling of pine and spruce seed which was sent to all provinces and territories in Canada and includes additional information from selected references. The Northwest Territories will not be referred to in this report because they do not collect seed.

SEED REGISTRATION

A seed registration system is essential to a progressive reforestation program. Registration means keeping track of seed from collection through to the field either as seedlings for planting or as seed for direct seeding. Post establishment surveys of plantations established with registered seed would generate valuable information on the quality of progenies produced from certain seed collection areas.

The Yukon and all provinces except Newfoundland and Prince Edward Island (P.E.I.) have formal seed registration systems. However, Newfoundland collects most of their seed from one general area and is planning to design a registration system for their needs, and P.E.I. keeps their seed separate by location of collection. In some instances the exact origin of all seed collected in quantity is not known. For example, seed generally collected in Ontario is bulked by seed zone but seed collected from orchards and seed production areas gets individual treatment.

Guarantees as to the quality of progeny produced cannot be made with most of the seed registered as to origin. Newfoundland, Alberta and the Yukon are the only agencies that do not have tree improvement programs which aim at producing seed with superior genetic qualities. The Canadian Forestry Service does, however, make a contribution in this respect in Newfoundland and Alberta.

CONE CROP FORECASTING

Any efficient operation requires advance planning, and the harvesting of cones is no exception. A sound cone crop forecast is the basis for organizing collections and is essential where expensive equipment is to be used to best advantage to aid in collecting cones from standing trees. Estimates of the coming crop based on actual developing fruit or flower bud counts are more reliable than those based on subjective assessments. Most methods employed by cone collecting agencies in Canada are based on occular estimates of cone abundance. Such methods were no doubt adequate in the past but need to be improved with the increased demand for seed from selected sources.

The method of crop forecasting proposed by Eis and Inkster (1972) in central British Columbia (B.C.) for white spruce (*Picea glauca* (Moench) Voss) is a quantative method of assessment which is simple to use; it could no doubt be modified for other species and areas. The method is a sequential sampling scheme that involves counting female reproductive buds during September of the year preceding the crop year. It was developed by making counts on a randomly selected branch from the third whorl of well distributed dominant trees 50-60 feet tall and 45 to 83 years old. A rating is determined by cumulatively recording bud counts and tree numbers and locating the data point on a graph (Fig. 1.).

The sampling continues until a definite crop rating on a one to five scale (B.C.'s crop rating categories) can be determined, i.e. where the point does not fall in the area of indecision. Ratings four and five are considered economically collectable. It was suggested that an average of nine or ten trees of similar crown class and approximate age to those used to develop the scheme would need to be sampled to make a decision.

The application of this method requires close examination of the branch in September when ovulate buds can be recognized. To do this the tree must be felled, topped or high lift equipment or ladders used. An easier and non-destructive count could be made with binoculars shortly after flowering in the spring but this would tend to underestimate the crop if ratings are determined using Figure 1 (Eis 1973, personal communication). The reason for this is that bud losses during winter and early spring due to a variety of reasons are

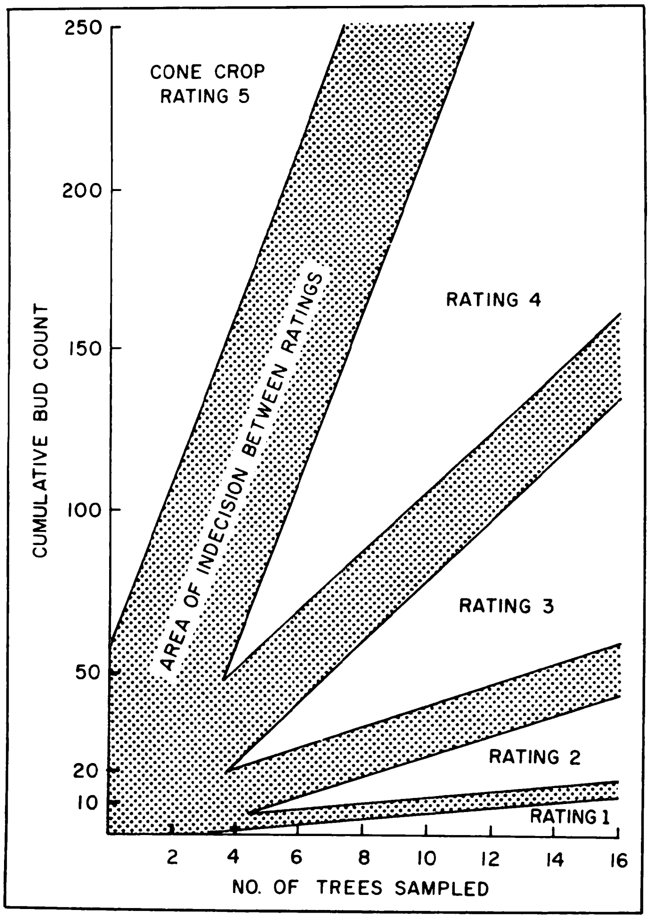

Figure 1. Classification of white spruce cone crops (Eis and Inkster 1972).

built into the system. The application of this approach to immature cone counts would be relatively easy but would require long term records relating early cone numbers to the final crop.

SEED YEAR FREQUENCY AND COLLECTING TIMES

Most of our spruce and pine do not produce annual cone crops. Wang (1973a), in a comprehensive review of the literature, reported the seed year frequencies and approximate months of collection recorded in Table 1.

The best seed yields and seed quality are obtained during good seed years and large scale collections should be planned for these crops. Amounts to be collected should be sufficiently large to satisfy seed requirements until the next good seed year.

Table 1. Frequency of seed years of native spruce and pine species (Wang 1973a).

Species	Frequency of Good Seed Crops (Years)	Time at Maturity
Whitebark pine (*Pinus albicaulis* Engelm.)	1–3	Aug. to Sept.
Lodgepole pine (*P. contorta* Doug.)	1–3	Aug. to Oct.
Jack pine (*P. banksiana* Lamb)	3–4	Oct. to Nov.
Limber pine (*P. flexillis* James)	3+ (Irregular)	Sept.
Western white pine (*P. monticola* Doug.)	3–4	End Aug. to mid–Sept.
Ponderosa pine (*P. ponderosa* Laws.)	2–8	Aug. to Sept.
Red pine (*P. resinosa* Ait.)	3–7	Mid–Sept. to late Oct.
Pitch pine (*P. rigida* Mill.)	3 (Irregular)	Oct. to Nov.
Eastern white pine (*P. strobus* L.)	3–5	Mid–Aug. to Sept.
Engelmann spruce (*Picea engelmannii* Parry)	3–6	End Sept. to early Oct.
White spruce (*P. glauca* (Moench) Voss)	2–6	Late Aug. to early Sept.
Black Spruce (*P. mariana* (Mill.) B.S.P.)	4–5	Sept.
Red spruce (*P. rubens* Sarg.)	3–8	Sept.
Sitka spruce (*P. sitchensis* (Bong.) Carr.)	4+ (Irregular)	Sept.

THE HARVESTING OPERATION

Responsibility and Personnel

The responsibility for harvesting cones in Canada varies across the country. The most common source of responsibility is the forest management staff in head office (6 agencies) followed by regional staff (3) and nursery staff (2). The actual harvesting of cones is done in most instances by supervised labor on an hourly wage or on piece work (5) as opposed to unsupervised pickers (3). Three of the eleven agencies use a combination of supervised and unsupervised pickers to collect their requirements.

Seed Maturity

As soon as seed is harvested its potential viability is established. Because of this, effort should be exerted to collect cones prior to natural seed fall when a high number of seeds are ripe (U.S. Forest Service 1948). The timing of collection is not important with species that have serotinuous cones because little or no seed falls after cones mature. For most of our spruces and pines the period available for cone collection, after an adequate degree of cone ripening on the tree, is relatively short. Once the cones are ripe collections should begin immediately.

Most agencies use a combination of factors to determine when cones are ripe. The most common of these is cone color (9) followed by seed cutting tests (7), flotation of cones (5) and when squirrels begin to harvest (4). Local experience no doubt plays an important roll in determining the time of collection.

Cutting tests and flotation of cones are reasonably precise measures to determine cone maturity. Cutting tests determine the maturity of the endosperm and embryo, which are the best indicators of seed maturity (Wang 1973a). A sectioned seed is considered ripe if it is firm and has a good white color (U.S. Forest Service, 1948). The seeds exposed on the surface of longitudinally sectioned cones are suitable for this determination as well as for giving an idea of the number of filled seeds per cone. Flotation tests are based on the principle that as cones ripen they become lighter (Morandini 1961). This loss of weight is brought about by a reduced moisture content and a point is reached when a certain percentage of cones float in a suitable test liquid. When a set number of cones float the crop is ready for collection. Some examples of this are 50% floatability of white pine in linseed oil, red pine in SAE 20 oil (U.S. Forest Service 1948) or kerosene, ponderosa pine in an equal part mixture of linseed oil and kerosene (Rudolf, 1961) and 90% floatability of white spruce cones in turpentine or 80% in kerosene (Cram and Worden 1957).

A fairly large number of cones from a number of trees in each area should be examined whatever tests for ripeness are used because seed ripening varies between locations (Rudolf 1961; Morandini 1961) and between individuals in the same stand (U.S. Forest Service 1948).

It has been suggested that there is a relationship between the time of pollination and seed ripening (Cram and Worden 1957; Waldron 1965). Cram and Worden (1957) suggested that cones of white spruce should first be tested for ripeness 90 days after pollen release. Such relationships no doubt exist and are useful knowledge but are probably subject to the same variations as those in annual climate.

Cone Collecting

Cones harvested from felled trees following logging operations are the main sources of seed used in Canada. Most agencies exert an effort to collect cones from their better stands or the best trees in any stand. Only three provinces fill part of their requirements from any trees in any stands and five make supplementary collections from rodent caches.

The problems encountered in harvesting cones varies across the country. Problems mentioned more than once and the frequency of times mentioned are: labor problems (4), collecting from standing trees (2), lack of mechanization in the operation (2), and seed year infrequencies (2). Seed year infrequency problems can be partially solved by a reliable crop forecasting system insuring that the required amount of seed is harvested during any one crop year. The other problems in the list are to some extent linked. Labor problems can partially be cured by increased mechanization which would no doubt also include increased efficiency in collecting cones from standing trees. Increased acreages of seed production areas would alleviate labor problems to some extent but would only be practical if cone harvesting from standing trees could be mechanically assisted.

COLLECTING FROM STANDING TREES. The collection of cones from standing trees in managed seed production areas or orchards is the preferred seed source because genetic quality, if not improved, will be maintained (Dorman, 1951). Eight of the agencies, which collect seed in Canada, harvest some cones from standing trees. The most common equipment used in this operation are ladders. Other equipment mentioned are long handled pruners, elevated truck platforms, climbers, .22 caliber rifles and 12 gauge rifled slugs (for research collections), Swedish tree bicycles, cone towers and tree shakers.

The collection of cones from standing trees appears to be more common in Europe than in Canada. The equipment commonly used in Europe is of four basic types (Seal, Matthews, Wheeler 1965; Morandini 1961). These are ladders, trunk climbers (tree bicycles, climbing irons, etc.), hydraulically operated high lift equipment and tree nets. All of these items have been available for some time, yet none of them have found much use in Canada for large scale collections. Trunk climbers and ladder systems leading to free climbing in the crown and tree nets would be very slow and expensive for large collections. Equipment that holds some promise in speeding up collections from standing trees are: 1) leaning ladders, 2) hydraulically operated high lift equipment, 3) tree shakers, and 4) tree topping.

1) Leaning ladders. – Extension ladders which lean close to a tree although not necessarily touching it, are probably more useful than those that strap against the trunk. Leaning ladder systems are often mounted on the rear of trucks, which limits their usefulness to flat, firm, nonobstructed ground. A similar but more versatile system was that used by Skilling (1960). He mounted a 45-foot extension ladder on a frame attached to a small tracked vehicle. The tracked vehicle would make the system much more flexible than the truck mount. A swivelling base would improve the use of any vehicle mounted ladder (Carmichael 1951).

Lowry and Avard (1969) used a 50-foot three-section aluminum ladder to collect foliage samples from black spruce and jack pine. The ladder was supported by ¼-inch nylon ropes tied to neighboring trees and leaned close to the tree but was not supported by it (Fig. 2.). The author has had the opportunity to climb this ladder and found it surprisingly stable. Lowry (1972, personal communication) estimated that it would take two men about 5 minutes to set-up the ladder and that 40 set-ups per day would be possible. It was suggested that the picker should not assist in setting up and taking down the ladder, thus a three man crew would be required. This ladder is easily carried on high quality car top racks on a suitable vehicle.

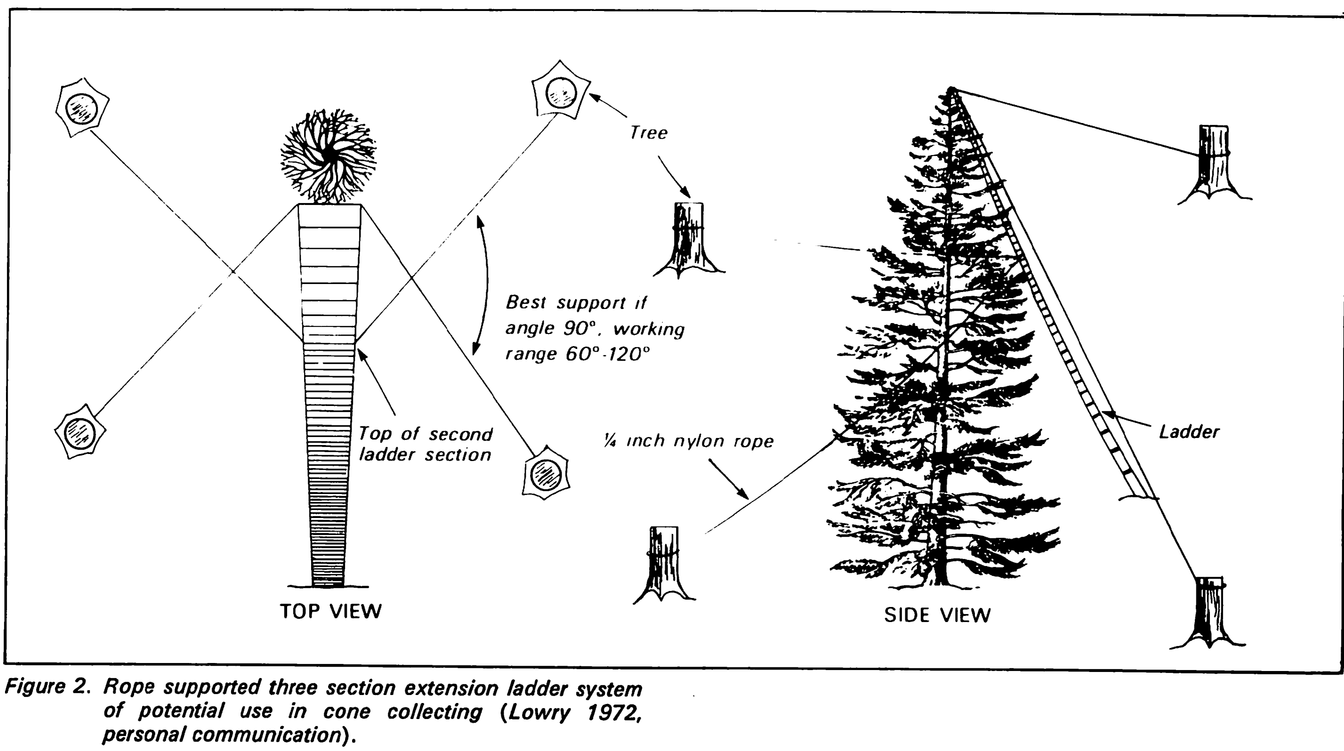

Figure 2. Rope supported three section extension ladder system of potential use in cone collecting (Lowry 1972, personal communication).

A ladder used in this manner would enable reasonably efficient cone harvesting from narrow-crowned trees up to 50 feet tall, especially in areas where the soil is organic or soft and manoeuverability poor.

2) Hydraulically operated lifts. – The U.S. Forest Service in 1968, conducted a comprehensive survey of high lift equipment that could be used to harvest cones. They found that units are available that have a vertical lift of 120 feet but most of the equipment is in the 30–60 foot range. These units are usually truck mounted, therefore the soil and stand conditions must be such that the vehicle can move around safely. It was pointed out by the U.S. Forest Service that a bucket lifted by a hydraulic elbow system with a maximum vertical reach of 75 feet (including the truck height) would have a relatively high center of gravity and this would limit off road travel. The overall length of the lift when in position to travel would be about 42 feet and it was determined that stands with over 27 trees per acre would restrict vehicle movement. The most efficient use of the vehicle to collect cones from 60 foot trees would be in stands with 40 trees per acre. A further problem with the use of this type of equipment is its horizontal reach limitations brought about by an overturning moment created when the bucket is moved horizontally. For example, using a 75-foot vertical lift bucket, the safe vertical height when the bucket is moved laterally from the vertical a distance of 36 feet is 60 feet.

One of the major drawbacks to the use of this equipment is the high cost of purchasing enough units to harvest adequate quantities of cones over the relatively short time available for harvest. Alternate uses for the equipment during the off season would have to be found to make the investment worthwhile.

Ontario has developed a hydraulic cone picking tower (Grinnell 1970) that has been successfully used to harvest red pine cones. Designed originally for black spruce, the device is a vertical tower with a horizontal platform on the top (Fig. 3.). The platform has a minimum level of 24 feet, a maximum of 54 feet, and can turn through 360°. The tower is mounted on a trailer bed equipped with an ordinary trailer hitch. The unit is very portable and with an appropriate mount could be towed by a variety of tracked or wheeled vehicles, thus giving it access to a variety of terrains.

3) Tree shakers – Tree bole shakers are getting some attention in Canada as a means of collecting cones from trees. They have been successfully used to harvest cones in the southern States (Kmecza 1970) and have been tested in the U.K. (Anon 1971). The unit used in the southern States was capable of clamping on trees up to 36 inches in diameter. In Canada, B.C. is initiating trials with a shaker and Alberta is using a shaker to harvest white spruce cones (Fig 4.).

Shaking units are relatively small compared to high lift equipment and could be mounted on tracked or wheeled all-terrain vehicles. The efficiency of the shaking units at removing cones decreases as the cones become lighter during ripening (Anon 1971). Thus their use would require precise timing to catch the crop when the seeds are ripe and the cones heavy enough for the shaker to dislodge an acceptable number from the tree.

4) Tree topping — A compromise between felling trees for cone collection and non-destructive harvest would be the topping of trees. Slayton (1969) found it feasible to top white spruce at the 2- to 4-inch diameter point and then to truck the tops to a central point for cone picking. The trees topped in this experiment seemed to be forming new cone bearing crowns.

CONE THRASHING. There is the possibility of increasing efficiency in harvesting cones from slash. Haig (1969) reported on the use of two prototype machines for removing the cones. One was a modified thrashing machine; the other, a modified combine. Slash was collected from harvested land and fed into the machines where the cones were removed and separated from the branches. Black spruce and jack pine were tested in the study and the results indicated that such an operation was feasible.

FIELD STORAGE AND SHIPPING OF CONES. All agencies place their cones in burlap bags after harvesting and in most cases they are field stored at ambient temperature in their shipping containers; one province refrigerates some of their cones. Cones that are likely to heat in the bags are spread out to the air as a safety measure until they are shipped for extraction. There is a period of up to 3 weeks between cone collection and their arrival at the seed extraction plant. Cones collected in the Yukon are shipped to B.C. or Alberta for extraction and usually take over a month to get to their destination.

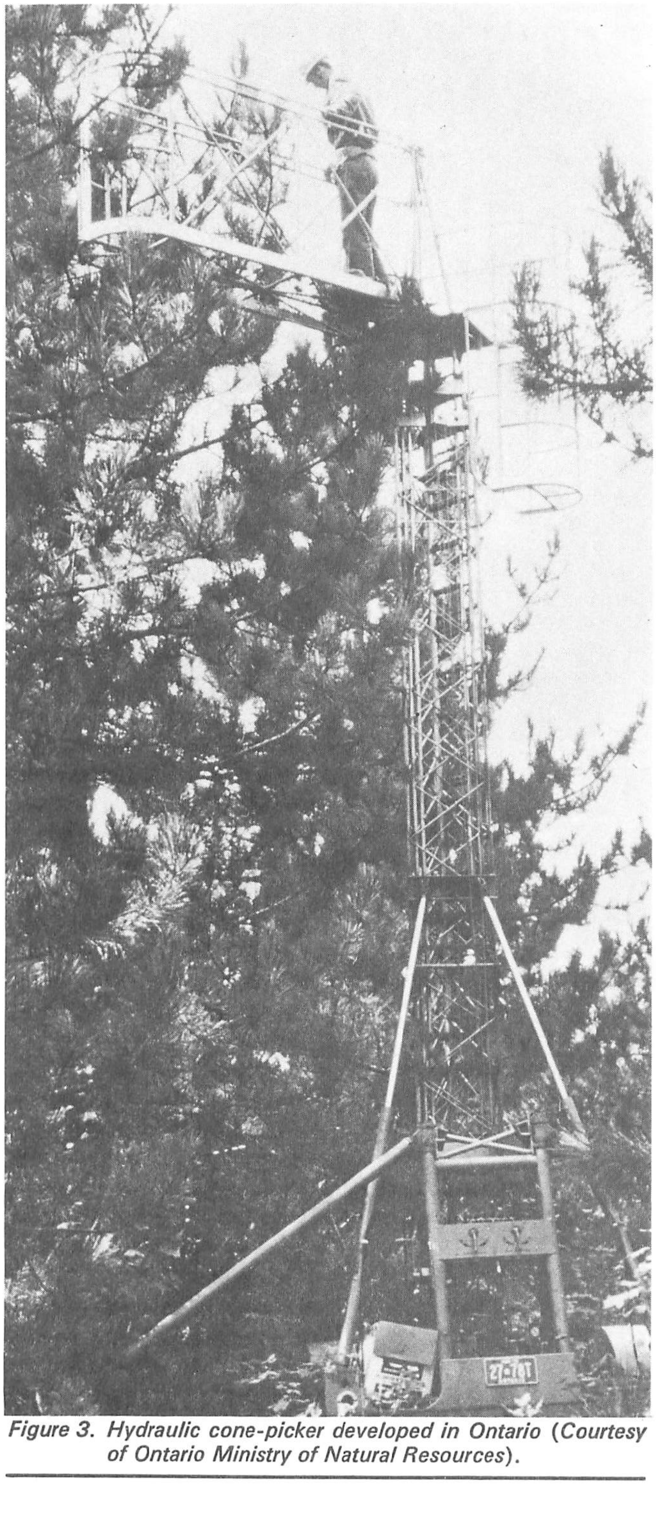

Figure 3. Hydraulic cone-picker developed in Ontario (Courtesy of Ontario Ministry of Natural Resources).

The most frequent method of shipping cones is in departmental vehicles, but five agencies rely to some extent on commercial transportation companies. Regardless of how cones are shipped, the sacks should be piled to allow air circulation among them (Wang 1973a).

SEED EXTRACTION

Cones of most species are placed on trays in sheds for precuring upon arrival at the seed extraction plant. Precuring serves an important function. It is an additional ripening period (Wang 1973a) that results in improved seed viability and reduces case hardening of cones when they are heated in a kiln (Morandini 1961). The curing sheds should be cool and well ventillated (Wang 1973a). The cones are placed in these sheds in shallow trays with a fine screen bottom. The screen serves to catch seed that may fall out of the cones. Curing sheds used in Canada vary in size, their capacities are listed in Table 2.

After an adequate precuring time, cones are placed in heated kilns for maximum cone opening. There are several types of kilns but those used in Canada are all of the forced-draft type, except one that is a convection kiln. The capacity of the kilns vary (Table 2.) according to individual needs.

Kiln schedules are different for different species. Generally, seed can withstand higher temperatures if the humidity of the air is kept low (Carmichael 1958) and the period of exposure kept to a minimum. High kiln humidities may also cause case hardening of the cones (Morandini 1961). Kiln temperatures can vary from 27 C to 65 C and heating times from 6 to 24 hours in forced-draft kilns. The most efficient operation is that which results in the shortest cone opening times, i.e. the highest safe heat-low humidity conbination for a species.

Cones that have adequately opened should be tumbled immediately upon removal from the kiln (U.S. Forest Service 1948) because, if they are left for any length of time, they may reclose slightly and trap some seed in the cones. This problem is overcome by tumbling the cones in the kiln as they dry; in this system, seeds that fall from the cones pass through an opening in the bottom of the kiln and are thus removed

Figure 4. Tree shaker used in Alberta (Courtesy of Alberta Department of Lands and Forests).

Table 2. Cone curing shed and kiln capacities in Canada.

Province	Cone curing shed capacity (Hectoliters) [1]	Kiln capacity (Hectoliters)
Newfoundland	–	–
Nova Scotia	72.8 [2]	72.8 [2]
Prince Edward Island	3.6	–
New Brunswick	109.2	9.7
Quebec	3,200	144.6
Ontario	10,000	80
Manitoba	1,092	21.8
Saskatchewan	728	72.8
Alberta	10,920	51
British Columbia	4,732	109.2

[1] 1 bushel — 0.364 hectoliter

[2] In Nova Scotia the curing shed has hot air outlets under the drying racks and cones are opened in the shed.

from the heat. Ontario is the only province that has such a combined operation. All other provinces (one did not answer the question) tumble the seed from the cones in progressive tumblers separate from the kiln. Six of the provinces made their own tumblers as opposed to purchasing the commercial apparatus.

Extracted seed is dewinged and cleaned of foreign material and empty seed before storage. Dewing can damage seed and reduce storability and viability (Wang 1973a) if not done carefully. There are two types of dewingers equally used in Canada, the brush and the cement mixer types. The brush dewinger requires adjusting for different seed sizes and if this is not done properly 10–30% of the seed may be damaged (U.S. Forest Service 1948). Wings can be removed from the seed with little damage if they are moistened and then placed in a rotating cement mixer (Wang 1973b).

The mixture of full seed, wings, empty seed and extraneous material is cleaned to retrieve the full seed. There are several different types of machines in which the cleaning can be done. The fanning mill, which is used by eight provinces, is the most widely used cleaner in Canada; two of the eight provinces clean their seed further, one with a belt cleaner and scalper and the other with a gravity table. One province uses a belt cleaner only and the other a screen cleaning machine and gravity table. After the seed is cleaned it may or may not be ready for storage.

The purpose for storing spruce and pine seed is to retain its viability and thus assure an annual supply of seed. The main reason for loss of viability during storage is continued respiration of the seed (Magini 1962). The moisture content of the seed and the storage temperature ate the most important variables that govern respiration rate. Seed extracted from cones that have been heated in a kiln often have acceptable moisture contents (Stoeckeler 1965). However, if the seeds are moistened before dewinging they must be redried (Wang 1973a). Only four provinces dry their seed prior to storage; although some of those who do do not mentioned that their seed is dry enough for storage after cleaning. Wang (1973a) summarized from the literature the required moisture contents for storage of seeds of several Canadian species; those for pine and spruce are given in Table 3.

Temperature, the other important storage variable, must be carefully controlled. Temperatures used in Canada range from —18 C to 2 C. The most common temperatures reported were between —1 C to 2 C; the desirable temperature varies with species (Table 3.).

It is usual to specify that storage containers be sealed against moisture to maintain the seed moisture content at the desirable level. The main storage vessels used in Canada are 1/8 inch thick polyethylene containers or glass bottles; one province uses four mil polyethylene bags in metal containers. When using polyethylene containers one should keep in mind that this substance is permeable to moisture (Wang 1973a) and if used for long-term storage it may be wise to control the humidity of the cooler.

The storage time for a seed lot in Canada is under 5 years for five provinces and up to 10 years for the others. The probable storage periods for several spruce and pine species, given the correct temperature/seed moisture content combination, are given in Table 3.

SEED TESTING FOR VIABILITY

Testing seed for viability gives an idea of the number of seedlings a certain amount of seed can be expected to produce (Magini 1962). The seed sample should be representative of the lot being tested and the environmental conditions during testing should be

Table 3. Specific conditions for safe dry storage of mature pine and spruce seed (Wang 1973a).

Species	Moisture content (%) (Fresh Weight)	Temperature (°C)	Possible Storage Period (Years)
Whitebark pine	5–9	−18 to 0	8+
Lodgepole pine	6–10	1 to 5	20
Jack pine	6–10	1 to 5	20+
Limber pine	6–10	1 to 5	6–10
Western White pine	5–9	−18 to 0	8–15
Ponderosa pine	6–9	0 to 5	11–30
Red pine	5–8	1 to 3	30
Pitch pine	6–9	1 to 3	10
White pine	5–7	–	10+
Engelmann spruce	4–6	1 to 3	10
White spruce	6–8	−10 to 2	15–20
Black spruce	4–6	1 to 3	17–20
Red spruce	4–6	1 to 3	15+
Sitka spruce	4–6	1 to 3	10

optimum for germination. The factors of most importance to germination are moisture, temperature and light (Heit 1968). Tests should be conducted using a minimum of four replicates of 100 seeds (Association of Official Seed Analysts 1970); if results are to apply to amounts of over 100 lb. of seed, 800 to 1000 seeds should be tested (Rudolf 1961). Seed counts are easiest made with vacuum counters that operate on the same principle as vacuum plates designed to seed flats for the production of container stock. Time can be saved by depositing the seed properly spaced in the germinating container if the counter is made the same shape as the container or vice versa.

Direct germination is the most common method of determining seed viability in Canada. Nine provinces test seed by germinating exposed seed on filter paper or some other inert media; the other province germinates covered seed in natural media. Over half of the provinces supplement direct germination tests with other methods. Three use cutting tests; one, flotation of seed; and one, germination of covered seed in natural media. All but three provinces conduct their germination tests in controlled environments. X-ray as a technique for determining viability is developing but is not yet considered operational in Canada.

SHIPPING OF SEED

Seed often has to be shipped from a central store to remote nurseries or to the field for direct seeding. As much care should be taken in handling seed for shipment as is taken in other parts of the operation. Five provinces in Canada ship seed in polyethylene bags which are usually placed inside metal, cardboard or cloth bag containers. One province ships seed in cloth bags, one in glass bottles or stiff-walled polyethylene containers and two provinces do not ship seed but use it in nurseries adjacent to their storage facilities. The most common shipping time for seed is 1 to 2 days with two provinces taking 4 to 7 days to deliver seed. All but one of the seven provinces who ship seed use government vehicles, with four of these relying to some extent on commercial transport companies; the other province relies exclusively on commercial carriers.

CONCLUSION

Seed procurement and handling practices for pine and spruce seed in Canada are fairly well developed. Procurement procedures of the past will change as emphasis shifts towards obtaining seed from standing trees in seed production areas and orchards. The desire to harvest seed in a manner not destructive to the tree combined with general labor problems will lead to increased mechanization in this respect. The methods of handling harvested seed is fiarly uniform across the country and procedures are not likely to change appreciably in the near future.

There is room for refinement in crop forecasting methods. Estimates based on actual counts of young cones or flower buds are better than those that are qualitative. Eis and Inkster (1972) proposed a sequential sampling scheme for estimating white spruce cone crops in central B.C. Their approach could be applied to other species and to binocular counts of spring flowers or young cones. Accurate determination of the size of the crop would be most useful where expensive equipment will be used in the harvest.

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Direct seeding in western Canada

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ABSTRACT

Direct seeding is not applied uniformly by province in western Canada. In British Columbia it is not considered as an acceptable reforestation technique, in Alberta it is the main method used and in Manitoba and Saskatchewan the method would seem to be used with some caution.

A total of 129,897 acres have been direct seeded in the four western provinces of Canada since 1925 and 98% of this area was seeded between 1960 and 1971 inclusive. The Alberta Forest Service seeded 103,970 acres in this period.

Hand seeding was more common than aerial seeding in the past and will probably remain so in the future due to seed availability. Mainly white spruce and lodgepole pine seeds were used at a density of between 20,000 and 200,000 seeds per acre on burns, undisturbed forest floor and scarified ground. Mineral soil exposures between 1–55% have been obtained (10–20% most common) in scarification. The 80% plus failure rate in direct seeding projects since 1960 can be attributed to many factors some of which are (a) inadequate seed used, (b) wrong season of application, (c) insufficient seedbed preparation, (d) poor ground control in seeding operations when more than 25% mineral soil exposure was obtained, and (e) heavy competition from grasses and herbs and losses to rodents.

In spite of the poor success in the past, the direct seeding method will be used even more extensively in Alberta in the years ahead because it has been proven that with better quality control over seeding and seedbed preparation, better results may be expected.

RÉSUMÉ

L'ensemencement ne s'applique pas de manière uniforme à travers les provinces de l'ouest du Canada. Non considéré comme une technique acceptable de reboisement en C.B., il est la méthode utilisée principalement en Alberta et, semble-t-il, avec une certaine circonspection dans le Manitoba et la Saskatchewan.

Depuis 1925 une superficie totale de 129,897 acres a été ensemencée dans ces quatre provinces,

dont 87% entre 1960 et 1971 inclusivement. Durant cette dernière période le Service forestier de l'Alberta a ensemencé 103,970 acres de terre.

Dans le passé le semis à la main était plus courant que le semis par avion et il en sera probablement de même à l'avenir, compte tenu des disponibilités en graines. On employait principalement des graines d'Épinette blanche et de Pin lodgepole à raison de 20,000 à 200,000 par acre sur les brûlis, la couverture morte non remuée et les sols scarifiés. Le scarifiage mettait à nu une proportion de 1 à 55% (plus communément 10–20%) du sol minéral. Les taux de 80% et plus d'échecs enregistrés depuis 1960 dans les programmes d'ensemencement sont attribuables à maints facteurs dont: (a) utilisation de graines inadéquates, (b) application en saison inopportune, (c) préparation de terrain insuffisante, (d) contrôle médiocre du sol dans les opérations d'ensemencement lorsque plus de 25% du sol minéral se trouvait exposé, et (e) forte concurrence du gazon et des autres plantes herbacées et pertes dues aux rongeurs.

Malgré son mince succès dans le passé, la méthode de l'ensemencement sera employé même plus extensivement dans les années à venir en Alberta, parce qu'il a été prouvé qu'en contrôlant mieux le semis et la préparation du terrain on peut s'attendre à de meilleurs résultats.

INTRODUCTION

The purpose of this paper is to report on direct seeding in western Canada, to summarize acreages reforested by this method, to give methods of seedbed preparation, to assess project failures and successes, and to consider future improvements in direct seeding techniques. The report is based almost exclusively on data from the 12 years between 1960 and 1971 due to lack of detailed older data and because 98% of all direct seeding in the four western provinces of Canada has been done since 1959.

Direct seeding implies seeding by man rather than by nature, and it includes all methods of application with or without seedbed preparation.

Seeding in the past was done mainly on old and recent burns with little or no artificial seedbed preparation. Today artificial seedbed preparation is predominant over no seedbed preparation. Industry in western Canada was not expected to reforest cutovers until recently and, as a result, data presented here pertain mostly to work done by the Provincial Forest Services, the custodians of the forests.

Direct seeding in western Canada has been practiced for nearly 50 years according to available records. This work has increased sharply over the last 10–15 years. It is suggested here that this increase has been brought about by three pressures:

1. An increasing need to reforest in order to manage timber production on a sustained yield basis. As long as small areas of virgin forest were cut and as long as the volume of cut was small, there was no recognized need to spend money on reforestation. Virgin forests are now being cut out at alarming rates.
2. An effort to minimize reforestation costs. History is repeating itself in western Canada. Direct seeding was used extensively in the eastern United States at the turn of the century (Toumey and Korstian 1949). Seeding costs then were only 40% of those for planting. This picture has not changed today.
3. A keen public awareness of the effects of cutovers on the landscape. It is therefore important that the forester reforest quickly after cutting for reasons of watershed management, wildlife management, recreation and future forest utilization.

ACRES DIRECT SEEDED

A total of 129,897 acres have been direct seeded in western Canada up to and including 1971. Records show that direct seeding was first done in Manitoba in 1925, in Saskatchewan in 1951, and in both Alberta and British Columbia in 1960. Table 1 shows that of the total workload, Manitoba and British Columbia each seeded 5% of the total, Saskatchewan seeded 1%, while Alberta seeded 89% of the total. About 3,500 of the acres direct seeded in British Columbia and 8,500 of the acres direct seeded in Alberta were seeded by industry.

It is inescapeable that this paper is based heavily on data from Alberta as a result of the concentration

Table 1. Direct seeding in the four western provinces of Canada between 1925 and 1971 inclusive.

Provinces:	B.C.	Alta.	Sask.	Man.
Total Acres:	7,000	112,470	2,493	7,934

of direct seeding activity in that province. Table 2 shows the annual acreages direct seeded in the four western provinces of Canada between 1960 and 1971 inclusive:

British Columbia

The method of direct seeding is not accepted as an operational reforestation technique in British Columbia today. Results from direct seeding have been too unreliable. Seed losses were blamed mainly on the peromyscus mouse. Early tests indicated that endrin-treated seeds were not eaten, but when such treatment had to be stopped, direct seeding lost its usefulness.

Seeding in British Columbia has been done mainly with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) on slash-burned sites and on sites scraped with bulldozer blades. All of the 7,000 acres direct seeded were treated on an experimental basis, half by industry and half by the B.C. Forest Service. Virtually all seeding was done from helicopters [1].

[1] Personal communication with Mr. A. H. Bamford, R.P.F., Reforestation Division, B.C.F.S., Victoria, B.C. dated January 5, 1973.

Saskatchewan

Direct seeding in Saskatchewan has been sporadic over the past 12 years, which shows that, here too there is caution in the use of direct seeding as a reforestation technique. All of the 876 acres were seeded by the Forest Service with cyclone seeders on scarified ground. Both Athens ploughs and bulldozer blades with raker teeth were used for scarification. Of the six projects reported on between 1960 and 1971, none were classified as fully successful; all projects showed a need for reseeding or supplemental planting.

One pound of seed was used per acre in operational seeding before 1959, but only one-half pound has been used since. In spite of this, the projects completed before 1959 were no more successful than those completed after this date.

Mainly jack and lodgepole pine (*Pinus banksiana* Lamb, and *P. contorta* Dougl. respectively) and white spruce (*Picea glauca* (Moench) Voss) were used with minor acreages also seeded to exotics.

Manitoba

The Manitoba Forest Service did all the seeding reported on here. Most of areas were confined to projects of less than 200 acres in size. The generally unpredictable results from direct seeding in Manitoba

Total 2. Total annual acreage, by province, seeded between 1960 and 1971 for the four western provinces of Canada.

YEAR	B.C.		ALTA.		SASK.	MAN.
	B.C.F.S.	Ind.	A.F.S.	Ind.	S.F.S.	M.F.S.
1960			450	497	241	351
1961			2,130	867	—	1,157
1962			5,198	2,588	310	321
1963			6,050	1,640	—	132
1964			4,602	261	—	2,160
1965			9,040	533	—	852
1966			13,604	293	—	53
1967			21,807	—	—	—
1968			8,249	1,345	225	190
1969			10,323	—	—	355
1970			9,513	506	100	850
1971			13,031	—	—	?
	3,500	3,500	103,970	8,530		
Totals	7,000		112,470		876	6,421

have probably prevented this method from increasing in popularity (see Table 2).

Nearly 50% of all seeding was done with cyclone seeders, 26% was seeded with fixed-wing aircraft, 13% with helicopters, and the remaining 11% by hand or other unspecified methods. A total of 53% of all seeding in Manitoba was done in old burns and only 15% on cutovers and cutovers subsequently burned. Nearly 19% was seeded on undisturbed seedbeds with the remaining 13% of the seeded acreage being without site description.

Of the 20 projects for which stocking data are available for the period 1960 – 71, only five were stocked to 40% or better. Of these, two were seeded to jack pine, one to white spruce, and two were without species description. The data do not permit one to determine the cause of failures, but the general lack of seedbed preparation is undoubtedly a contributing factor.

Athens ploughs, middlebuster ploughs, bulldozers and drums were used for scarification and some areas were also prepared by hand.

A total of 88% of all sites were seeded with between 50,000 and 200,000 seeds per acre; 58% of the sites received 100,000 – 200,000 seeds per acre; 12% of the sites were seeded with less than 50,000 seeds per acre.

Nearly 62% of the area was seeded to white spruce at the rate of 0.4 – 1.6 lb. per acre. One percent of the sites were seeded with other native and exotic species.

Alberta

Scarification and direct seeding is the main method of reforestation applied in Alberta (McDougall and Kennedy 1972). Of approximately 137,500 acres scarified by the Alberta Forest Service between 1960 and 1971 inclusive, 103,970 have been direct seeded. Approximately 6,000 acres have been planted, while about 27,530 acres were scarified and then left to seed naturally. This is in stark contrast to British Columbia where 923,000 acres were planted and only 7,000 acres seeded over the full period of reforestation in that province [1].

Of the 103,970 acres seeded by the Alberta Forest Service and the 8,530 acres seeded by industry between 1960 and 1971, most was done with cyclone seeders and by hand (pinch method). Helicopter seeding was started in 1968 by the Forest Service (in 1966 by industry), and 10,307 acres were seeded this way (1,299 acres by industry). There has been no fixed-wing aircraft seeding in Alberta.

Table 3 gives a breakdown of acreages by forest region in Alberta. Figure 1 shows the location of these forests.

Virtually all seeding in Alberta has been done on scarified ground, Athens ploughs, Imset ploughs., bulldozer blades and specially constructed Vee-blades were used. The latter type is very popular for its ease of use. Industry has scarified most of its land with drums and anchor chains, which work well for lodgepole pine but not for white spruce.

To qualify as successful reforestation in Alberta, 40% stocking or better must be achieved; but few project qualify as successful due to inadequate methodology in the past. There is a general belief (Toumey and Korstian 1949) that a 20% success ratio is normal with direct seeding for areas seeded only once. For Alberta, only 4% of 174 surveyed projects had 40% stocking or better to conifers, 13% had 20 – 40% stocking to conifers and 83% had less than 20% stocking to conifers. Results in terms of project

Table 3. Direct seeding in Alberta between 1960 and 1971.

Forest	Acres Seeded
Crowsnest	3,719
Bow	1,809
Rocky/Clearwater	22,238
Edson	3,627
Whitecourt	7,720
Grande Prairie	12,665
Slave Lake	25,024
Lac La Biche	10,981
Athabasca	2,962
Peace River	12,420
Footner Lake	805
TOTAL	103,970

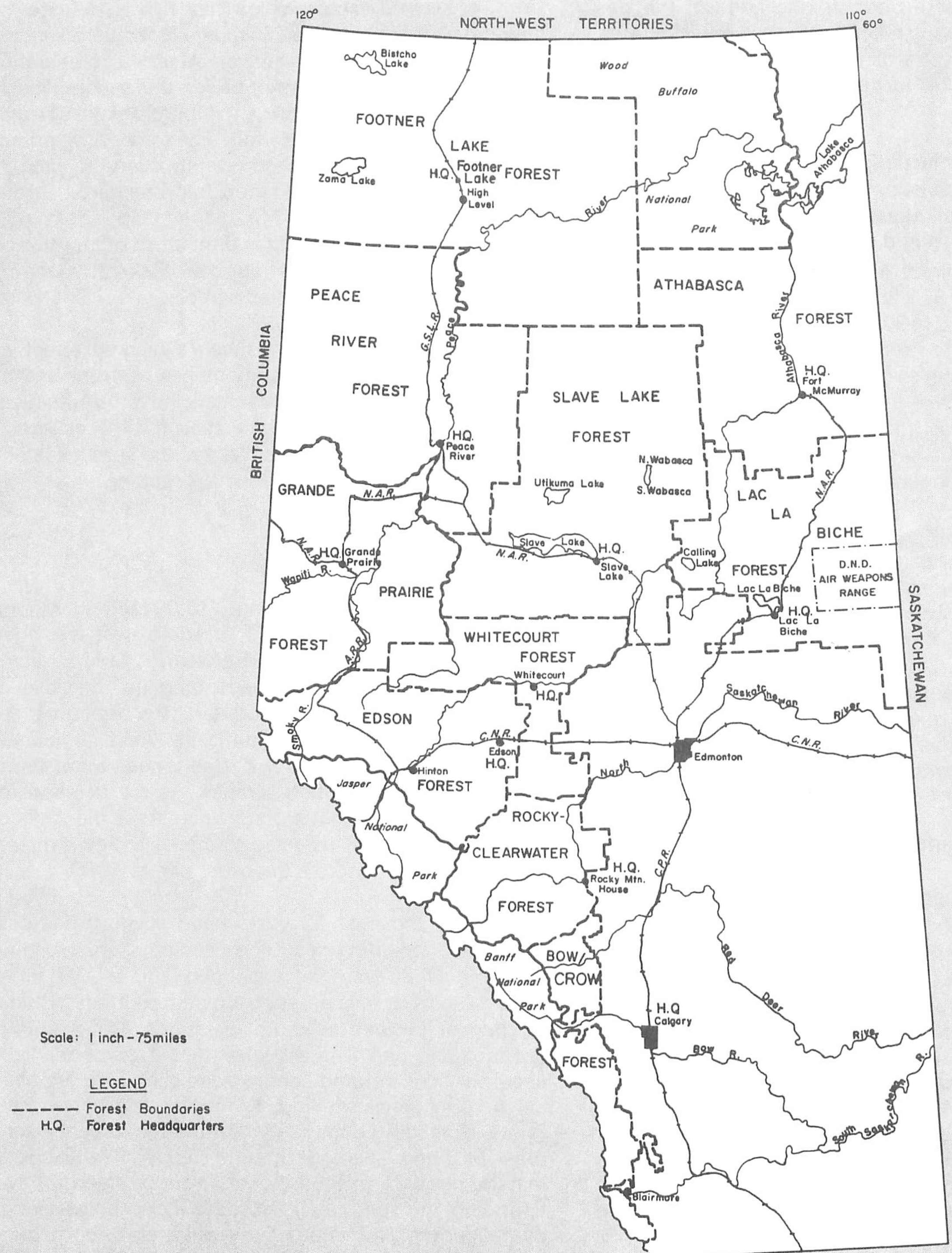

Figure 1. Forests of Alberta, 1973.

successes are therefore poor. If one adds in the deciduous stocking (poplar and aspen) a total of 47% of all projects had 20% or better stocking, which is probably adequate to reestablish the stands which were cut.

Of the 122 projects, 200 acres in size or greater for which data are available, seven were carried out in June and July, 50 in August through October, and 56 between November 1st and the end of March.

Of the 172 direct seeding projects completed between 1960 and 1971 in Alberta for which there are species designations, 130 were seeded with white spruce (76%), 20 were seeded with lodgepole or jack pine (11%), 10 were seeded to a mixture of white spruce and lodgepole pine (5%), and another three projects were seeded to Douglas-fir (2%). The remaining 6% was seeded to other species mixtures such as pruce–Douglas–fir and pine–Douglas-fir.

Between 20,000 and 30,000 viable seeds are commonly spread per acre in direct seeding operations. Germinability has ranged from lows of 20% to highs of 95% varying from project to project and sometimes also from one part of a project to an other when several seedlots were used. Generally, it is current practice to reserve the highest quality seed for container seedling production, medium quality seed for bare root seedling production in nurseries (50 – 70% germinability), and to broadcast the poorest and oldest seed in the direct seeding projects.

CAUSES OF FAILURE

Far too few seeds are seeded per acre in direct seeding operations to expect a large amount of success (40% stocking) with direct seeding. When a mature stand of white spruce in Alberta could produce up to 150 million viable seeds per acre in bumper seed years[2], and when white birch has been reported to be as prolific (Zasada and Gregory 1972), it is apparent that direct seeding intensity should be increased at least by a factor of 3. This is especially true in view of the fact that field germination rarely exceeds 30% of laboratory germination even under optimal conditions. Waldron's (1965) report from Manitoba suggests that 5 million white spruce seeds/acre are possible in good seed years in Manitoba.

[2] Personal observations during the 1968 bumper seed year in the Slave Lake Forest.

A second factor which has had a definite influence on the success or failure of direct seeding operations is the intensity of seedbed preparation coupled with good supervision of the seeding itself. Earliest scarification work in Alberta exposed only 10 – 20% of the mineral soil. By today's standards 40% plus must be exposed evenly over the area to attain the required 40% stocking standard. Strong efforts are being exerted in Alberta to attain 40% mineral soil exposure, but it is difficult to obtain this on sites with heavy debris due to lack of space for overburden between scarified scrapes.

A third factor that has had a marked effect on the success of seeding operations has been the season of application. Figure 2 shows clearly how the influences of scarification exposure and season of seeding influence stocking percentage. Winter and spring seeding is clearly better than summer or fall seeding.

COST CONSIDERATIONS

Scarification costs about $16.00/acre in Alberta (Smyth and Karaim 1972). It used to cost less then $12.00/acre 10 years ago. Between 1 and 2 acres can be scarified per hour depending on the ease of operation. The humus and litter plus most of the A-horizon is removed in scarification and sometimes this creates problems on wet sites where water tends to collect in the scarified scrapes. As the demand for more exposure to mineral soil increases, the cost of scarification can be expected to increase. Few projects achieved more than 25% exposure before 1969.

Over the past 12 years hand seeding has cost $2.39/acre including seed and seeding. Aerial seeding has cost $4.30/acre because two and a half times more seed is spread in such operations than in hand seeding or cyclone seeding operations. Travel time is not included and it is assumed that 2 oz of seed are used per acre in hand seeding and that 5 oz are used per acre in aerial seeding. While the application cost for aerial seeding commonly falls below 75 cents/acre, that for hand seeding often exceeds $1.50/acre. It may be possible to seed 2 acres/hour by hand if travel time is not included; over 150 acres/hour can be seeded by helicopter. The value of the seed has been pegged at $10.00/lb. for white spruce and $12.00/lb. for pine for the full 12-year period.

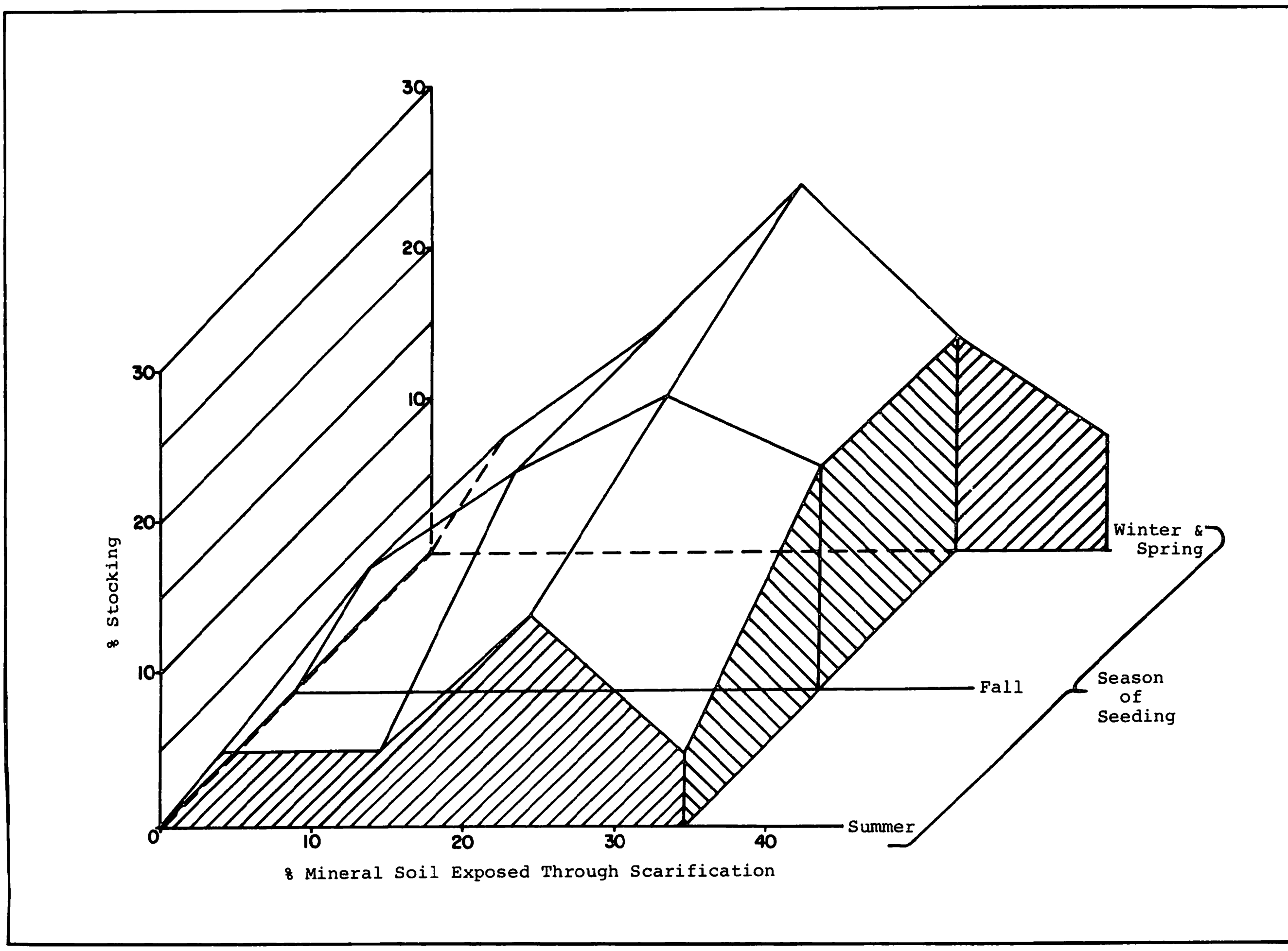

Figure 2. Three dimensional illustration of mineral soil exposure and season of seeding and their influence on stocking to white spruce, based on 122 areas of 200 acres each.

The cost of aerial seeding is variable because it depends on the shape and the size of the area to be seeded. Figure 3 shows a simplified comparison of area size with area shape expressed as the number of turns a helicopter must make to cover the area. Each pedal turn takes 15 sec, each sweep covers 66 feet when the helicopter flies 100 feet above the ground.

DISCUSSION

When seeding is done in winter in Alberta, percent stocking seems to be directly correlated with percent mineral soil exposure up to an exposure of 25%. The drop in stocking above this exposure percentage is probably related to spotty seeding, which does not take advantage of soil exposure, and to the fact that no allowance has been made in the past to seed more heavily when larger areas of mineral soil are exposed. Another reason for this drop may be that some projects with the smallest exposures are the oldest and thus may have had a chance to seed in from adjacent seed sources as well. Scarification from 1968 and 1969 (which is the last year for which data were used for this study of stocking) have had little or no time to seed in from the sides. Also, cut areas have increased markedly in size in white spruce over the years so local seed sources have not been as available as they were in the years between 1960 and 1966.

GUIDELINES FOR FUTURE DIRECT SEEDING IN ALBERTA

Rodent problems in Alberta, where both seeds and seedlings are commonly damaged, are most excessive in the northern part of the province and it would seem that direct seeding in mixed-wood stands north of the 55th parallel are almost certain to lead to failure. Grass and herb competition is also a serious deterrent to plantation success in this area. The first guideline has therefore been implemented: There is to be no seeding to pine or spruce in aspen and poplar stands in northern Alberta until better knowledge and control over rodent problems are available.

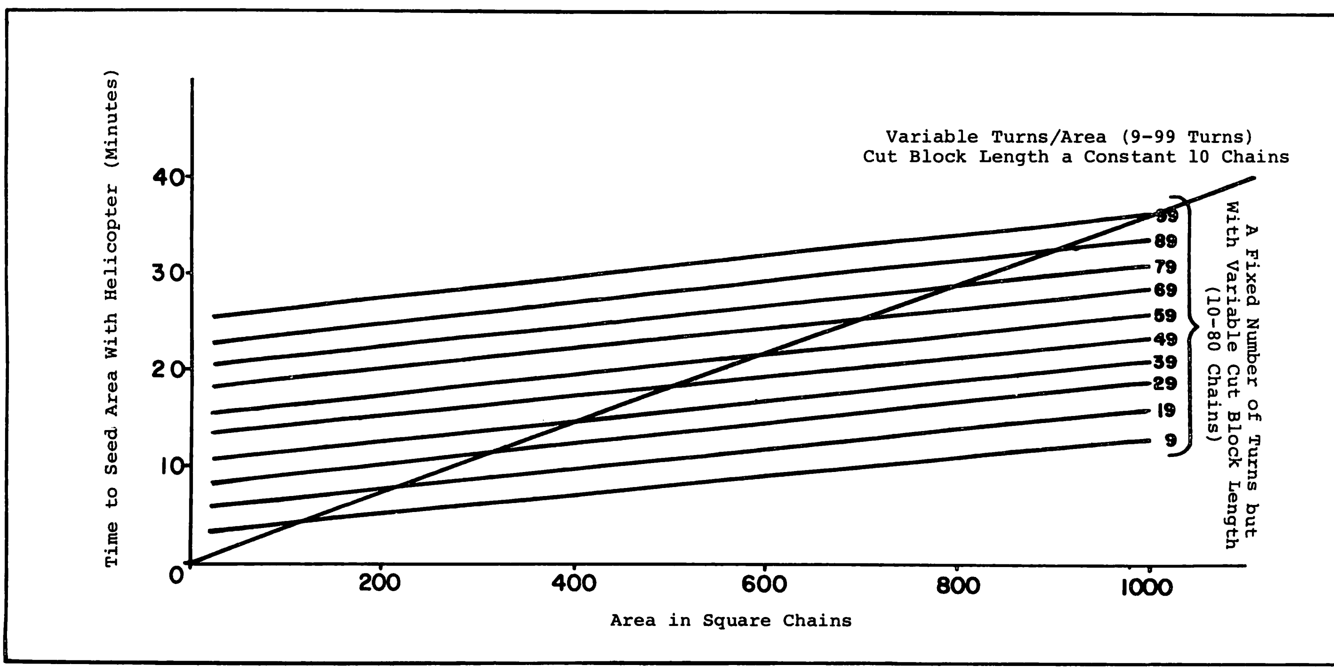

Figure 3. The number of turns a helicopter has to make to seed an area influences the time needed to complete the work.

SECOND. Seeding should be confined to spring and it should be done on fresh snow; the seeds are thus raised above the forest floor where the mice and moles feed. By using snowmobiles and cyclone seeders, one should obtain good seeding results.

THIRD. The amount of seed should be three times or more the amount applied in the past. This is to conform more closely with natural seed fall. This will increase the cost of the initial application from $2.39/acre for hand application to about $4.50/acre, not counting failures and reseeding. Reforestation can therefore be costed as $20.50/acre for seeding and $55.00/acre for planting, both on scarified ground.

FOURTH. Any seeding project that fails within a year should be reseeded immediately to take advantage of the scarification, which is effective for seeding for up to 4 years after treatment. In areas that are lightly scarified, grass and herbs compete with tree seedlings for space, light, water and nutrients soon after the seedbed has been scarified. This kind of built-in check system is not used today, but it should become standard practice in the near future.

FIFTH. Aerial seeding is going to be too expensive compared to cyclone or hand seeding because so much more seed is needed for success. Sixty percent of the seed falls on unreceptive ground in aerial seeding. The difficulty in obtaining enough seed for aerial applications will naturally limit this method in the near future unless different methods of seedbed preparation are applied.

CONCLUSIONS

The information available for Alberta should also be applicable to the other three western provinces of Canada. It appears that winter seeding or early spring seeding is to be preferred over summer or fall seeding. It would also appear that scarification is essential for success and that the degree of success is directly proportional to the degree of mineral soil exposure up to 25%. Above this point, methodology has failed and one can only assume that better methods will lead to better results. This applies to the quality of scarification, the seeding jobs, the amount of seed applied, and the season of application, to name only four important factors.

Scarification and direct seeding in Alberta has been successful only to the extent that practices have permitted. This method of reforestation will be applied at an increasing rate in the future and degrees of success will increase as more and more of the guidelines can be applied.

ACKNOWLEDGEMENT

The Canadian Forestry Service has just completed a survey of scarification and seeding projects in Alberta between 1960 and 1969 inclusive. This paper could not have been completed without the help of C.F.S. Special appreciation is expressed to Mr. H. J. Johnson for initiating and supervising this survey. A report will be published shortly on his work.

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Ground application methods in northeastern United States

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ABSTRACT

A direct sowing technology adapted to the soils, terrain, and vegetation as well as the ecological requirements of the seeded species in the northeastern United States has been developed. Further refinements in technique are desirable to lower costs and to reduce the environmental impact of ground seeding methods.

RÉSUMÉ

Dans le nord-est des U.S.A., on a mis au point une technologie d'ensemencement direct adapté aux sols, à la topographie et la végétation, de même qu'aux caractères écologiques des espèces dont on sème les graines. Il serait préférable que la technique nouvelle soit raffinée en vue de baisser les coûts d'opération et de réduire l'impact sur l'environnement.

INTRODUCTION

Securing adequate new stands of desirable tree species has long been a critical problem for the managers of forests in the northeastern United States. In the past, when natural regeneration was inadequate or of undesirable species, the only reliable choice was to plant nursery grown seedlings. However, the high cost of planting seedlings limited artificial regeneration to only the best and most accessible sites.

During the past decade a concerted effort has been made to develop an efficient direct sowing technology for the Northeast. At first, the seeding methods being practiced successfully in the Southern States (McQuilkin 1965) were tried, often without modification. The results of these attemps were erratic and failures occurred more often than successes (Abbott 1965). Emphasis were then shifted to defining more precisely the requirements and tolerances of the most desirable tree species. A series of experiments sharply defined the biological obstacles to establishment of trees by direct sowing (Smith 1951 ; Abbott 1961 ; Hocker 1961 ; McConkey 1964; Graber 1968).

SEEDING EXPERIMENTS

The results of these studies demonstrated the superiority of a mineral soil seedbed, particularly on the drier sites, and the advantages of partial shading from an existing overstory to provide a microenvironment favorable for germination and seedling survival. It was found that the protective seed coating (endrin-arasan) used successfully, in the southern States, to prevent seed destruction by birds and small mammals, did not give adequate protection under northeastern conditions (Abbott 1961) unless the seed was covered with soil (Graber 1969). Our most recent tests indicate that it may be possible to eliminate the endrin entirely when seeds are buried in a mineral soil seedbed.

Other reasons for the slow development of a sowing technology in the Northeast are found in the nature of the climate, soils, vegetation, and topography. The climate is characterized by long dormand season, and frost heaving of seedlings exposed on mineral soil seedbeds may exceed 75% during the first winter (Graber 1971). Another factor is that much of the soil is stony and the topography tends to be steep and broken, sharply limiting the type of equipment that can be used. And, finally, there is very little open land. A woody growth of shrubs and brushy trees of little commercial value quickly dominate most potential, direct sowing sites, which makes cultural operations difficult.

The goal under this set of circumstances was the development of a reliable and economical direct sowing technique adapted to these conditions and the ecological requirements of our most desirable conifer species, especially eastern white pine. Griffin *et al.* (1965) broadcast red pine and white spruce seed on a site prepared by a hot summer wildfire. Part of the burned area was scarified with a large bulldozer to further improve the seedbed. After 4 years, stocking was adequate for both species on both the burned and the burn plus scarified seedbed. (Griffin, R.H., personal communication).

Abbott (1966) conducted trials culminating in a satisfactory technique for establishing white pine in the understory of sprout hardwood stands. His method consisted of preparing a mineral soil seedbed with a rock-rake equipped bulldozer, then hand seeding in spots or broadcasting the seeds at rates of up to 2 lb. per acre.

DIRECT SEEDING EQUIPMENT

A series of direct seeding experiments in Maine and New Hampshire resulted in the development of a furrow seeder (Fig. 1). The equipment used and modifications required have been described in detail previously (Graber and Thompson 1967). The new furrow-seeder consists of a modified International Harvester beet planter, coupled behind a fireline plow (Sieco C154). The rig is pulled by a small crawler tractor (John Deere 1010). The tractor and fireline plow produced an excellent mineral-soil seedbed at low cost, and worked well on the stony, wooded lands commonly encountered in the Northeast.

Modifications made to the seeder included: the use of an oversized drive wheel and a runner opener with a steel ski on the bottom; a new free-floating mount that allowed the seeder to ride up and over obstacles such as large stones, stumps, or logs; and general reworking and strengthening of the seeder unit at all points of strain (Fig. 2).

Furrow seeding has proved to be an efficient one-pass method well adapted to the stony soils and rough brush terrain of the Northeast (Graber and Thompson 1969).

The furrow seeder can be used to direct seed land at a sustained rate of 1–4 acres per hour of operating time. Costs of these operations have been about one-third that of planting nursery stock on similar sites. Seeds are efficiently used with this equipment, 8,000 to 10,000 viable seeds per acre provide adequate stocking on all but the most difficult sites.

THE FUTURE RESEARCH GOALS

We must develop more efficient ways of direct sowing, but operational efficiency must not be our only objective. We require less destructive, disruptive, and unsightly methods. Ideally our technique should prepare a suitable ecological niche for the desired seedling with a minimum disturbance. The furrow seeding technique described here is a step in this direction and further developments of this and similar systems are desirable. The heavy-handed measures of the past and present where large tractors are used to strip

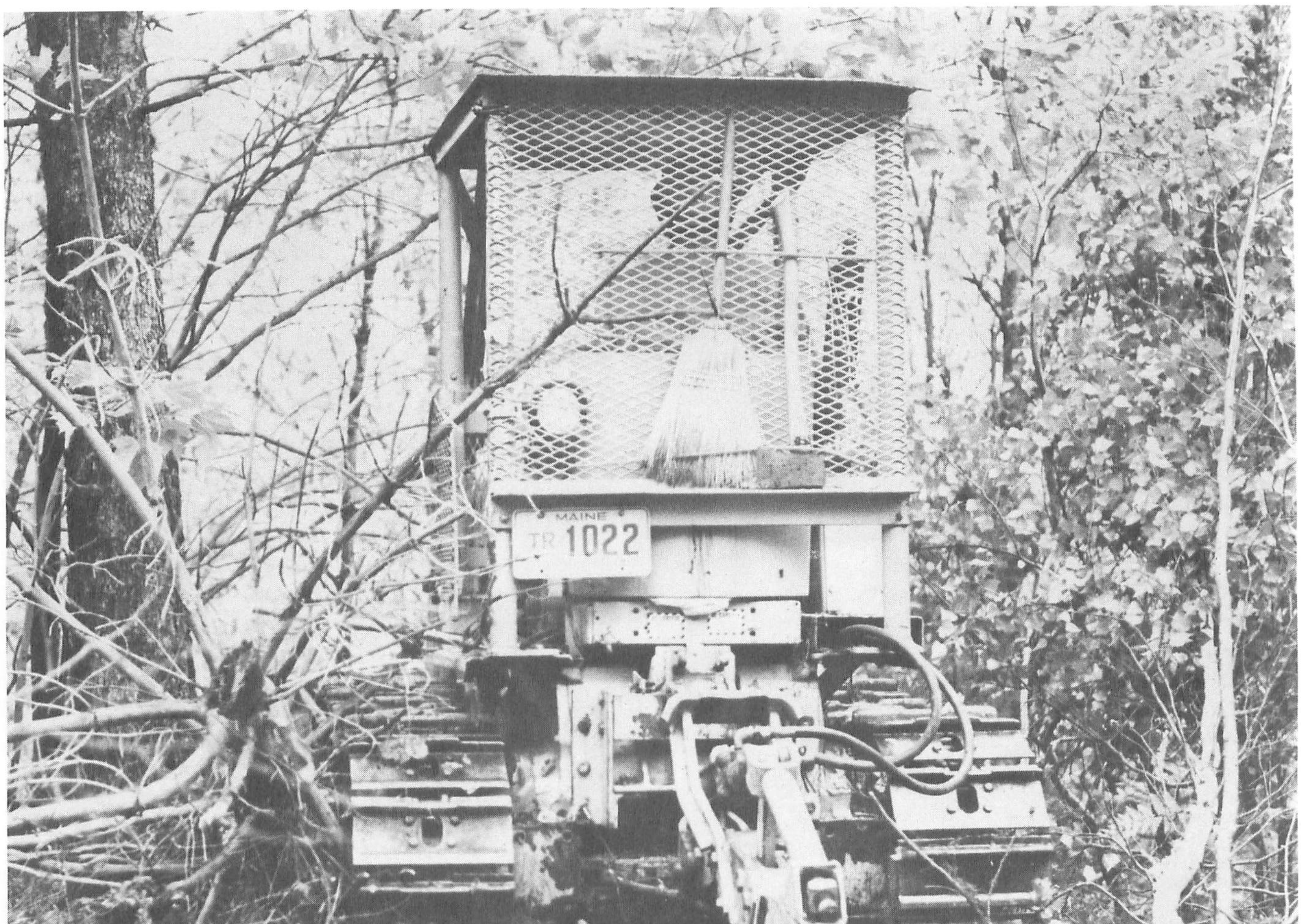

Figure 1. A furrow seeder is operating here in a low-quality sprout hardwood stand. This scrub vegetation will be converted to a thrifty stand of pine at a cost of $10–15 per acre.

Figure 2. A side view of the seeder unit showing heavy steel hitch, vertical pivot, side guards, reinforced seed hopper, and ski.

the vegetation off extensive areas in preparation for direct sowing are not likely to find acceptance in the future. The public's tolerance of devastation in the name of good forest management is at an end in many parts of the country. The challenge of the future, then, is the development of methods and machines with which we can reestablish a forest without visual degradation or even minor injury to fragile forest ecosystems.

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Direct seeding in Ontario

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ABSTRACT

The development and popularity of direct seeding as a method of artificial regeneration in Ontario was due to a two pronged approach by Federal forest researchers and Provincial foresters arising from research on such problems as equipment, site preparation or seed bed requirements, germination requirements, seed and germinant losses of individual species.

There has been an 11 fold increase in seeding in the past decade. Direct seeding in the Boreal Forest Region of Ontario with jack pine accounts for almost 20% of the artificial regeneration and almost 90% of the species sown.

RÉSUMÉ

Le développement et la popularité de l'ensemencement direct comme méthode de régénération artificielle en Ontario fut le résultat du travail conjoint des agents de recherche forestière fédéraux et des forestiers provinciaux. Leurs recherches portèrent sur l'équipement, la préparation de la station ou de la couche à semis, les caractères de la germination, les pertes de graines, germées ou non, pour chaque espèce.

On ensemence 11 fois plus depuis 10 ans. L'ensemencement direct de Pins gris (*Pinus banksiana*) dans la Région forestière boréale en Ontario compte pour près de 20% de toute la régénération artificielle et pour près de 90% des espèces semées.

INTRODUCTION

Interest in direct seeding as a method of artificial regeneration was solely a research activity until the post World War II period. The operational seeding trials attempted in the late forties and early fifties on areas burned by wildfires failed for reasons unrecorded at both District and Head office level.

In the decade that spans the period from 1956 to 1965, the practical application of direct seeding was established and accepted through the development of various hand operated spot seeding devices in the form of the "walking stick", "oil can seeders", "shakers" of various sorts, and lawn grass seeders, as described by Scott (1966) and used on manually or mechanically prepared seedbeds. These manual seeding devices have been abandoned except for experimental purposes because they are labor intensive. The promise of seeding success indicated by the manual seed disseminators and the continued effort on the part of Federal and Provincial research branches led to the purchase of the Swedish Forestry Institute mechanical scalper and seeder in 1968 and the Brackekultivatorn in 1970 (Parker 1972). Success with the manual tree seed disseminators was also responsible for the development of the new site-preparation and seeding equipment (Horton and Flowers 1965). According to Brown (1969) one third of the total seeding and almost all of the ground seeding since 1966 has been done with various mechanical devices including motorized tree seed broad casters.

Seeding as a method of artificial regeneration has increased 11 fold in the 10-year period from 1962 to 1971. The steady gain from 1986 acres to 22161 acres outlined in Table 1, is primarily due to the growing popularity of aerial seeding which is not labor intensive relative to ground methods.

Table 1. Method of seed application in acres.

Year	Aerial	Ground	Total
1956		80	80
1957		214	214
1958		1070	1070
1959		366	366
1960		189	189
1961		92	92
1962	1341	645	1986
1963	1122	2626	3748
1964	2632	2216	4848
1965	6464	738	7202
1966	6697	2226	8923
1967	8541	2594	11135
1968	6821	2797	9618
1969	8923	2233	11156
1970	15934	5377	21311
1971 [a]	16861	5500	22161
1972 [a]	15510	5200	20710

[a] Preliminary information.

GROUND SEEDING EQUIPMENT

The mechanical scalper and seeders used in Ontario are the S.F.I. and the Brackekultivatorn. Both machines can prepare and seed approximately 1000 scalps per acre with a production rate of 2 to 3 acres per hour (Parker 1972), and both can be towed safely by a 190 d.b.h.p. wheeled skidder equipped with tire chains.

For row seeding, the modified corn seeder (Horton and Flowers 1965) has been replaced by the seeding cone developed by J. Flowers in 1970. This seeder can be attached to the back of a barrel scarifier to combine site preparation and seeding operations. Because the corn seeder and the seeding cone require heavy tractors as motive power, production rates are limited by the speed of the tractor and average from 1 to 2 acres per hour.

The motorized tree seed broadcaster (Brown 1969), first used in 1966 and modified in 1972, is capable of seeding up to 60 acres per hour under ideal snow conditions.

AERIAL SEEDING EQUIPMENT

The revolution in seeding technique was initiated in 1962 with the invention of the airborne tree seed broadcaster developed by the Research Branch of the Ontario Department of Lands and Forests at Maple. This seeder, first mounted on a helicopter, has been and continues to be the only aerial seed applicator used in Ontario (Lynn unpublished; Scott unpublished; Scott 1966; Spencer 1965). In 1968 it was mounted on a fixed winged aircraft which reduced seeding costs. Since 1968, almost all aerial seeding has been done from fixed winged aircraft.

SITE PREPARATION OR SEEDBDED REQUIREMENTS

The authors of various reports and publications are unanimous in their agreement that adequate site preparation for seeding requires mineral soil exposure (Bockhoven 1964; Brown unpublished; Horton and Wang 1965; Jarvis 1966; Lynn unpublished; Scott 1966; Spencer 1965). The intensity of site preparation reported varies with the writer and nature of the seeding operation carried out.

The presence or absence of seedlings was reported to be directly proportional to mineral soil exposure in row seeding. Most seedlings occurred on mineral soil, few on mineral soil mixed with humus and none on deep humus (Horton and Flowers 1965).

Stocking and seedling success of jack pine was rated as best on mineral soil, next best on mixed mineral soil and duff and absent on undisturbed duff by Jarvis (1966) in Manitoba. Jarvis further rated his seedling success with jack pine as best on mechanically scarified ground, next best on scalps produced manually and poorest on undisturbed soil. He also rated stocking and seedling success for the same intensity of site preparation by species as best–jack pine, next best–black spruce, poorest–white spruce. The Cochrane District project records substantiate these findings for black and white spruce. Brown (unpublished) noted the best seedling success with mechanical scarification in rows, spots on mechanical scarified rows as next best, deep mechanical scalps as poor, and total scarification and light burn as very poor.

Seeding projects with jack pine and black spruce in the Kenora and White River districts show a similar decrease in stocking for row and scalp seeded areas regardless of the season sown or the method of seed dissemination, except for mechanically scalped and seeded areas with the S.F.I. and Brackekultivatorn.

The records for these projects appear to indicate that seeding success with jack pine and black spruce was almost always less than 30% stocked regardless of the season sown or the method of seed dissemination on mechanically scarified areas for seed sown immediately following or within a month of site preparation; areas seeded 1 or 2 months after site preparation had stockings of 69% to 85% due to a slight packing of the seed bed.

In Sault Ste. Marie District the degree of success with jack pine appears to be related to the length of time between site preparation and seeding. The highest stockings 68% and 78% were recorded for areas seeded within 1 year of site preparation and the poorest stocking, 18% and 32%, on areas sown 1 or 2 years after site preparation.

GERMINATION REQUIREMENTS

In forestry, the germination of the seed and the survival of the germinants is affected by the local weather, the latitude and the season of the year that the seed was sown. In agronomy the parimeters of sowing are worked out for these conditions by species and by genus, e.g. winter wheat is sown in the fall and spring wheat in the spring. Could we not, therefore, have a different sowing period for black and white spruce?

To determine the best seeding period for jack pine, Brown (unpublished) carried out a sowing experiment in the Swastika District during the growing season of 1967. This experiment indicated that although jack pine seed germinates throughout the growing season, there appeared to be two major germination periods, one immediately following a spring drought and the other immediately following a summer drought. Vincent (1966), for the Cochrane area noted a major germination period for black spruce after a summer drought period. Lynn (unpublished) noted delayed germination of summer sown jack pine in the Geraldton District. Page (unpublished) noted 9.3% higher stocking for spring sown jack pine over fall sown jack pine in the Chapleau District.

The seeding records of the White River District also indicate higher germination for spring sown jack pine and black spruce regardless of the dissemination method. However, survival dropped from 73% and 85% stocking in the first year to 16% stocking in the second year due to loose soil conditions at the time of sowing and the subsequent flooding of the seedlings.

Two sterile periods have also been noted by Brown (unpublished) which coincide with the spring and summer drought periods. No germination has been noted with jack pine during these periods. Germination and survival was highest with jack pine followed by red pine with white pine being lowest. A higher success was noted with black spruce than with white spruce. A higher success was noted with pines than with spruces (Scott 1960; Bockhoven 1964; Horton and Flowers 1965; Jarvis 1966).

The Cochrane District records indicate better success with black spruce than with white spruce for spring sowing under the same conditions on similar sites.

Brown (unpublished) noted a decrease in the number of germinants with an increase in time between sowing and the start of germination, and advocates spring sowing of jack pine and black spruce for maximum germination in a short period of time although results with late fall sowing appears to be about the same.

Monk (1965) noted a decrease in the germination of Scots pine sown during the growing season in Norway. Generally the highest germination and survival has been obtained with spring sown seed and poorest with early fall sown seed.

QUANTITY OF SOWING RATES

The amount of seed required to produce a fully stocked stand is not yet known although it has been estimated by Lynn (unpublished) that approximately 20,000 to 30,000 jack pine and 100,000 to 200,000 black spruce seed are required to produce a fully stocked stand with broadcast seeding after a 40% mechanical scarification.

Spencer (1965) suggests that 11 jack pine seeds are required to produce a single germinant and 22 seeds to produce a survivor.

The assessment and survival of jack pine on project 479–01–67 in the Swastika District would indicate that five jack pine seeds will produce a survivor to the age of 3 years after broadcast sowing in scarified rows. No germinants or survivors were found between the scarified rows even though 80% of the 20,000 seeds sown per acre fell on these areas.

SEED AND GERMINANT LOSSES

The largest cause of seed loss has been dissemination on to a poor or non-existent seedbed as noted with row scarification followed by broadcast seeding. The quantity of seed lost is directly proportional with the degree or percentage of scarification. Only 20% of the seed broadcast will land on mineral soil at 20% scarification rate of the area. Jarvis (1966) noted the absence of germinants on undisturbed duff and Lynn (unpublished) estimated that in the Geraldton District 3 seeds will produce a seedling on sites where the mineral soil is 40% exposed. Brown (unpublished) and the Sault Ste. Marie records and the Thunder Bay trial with the motorized tree seed broadcaster indicate poor germination with jack pine on hard packed sand and clay.

Another major cause of seed losses has been decomposition (Brown unpublished) probably due to to burying and to the failure of the seed to germinate by the end of the second growing season. Horton and McCormack (1962) noted that a quarter inch of soil cover is the best for optimum germination although germination will occur up to the depth of one inch. Mechanical erosion (Brown unpublished) may account for 20% of the seed losses regardless of the degree of slope.

The largest losses of germinants have been attributed to summer dessication (Brown unpublished) probably caused by high temperatures near the soil surface. One third of spring germinants are lost to desiccation (Brown unpublished) during the summer drought period. The heavy germinant losses of jack pine and spruce in the White River District during the first year appear to support this theory.

The second largest loss of germinants was attributed (Brown unpublished) to smothering by debris on deep scalps caused by flooding brought about by summer rains.

Winter kill (Brown unpublished) may cause the loss of half of the late summer germinants in jack pine. Vincent (1966) suspected the same for black spruce in the Cochrane District. Some germinant losses in the Thunder Bay District were attributed to grasshoppers. Losses to sweet fern blister rust and *Scleroderris lagerbergii* although noted, have not been assessed to date.

Site preparation for the survival and performance of the germinants have been indicated for white pine (Horton and Wong 1965), white spruce (Horton and Flowers 1965), and for jack pine (Brown unpublished).

PERFORMANCE OF SEEDED STANDS

As the number of trees per acre may not convey a true picture of stand condition, the stocking as described by the 1959 report of the committee of the Ontario Department of Lands and Forests on the standards of regeneration stocking (Anon. 1959) with its base of 1000 trees per acre at 100% stocking has been used as a measure of comparison for the purpose of this report. However, to give a means of expression to the stocking figures, the height data obtained from the Forest Districts of the Province have been plotted (Fig. 1) for comparison with the performance of bareroot nursery and tube seedling stock in the Swastika District.

This graph appears to indicate a slower start for seeded and container stock compared to that of the 2-year-old bareroot stock at the time of planting. However, seeded and container stock appear to overtake and surpass the performance of bareroot nursery stock in the 5th year after planting.

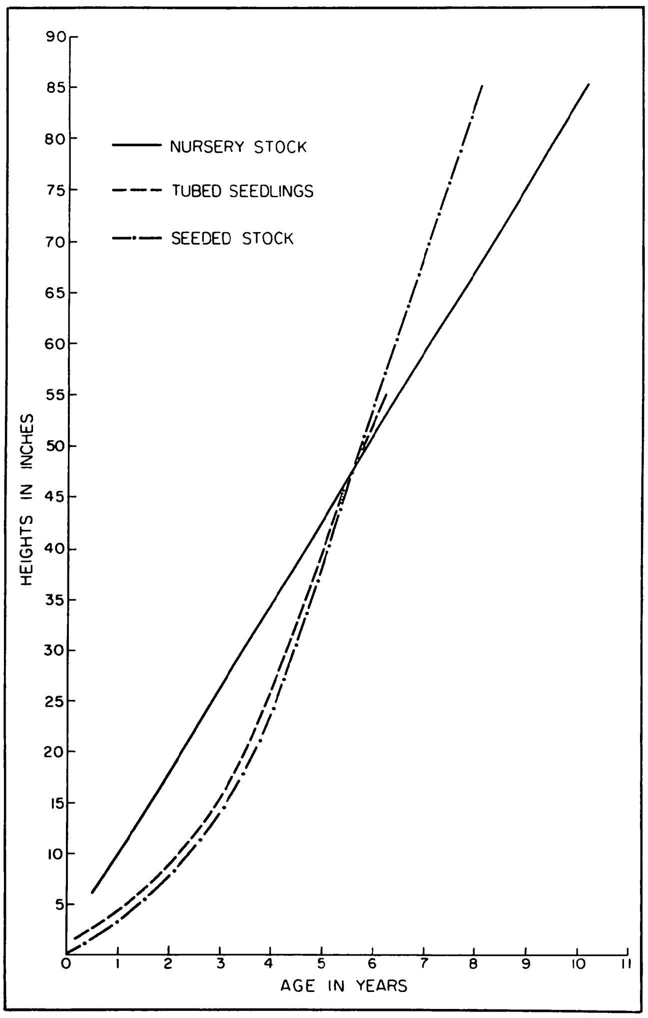

Figure 1. Age-height relationships of jack pine stands by origin.

THE FUTURE OF SEEDING IN ONTARIO

Seeding accounts for nearly 20% of the artificial regeneration program of the Province. Practically all operational seeding takes place in the Boreal Forest Region. The seeding success with jack pine has increased the popularity of this species to where it now accounts for almost 90% of the area seeded. Black spruce is the next most popular species with white spruce and white pine as close contenders.

A breakthrough in the technique of black and white spruce seeding in the next 10 year period is urgently required for the regeneration of cutover areas formerly occupied by these species. Such a breakthrough would raise the importance of seeding as a method of artificial regeneration in the Boreal Forest Region of the Province from the present 20% to at least 40% of the total regeneration effort.

CONCLUSIONS

Mineral soil is required for germination of most species of seed and for the establishment of stands of seeded origin.

The exposure of mineral soil should range from 20% to 40% of the total area treated.

Site preparation in strip is more desirable from the site and germinant protection point of view than other methods.

Severely scarified mineral soil is also a poor seed bed.

Hard weather-packed mineral soil is as poor a seed bed as burned and/or undisturbed duff.

Burned duff and undisturbed duff is a very poor seed bed.

Seed requires a ¼ inch of soil cover for best germination.

Seeding on scarified areas should be carried out not earlier than one month and not later than 6 months after scarification for best results.

Spring sowing of jack pine and black spruce is superior to early fall sowing.

Spring sowing should take place just before the snow leaves the ground.

Fall sowing should take place as late in the season as possible.

Summer sowing produces irregular germination.

The germination of seed shows a general decline with the advancement of the growing season.

Germination occurs almost throughout the growing season.

There are two major germination periods during the growing season one each following the spring and summer drought periods.

Only 1/3 of the spring germinants are lost to desiccation during the summer drought period as opposed to ½ the late fall germinants lost to winter kill.

Approximately 10 seeds are required to produce a single germinant after broadcast sowing.

Approximately five seeds are required to produce a single survivor in row seeding.

Spot and row seeding succeeds best if carried out in early spring or late fall in Northeastern Ontario.

The higher degree of success in Northwestern Ontario is probably due to weather conditions more condusive to the germination of the seed and to the survival of the germinants.

ACKNOWLEDGEMENT

The contribution to this article by R.J. Lynn, G. Page and J.D. Scott, Ontario Ministry of Natural Resources, through unpublished reports is greatly appreciated, as is the contribution of the many Unit Foresters who faithfully answered a direct seedling questionnaire and collected data on the seedling age/height relationship.

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Aerial seeding by fixed-wing aircraft

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ABSTRACT

Factors affecting a successful aerial seeding operation from the seeding contractor's point of view are discussed. The importance of preplanning are emphasized in terms of tendering, equipment, preparation of seed and marking flight-paths, and items that affect the cost of a seeding operation.

RÉSUMÉ

L'auteur, en tant qu'entrepreneur en ensemencement, discute les facteurs qui conditionnent le succès d'ensemencements aériens. La préplanification importe beaucoup en termes de soumissions, équipement, préparation des graines, cartographie des trajets d'avion et facteurs du coût d'opération.

INTRODUCTION

The Ontario Ministry of Natural Resources undertakes a comprehensive regeneration silviculture program in order to ensure that cut-over areas are promptly and adequately stocked with commercially important tree species. One technique which is being applied on an increasing scale is direct seeding and about 75% is carried out from the air using both fixed-wing aircraft and helicopters.

Over the past 6 years General Airspray Limited has acquired considerable experience in aerial seeding from fixed-wing aircraft. As much of today's aerial seeding is undertaken by tender and contract, an appreciation and understanding of the contractor's seeding operations should benefit those responsible for direct seeding operations. For convenience, General Airspray's experiences are presented under the following headings: aircraft, seeding unit, seed, tender and operational procedures.

EQUIPMENT

Aircraft

The aircraft used by General Airspray Limited in forest seeding operations is a PA-18A, more commonly known as a Super Cub. Developed by Piper for crop dusting and spraying, it is a fixed, high wing aircraft with a 135 hp Lycoming engine. A very economical, flexible and dependable aircraft to operate, the Super Cub uses only 5 gal of fuel per hour when seeding and 6½ gal per hour when cruising cross country at 75% power. With its two wing fuel tanks, the Super Cub has an endurance of 5 hours plus a 45 minute reserve. More simply, this means that the Super Cub can fly out approximately 100 miles and seed for 2 – 3 hours, covering approximately 200 – 1500 acres, depending on the number, size and shape of the areas to be seeded.

The aircraft will operate with ease from 700 – 1000 feet of runway; it lands at 38 mph. Often, suitable logging haul roads are readily available, and they need only be brushed out on each side for approximately 25 feet. When scarifying cut-overs, foresters should bear in mind that a few hours work with a bulldozer, involving road improvement for use as a loading strip, will not only bring savings in aerial seeding, but also in future treatments, such as chemical release, fertilizing, and perhaps chemical thinning or insect and disease protection. When one realizes that there may be several applications of each treatment, the investment can be well worthwhile.

Communications

As added insurance for an efficient and acceptable treatment, General Airspray Limited has undertaken to purchase radio equipment consistent with the systems used by the Ontario Ministry of Natural Resources. This not only allows "on the job" communications with ground personnel, but permits advance notice to the various field offices when ferrying the aircraft and seeder.

Seeding Unit

The basic seeding unit is known as the Brohm Seeder Mark 3. It is the latest, revised model developed by Mr. Howard Brohm of the Ministry of Natural Resources, Mechanical Research, Maple, Ontario.

Initially designed in the 1960's for rotary-wing aircraft (helicopters) the Brohm seeder has since been modified and adapted for use in fixed-wing aircraft. During this period of modification and adaptation, General Airspray Limited worked directly with Mechanical Research and were instrumental in initiating several important modifications to the basic seeding unit.

Simply, the seeder consists of a seed tank or "hopper", to the bottom of which is affixed a grain type auger that moves seed to a revolving slinger. This slinger is basically a central hub with four protruding, horizontal, plastic tubes, from which the seed is cast from beneath the moving aircraft. The seed auger is powered by a mechanical drive from an electric motor, which also provides a constant speed, through belt-drive, to the slinger.

The speed of the seed auger can be varied, to control seed output, and hence number of seeds per acre. The auger speed is monitored on a tachometer.

The slinger rotation is maintained at a constant 1,000 revolutions per minute. Tests have shown that increasing the slinger rotation beyond 1,000 rpm, to increase the width of swath, has resulted in reducing the viability of the seed.

Ownership

It has been the experience of General Airspray Limited that it is best for the contractor to own his own equipment (including spare parts). The reasons for this are obvious. The condition of contractor-owned equipment, on which his livlihood and in fact life may depend, is more likely to be fault-free and hence perform better. The result is a more satisfactory treatment for everyone. This principle particularly applies to radios and seeding units.

SEED

In contract forest seeding operations by General Airspray Limited for the Ministry of Natural Resources, the seed is provided by the Ministry. Requisitioned by the individual unit foresters, the seed is then supplied to the contractor. Using the Brohm seeder and the Super Cub aircraft two drums of seed (approximately 120 lb.) can be carried.

Both treated and untreated seed can be used. However, it has been found that treated seed augers more slowly, and hence requires faster auger speed to achieve the same seed per acre output as untreated seed of the same species. Some of these augering differences between treated and untreated seed seem to have been overcome in recent years at the Ministry of Natural Resources Nurseries, where better treatments for seed have been applied.

TENDERING

All contract seeding work done by General Airspray Limited for the Ministry of Natural Resources has generally been tendered.

As commonly known, tendering can provide problems for everyone, but many can be eliminated, for the contractor at least, by employing the following in any seeding tenders:

1. Tender as early as possible.
2. For best prices, tender in as large amounts as possible, combining several individual projects, or management units or perhaps even districts within a region. This effectively removes ferrying costs for aircraft and seeding unit from the contractor's home base.
3. After November 15th, seeding costs can be more expensive, as weather becomes very unreliable and "down-time" adds to individual project costs. However, the chances of a snowfall protecting seed against rodents and birds is greater then.
   Aerial Seeding has been done in the favorable weather of the late spring, but there have been reports of seed being blown away, and hence poorly scattered by strong winds over the crusty snow. Conversely, there have been reports that the combination of bright sun and dark seeds on snow has caused the seeds to melt into the snow and hence be protected from wind and rodents. There is obviously much to learn yet.
4. Most important for the contractor are good maps of the areas to be treated. There should be a "cross-country" map giving the generalized locations of the areas, and then detailed maps of each individual area, preferably at a scale of 20 chains per inch (4 inches per mile). For the latter, current aerial photographs are of even greater help to the contractor.

OPERATIONAL PROCEDURES

Calibration

Essentially, "calibrating" refers to adjusting the aircraft and seeding unit to consistently cast out the required number of seeds per acre.

As an example in "calibrating":

1. Aircraft speed – 80 mph.
2. Proposed swath width of seeds – 75 feet.
3. Therefore acreage covered per minute of flight is $\frac{80 \times 5{,}280}{60} \times \frac{75}{43{,}560}$ or approximately 12 acres/minute.
4. Viable seeds per ounce – 8,000 (nursery information supplied with seed).
5. Desired coverage – 20,000 seeds per acre.
6. Therefore weight of seed per acre is $\frac{20{,}000}{8{,}000} = 2\text{-}\frac{1}{2}$ oz of seed per acre.
7. Therefore, seeding unit must emit 2-½ x 12 acres of seed per minute of aircraft flight to give required 20,000 seeds per acre coverage on the 12 acres of area covered per minute of aircraft flight.
8. By putting the seeding apparatus in action, one can collect the cast seed for a known time interval (15 seconds) and then weight it (7-½ oz) to check the seeding unit calibration.

With the seeding unit as employed by General Airspray Limited, there can be greater ease in tailoring treatments to specific areas. The unit forester need only tell the pilot, in advance, of the treatment that he requires on any specific area (i.e., the number of seeds per acre). Prior to take-off, the pilot need only calibrate the seeding unit for each specific treatment requested and note the respective rpm on the tachometer. During flight, when moving between treatment areas, the pilot need only adjust the speed of the spinning auger to insure proper seed volume displacement. All of this can be accomplished without landing, to make any external adjustments to the seeding unit.

Seeding Procedures

Prior to actually seeding an area, General Airspray Limited pilots use the detailed maps provided by unit foresters to familiarize themselves with the terrain to be treated.

Generally speaking, in progressively covering the cut-over area with 75 foot wide swaths, the pilot will normally fly straight lines parallel to the longitudinal axis of the treatment area. This procedure has long been used in highly successful forestry and agricultural insect, disease and fertilizing operations.

The flying altitude is approximately 75 feet above the ground and the aircraft speed is about 80 mph. The pilot makes considerable use of a "directional gyro compass" in maintaining straight and parallel flight lines over long distances. Many aircraft do not have this feature. As a further aid to insuring proper seed coverage of the area, seeding operations are conducted under less than 5 mph of wind.

Small areas (100 acres or less) are easily treated without help of any form of ground control, much as small fields of agricultural crops would be sprayed or dusted. However, larger acreages are better treated when some type of visual ground aids are used. These visual aids can be of different forms, but the simple and easy to construct, florescent "flag" on a pole is as satisfactory a method of ground control as any.

The most important aspect in flagging for the seeding aircraft, is to pre-determine the location of the various "flaggers", i.e. the personnel who will progressively move the fluorescent markers across the area to be seeded as the seeding aircraft flies the new visible swaths. Pre-marking the required locations of the "flaggers" can be easily accomplished with flagging tape and a tape measure. There is no doubt that "flagging" will improve the distribution of seeds on any seeding project.

As a check on the number of seeds per acre being dispersed, it is a simple matter to place several tarpaulins of known dimensions in the area prior to treatment to trap falling seed for counting. General Airspray Limited encourages unit foresters to do this, as a confirmation of correct treatment, and of proper equipment operation.

As for the minimum size of an area that can be economically treated, it is felt that any area that a unit forester considers to be large enough to be economically regenerated and brought to maturity, is more than adequate for aerial seeding. Actually, the minimum seeding area for a contractor's purposes would be considerably smaller than any sufficient by large for the Ministry's purposes.

When seeding in cold weather, and especially when using treated seed, General Airspray Limited believes in pre-heating all equipment prior to use. Additionally, aircraft engine heat has been directed into the seed auger, where the seed enters the sling. This prevents "clogging" of the apparatus due to sticky or cold seed massing together during the actual seeding operation.

Maintenance

On any seeding project, General Airspray Limited has always had a maintenance vehicle accompany the seeding aircraft. Not only does this vehicle provide accommodations for the seeding crew, but it also serves as an excellent field base for servicing both the aircraft and seeding unit. Concerning the latter, a complete second unit is provided on all seeding projects, to eliminate loss of any favorable seeding weather, and reduce "down-time" costs.

AERIAL SEEDING COSTS

As planners and budgeters of silvicultural projects, foresters are well aware of indirect costs attributable to "overhead". The following list is an attempt to give some idea of the types of costs encountered by General Airspray Limited in a normal aerial seeding treatment:

1. Initial aircraft investment	$10,000.00
2. Initial seeding unit investment	3,000.00
3. Aircraft depreciation	
4. Aircraft upkeep	
– re-fabric a/c every 10 years	3,000.00
– complete engine overhaul – at 1200 hours	2,500.00
– regular engine checks	
– "top" engine overhaul at 600 – 700 hours	1,000.00
5. Equipment storage	$25.00/month
6. If aircraft is leased then it requires re-wiring and a 50 amp generator.	
7. Paperwork and office costs.	
8. ¾-ton truck and camper costs for equipment servicing, maintenance and room and board on job site.	
9. Aircraft gas and oil on job site and in ferrying.	
10. Combination back-up pilot and maintenance man wages.	
11. Aircraft ferrying costs.	
12. Landing fees.	
13. Aircraft and seeding unit maintenance costs on job site.	
14. Pilot costs.	
15. Insurance costs	$640.00/year
16. Licence fees	10.00/year
17. Costs due to poor weather.	
18. Costs due to distance of land strip from job site.	
19. Size of treatment area; the larger, the cheaper.	

Since General Airspray Limited commenced seeding operations in 1968 (5 years ago), we have treated over 38,000 acres, mostly in Ontario but some in Quebec. We have seeded areas as small as 50 acres, and as large as 2,600 acres. Costs per acre presently range from 75c to 90c per acre.

Aerial seeding of spruce in Maine[1]

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ABSTRACT

A 346-acre forest tract in Township 6 N.D., Washington County, Maine burned over by a wildfire in June 1965 was aerially seeded in October 1966 to white spruce (*Picea glauca* (Moench) Voss.) at the rate of 0.681 pounds (76,621 viable seed) per acre with a Brohm aerial seeder mounted in a 47D-1 Bell helicopter. A regeneration survey in August 1967 indicated an average of 2,826 ± 8,719 white spruce seedlings per acre with 72% stocking on a milacre basis. By the close of the sixth growing season in August 1972, seedling mortality had reduced the average number of seedlings per acre on the burn to 1,131 ± 1,977 with 54% stocking on a 2-milacre basis. However, four adequately stocked areas could be delineated on a map of the burn. Over these four areas, accounting in aggregate for approximately 51% of the total acreage of the burn, the estimated average number of seedlings per acre was 2,020 ± 2,478 with 87% stocking on a 2-milacre basis. The remainder of the burn having an average of 237 ± 498 white spruce seedlings per acre with 30% stocking on a 2-milacre basis was only partially stocked in August 1972.

RÉSUMÉ

Une région forestière de 346 acres située dans la Commune 6 N.D., Comté de Washington (Maine) et qui avait été brûlée en juin 1965 par un incendie hors contrôle, était ensemencée par avion au mois d'octobre 1966 en Epinette blanche [*Picea glauca* (Moench) Voss.] à raison de 0.681 livres (76,621 graines viables) à l'acre, au moyen d'un semoir aérien Brohm monté sur un hélicoptère Bell 47D-1. Selon un relevé de régénération effectué en août 1967, il y avait une moyenne de 2,826 ± 8,719 semis d'Epinette blanche à l'acre avec une densité de 72% sur base d'un milliacre. Au terme de la sixième saison de végétation, en août 1972, le chiffre moyen des semis sur le brûlis se trouvait par suite de mortalité réduit à 1,131 ± 1,977 à l'acre sur base de 2 milliacres. Toutefois, on pouvait distinguer quatre aires adéquatement boisées sur une carte du brûlis. Sur ces quatre aires réprésentant 51% de la superficie totale du brûlis, le nombre moyen de semis à l'acre était estimé à 2,020 ± 2,478 avec une densité de 87% sur base de 2 milliacres. Accusant une moyenne de 237 ± 498

[1] This paper reports a study conducted while the junior author was a Graduate Research Assistant in the School of Forest Resources, University of Maine and is based in part on a portion of a thesis submitted by him in partial fulfillment of the requirements for the degree of Master of Science.

semis d'Epinette blanche à l'acre avec 30% de densité sur base de 2 milliacres, le reste du brûlis était regarni en août 1972.

INTRODUCTION

Aerial seeding of forest land in Maine was first tried in an effort to develop a method of rapidly reforesting extensive areas following the devastating forest fires that swept through the State in October 1947. In late February 1948, a gravity-fed seed hopper mounted in a U.S. Navy biplane trainer was used to sow eastern white pine (*Pinus strobus* L.) seed mixed with sawdust on some 2,320 acres of burned-over land on U.S. Forest Service holdings in York County, Maine (Westveld, 1949). Seeding rates of 4,000 and 8,000 white pine seeds per acre on ground covered with a 2-foot mantle of snow resulted at the end of the first growing season in stockings per acre of 1,325 and 2,475 seedlings respectively on moderately-burned sites and 25 and 75 seedlings respectively on severely-burned sites. Corresponding figures for the percent of stocked quadrats were 53 and 73 on moderately-burned sites and 3 and 15 on severely-burned sites.

In early March 1948, the U.S. Navy biplane trainer was used again to sow white pine seed on 400 acres on St. Regis Paper Company holdings in Washington County, Maine which was also burned in 1947. A seeding rate of 5,000 white pine seeds per acre resulted in a stocking of approximately 175 seedlings per acre in October 1948 (Westveld 1949). Re-examination in November 1949 of 120 milacre plots, which had been established to test the effectiveness of the aerial seeding, found air-sown plots had no more white pine seedlings than unsown check plots and it was concluded that the aerial seeding had failed (Hart 1954). Presumably the aerial seedings in York County were also either failures or only moderately successful for no more attempts to reforest land by aerial seeding was apparently made in Maine until 1966.

In 1966, the Maine Forestry Department, the Georgia-Pacific Corporation, and the Maine Life Sciences and Agricultural Experiment Station collaborated in the aerial seeding of a 346-acre burned-over area on Georgia-Pacific holdings located along the western shore of West Grand Lake in Township 6 N.D., Washington County, Maine.

DESCRIPTION OF AREA BURNED

The burned area was on rolling terrain 300–400 feet above sea level. Three, sandy-loam soil types, each occupying about one-third of the area, and each derived from a till whose parent material was a granite-gneiss, were present: Hermon, extremely stony and excessively drained, covered hillsides having slopes up to 45%; Waumbek, very stony and moderately-well drained, occupied relatively level upland sites having slopes of less than 15%; and Leicester, very stony and poorly drained, on lowland sites with slopes of less than 8%.

Diameter-limit cutting in 1960–61 removed all spruce (*Picea* sp.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.) greater than 8 inches d.b.h., and all balsam fir (*Abies balsamea* (L.) Mill.) greater than 6 inches d.b.h., from the area. Subsequent to the diameter-limit cutting, immature spruce-fir stands occupied 260 acres; mixed-growth stands, 66 acres; hardwood stands, 9 acres; and marshland, 11 acres.

In June 1965, a wildfire originating from a lightning strike in a dead tree located some 65 chains west of West Grand Lake burned to the lake shore. This area was classified in the fall of 1966 on the basis of intensity of burn as: severely burned, moderately burned, lightly burned, or unburned. Severely burned areas, characterized by a thin layer of burned residue, or by exposed mineral soil, amounted to 130 acres and supported primarily bristly sarsaparilla (*Aralia hispida* Vent.), fireweed (*Epilobium angustifolium* L.), pin cherry (*Prunus pensylvanica* Lf.), and bracken fern (*Pteridium aguilinum* (L.) Kuhn.). Moderately burned areas, characterized by deep, burned residue containing only a small amount of unburned organic material, covered 160 acres and supported bristly sarsaparilla, raspberry (*Rubus* sp.), and dense patches of fireweed. Lightly burned areas, characterized by a slightly burned organic layer and heat-killed softwood trees, covered 27 acres and supported sparse stands of barnyard grass (*Echinochloa* sp.), quack grass (*Agropyron repens* L. Beauv.), sedge (*Carex* sp. and *Scirpus* sp.), and rush (*Juncus* sp.). Unburned areas occurred as small islands of mixed coniferous growth surrounded by lightly burned areas amounted to 29 acres.

Censuses of the small mammal population in the burn were made during 12–17 October, 1966 and again during the period of 20–28 October, 1967. Two half-acre plots, one located in a moderately burned area and the other in a severely burned area, were established in the fall of 1966. Each plot contained 30 stakes located at half-chain intervals near which two Sherman live traps were placed. The traps were visited daily and counts made of red-backed voles (*Clethrionomys* sp.), deer mice (*Peromyscus* sp.), and big short-tailed shrews (*Blarina* sp.) captured during the 600 trap-night survey. The 1967 census, based on 960 trap nights, was conducted on the same plots and in the same manner as the 1966 census. Estimates of the small mammal population based on the Lincoln Index are given in Table 1. The mouse population remained relatively stable on the moderately burned area but increased greatly on the severely burned area during 1967. The big short-tailed shrew, a predator of small mammals, had appeared in both survey plots by the fall of 1967.

An indication of the weather that prevailed on the burn during the 1967 growing season was provided by weather data recorded daily from 1 May through November at the Maine Forestry Department's St. Croix District Headquarters in Topsfield, Maine, approximately 15 miles northeast of the burn at an elevation of 500 feet above sea level. In 1967, temperatures from May to November averaged 60°F, 4°F above the normal; the total precipitation was 33.86, 8.9 inches above normal. Fifty-three percent (4.67 inches) of the above normal precipitation was deposited during the months of May, June, and July.

Table 1. Estimated populations of small mammals on moderately burned and severely burned areas in October 1966 and October 1967.

Species	Moderately Burned Area		Severely Burned Area	
	1966	1967	1966	1967
	number per acre			
Deer mice	26	20	6	20
Red-backed voles	6	16	0	4
Total mice	32	36	6	24
Big short-tailed shrews	0	10	0	4
Totals	32	46	6	28

The preponderance of very stony to extremely stony soils covered by numerous large boulders precluded mechanical scarification of seedbeds, except on small areas. Only two areas, one of 14.3 acres and the other 0.4 acres, were scarified with a bulldozer prior to being seeded.

AERIAL SEEDING

White spruce (*Picea glauca* (Moench) Voss.) seed colledted in Washington and Penobscot counties in Maine in 1964 and stored at the Maine State Forest Nursery was used to seed the burn. The seed, averaging 178,591 seeds per pound, had a purity of 97% and a mean germinative capacity of 63%. Prior to sowing, the seed was coated with: Stauffer's Endrin 50 W, a rodent repellent; Arasan 42-S, a bird repellent; Dow Latex 512-R, an adhesive; and aluminum flake, a lubricant, as recommended by Derr (1964). Treatment of the seed according to Derr's recommendation of 2.4 gal of mixture per 100 lb. of seed resulted in the formation of large lumps of seed. To eliminate lumping, the mixture was diluted by adding 1 qt of water to 2 qt of the original mixture. The diluted mixture was then applied at a rate of 1.25 gal per 100 lb. of seed.

Seed lots totaling 377.8 lb. were treated at the rate of 2.77 lb. of Thiram (the active ingredient of Arasan) and 0.70 lb. of Stauffer's Endrin 50 W per 100 lb. of seed. The amount of Thiram was greater and the amount of Stauffer's Endrin 50 W was less than Abbott's (1966) recommendation of 1.5 lb. of Thiram and 1.0 lb. of Stauffer's Endrin 50 W per 100 lb. of northern conifer seed. The amount of both chemicals per 100 lb. of seed was less than Derr's (1964) recommendation of 8 lb. of Thiram and 2 lb. of Stauffer's Endrin 50 W per 100 lb. of southern pine seed.

Aerial seeding of the burn was accomplished on 26 October, 1966 with a Brohm aerial seeding unit, developed by the Ontario Department of Lands and Forests, mounted in the Maine Forestry Department's 47-D-1 Bell helicopter. The seeding unit consisted of four principal parts:

A seed hopper having a capacity of 120 lb. of seed.

A metering auger that, depending upon the seeding rate desired, could be rotated at variable speeds up to 600 rpm.

A slinger that rotated at a constant rate of 1,000 rpm and distributed seed in an even circular pattern having a diameter of 90 feet.

A drum-and-cable type of retraction device enabling the helicopter pilot to lower the slinger beneath the helicopter skids to prevent the seed from hitting obstructions and being damaged.

The seeder was calibrated by weighing the seed dispersed in 15 sec at various auger speeds. The seed weights were then converted to pounds of seed dispersed per acre when flying at 50 mph.

Prior to the seeding operation, a base line was established diagonally across the burn at right angles to the topography with offsets being made when necessary to avoid dense accumulation of down timber. Stakes, numbered 1 to 50, were set at 90-foot intervals along the base line.

Fifty 90-foot-wide-flight strips, oriented at right angles to the base line and having the numbered stakes as centers, were drawn on a map of the study area. The estimated acreages, based on the measured length of each flight strip and a seeding width of 90 feet, were then used to determine the number of strips that could be sown before the pilot had to return to the heliport, an old-field site located one-half mile northwest of the burn, for reloading.

During the seeding operation, the helicopter flew at altitudes between 150 and 200 feet and at a speed of 50 mph. An attempt to control the flight pattern by marking the location of successive flight-strip centers along the base line with a weather balloon as seeding progressed across the area was only partially successful because wind prevented elevation of a balloon at some flight-strip centers. Additional ground control of the flight pattern attained by direct radio contact with the pilot was apparently successful in obtaining complete coverage of the area but probably failed to provide for a uniform rate of sowing.

To obtain information on the coverage and uniformity of seeding attained, 49 polyethylene "flats" (each 3 feet square) were placed along the base line. The flats were located 30 feet to the right and left of the even-numbered stakes except for the fiftieth stake which was represented by a single flat. Shortly after sowing, a count was made of the seed on each flat. Only two flats had no seed. Counts on the remaining 47 flats ranged from 1 to 28 seeds, average 8.9 seeds per flat. Based on these samples, the estimated seeding rates on portions of the burn, each portion including from five to nine flight strips, ranged from a low of 15,628 to a high of 36,592 viable seeds per acre with a mean of 27,133 $\pm$ 16,680 viable seed per acre.

Additional estimates of seeding rates were obtained by dividing the weight of the untreated seed by the area of the flight strips over which it was apparently sown. On a weight basis, estimated rates of seeding ranged from 0.386 lb. (43,430 viable seed) to 2.347 lb. (264,066 viable seed) per acre, mean 0.681 lb. (76,621 viable seed) per acre. The wide difference between the estimated average rate of seeding based on the catch of seed on polyethylene flats and that based on the actual weight of the seed sown was attributed to seed bouncing off the polyethylene flats and to the erratic flight pattern of the helicopter due to inadequate ground control.

REGENERATION SURVEY, AUGUST 1967

In August 1967, a regeneration survey was made to assess the abundance and frequency of white spruce seedlings. A total of 3,698 one-tenth milacre plots were located in pairs at 33-foot intervals along lines spaced 360 feet apart. The number of white spruce seedlings, seedbed condition, aspect, degree of shading, and soil depth were recorded for each plot. Seven seedbed conditions were recognized as follows:

1. Thin residue – Seedbeds on severely burned areas having a layer of residue less than 0.5 inch thick.
2. Thick residue – Seedbeds on moderately to severely burned areas having a layer of residue greater than 0.5 inch thick.
3. Mineral soil – Seedbeds on either severely burned areas with no residue or on roadbeds.
4. Duff – Seedbeds on lightly burned areas having a deep layer of unburned organic matter.
5. Unburned – Seedbeds in unburned islands occurring throughout the study area.

6. Rock – Seedbeds on exposed rock.
7. Prepared – Seedbeds on the exposed mineral soil within the two areas scarified prior to sowing.

The degree of shading recognized was as follows:

1. Open – No shade provided on the plot at any time.
2. Light – Partial shading of the plot with direct sunlight being received sometime during the day.
3. Heavy – Considerable shading of the plot with little or no direct sunlight being received at any time.

Aspect was recorded as being either northeast, southeast, southwest, northwest, or level. Soil depths were noted as being either deep (greater than 6 inches) or shallow (less than 6 inches).

The results of the survey in August 1967 are summarized by seedbed condition in Table 2. The estimated number of white spruce seedlings per acre ranged from a low of 790 on rock seedbeds to a high of 5,700 seedlings on bare mineral soil seedbeds and averaged 2,826 ± 8,719 seedlings per acre over all seedbed conditions. As indicated in Table 2, seedbeds on rock, on unburned areas, and on moderately to severely burned areas having a layer of residue greater than 0.5 inches thick apparently provided the most unfavorable environment for the germination and initial establishment of seedlings.

The estimated average number of seedlings per acre showed less variation when the survey plots were grouped by aspect than when grouped by seedbed condition (Table 3). Excluding the northwest aspect, which was represented by only 12 plots, the estimated number of seedlings per acre ranged from a low of 1,909 on southwest aspects to a high of 3,199 on level terrain. An absence of seedlings on the 12 sample plots having a northwest aspect was due apparently to a combination of conditions unfavorable for germination and seedling establishment. Eight of the 12 sample plots had either a thin residue or rock seedbed, no shade, and a shallow soil.

When the survey plots were grouped according to the degree of shading, the estimated average number of seedlings per acre was 2,363 ± 7,838 for unshaded seedbeds (1,020 plots), 3,469 ± 8,471 for partially shaded seedbeds (1,032 plots), and 2,710 ± 9,347 for heavily shaded seedbeds (1,646 plots) with the percent of stocked plots for each of the three degrees of shading being 14, 23, and 15% respectively.

Of the factors considered, soil depth apparently had the least effect upon the germination and initial establishment of white spruce seedlings. The estimated average number of seedlings per acre was 2,901 ±

Table 2. Estimated number of white spruce seedlings per acre and percent of sample plots stocked by seedbed condition in August 1967.

Seedbed Condition	Number of Plots	Percent of Total Number of Plots	Number of Seedlings Per Acre: Average	Number of Seedlings Per Acre: Standard Deviation	Percent of Plots Stocked
Thin residue	904	24.4	3,153	9,617	18
Thick residue	1,730	46.8	2,514	6,251	18
Mineral soil	193	5.2	5,700	13,604	28
Duff	249	6.7	4,378	15,336	20
Unburned	306	8.3	2,288	9,233	11
Rock	291	7.9	790	4,034	6
Prepared	25	0.7	5,200	7,703	36
All seedbeds	3,698	100.0	2,826	8,719	17

Table 3. **Estimated number of white spruce seedlings per acre and percent of sample plots stocked by aspect in August 1967.**

Aspect	Number of Plots	Percent of Total Number of Plots	Number of Seedlings Per Acre		Percent of Plots Stocked
			Average	Standard Deviation	
Northeast	764	20.7	2,016	7,410	13
Southeast	32	0.9	2,812	7,119	16
Southwest	330	8.9	1,909	5,540	14
Northwest	12	0.3	0	0	0
Level Terrain	2,560	69.2	3,199	9,396	19
All aspects	3,698	100.0	2,826	8,719	17

8,985 on shallow soils (2,020 plots) and 2,735 ± 8,386 on deep soils (1,678 plots) with the percent of stocked plots being 18 and 17% respectively.

The percent stocking observed on the burn was expressed in terms of milacres by combining groups of ten consecutively observed one-tenth milacre plots (Grant 1951). On a milacre basis, the aerial seeding resulted in 72% stocking. The percent of milacres stocked at various levels for all plots observed on the burn in August 1967 is given in Table 4.

The estimated number of seedlings per acre was found to be considerably greater on an area of approximately 65 acres located in the center of the burn (Area B) than on the surrounding area (Area A). The estimated number of seedlings per acre and the percent of plots stocked on Area A and B respectively are contrasted by seedbed condition in Table 5.

Table 4. **Percent of milacres stocked at various levels for all sample plots observed in August 1967.**

Minimum Number of Seedlings	Percent of Milacres Stocked
1	72
2	53
3	39
4	29
5	21
10	3
15	2
20	0

With the exception of the prepared areas, which were outside Area B and duff seedbeds, the number of seedlings per acre was consistently greater on Area B than on Area A. The percent of plots stocked with one or more seedlings was consistently greater on Area B than on Area A for all comparable seedbed conditions.

REGENERATION SURVEY, AUGUST 1972

A second regeneration survey of the burn was made in August 1972, 6 years after the aerial seeding. A total of 556 sample plots, each 2 milacres in size, were located at 165-foot intervals along lines spaced 180 feet apart. Results of the survey indicated an average of 1,131 ± 1,977 white spruce seedlings per acre with 54% of the 2-milacre plots being stocked with one or more seedlings. Although the estimated average number of white spruce seedlings per acre in 1972 was 60% less than that in 1967, portions of the burn were still adequately stocked.

On a map of the burn showing the location and stocking of each of the 556 survey plots, four adequately stocked areas, each greater than 10 acres in size, could be delineated. Over these four areas, in aggregate approximately 51% (177 acres) of the total acreage of the burn, the estimated average number of white spruce seedlings per acre was 2,020 ± 2,478 with 87% of the sample plots being stocked. The remainder of the burn included a mix of sparsely stocked to nonstocked areas over which the estimated average number of white spruce seedlings per acre

Table 5. Number of seedlings per acre and percent of plots stocked with at least one seedling on areas A and B by seedbed condition in August 1967.

Seedbed Condition	Number of Plots		Percent of Total Number of Plots		Mean Number of Seedlings Per Acre		Percent of Plots Stocked With at Least One Seedling	
	Areas A	B	A	B	A	B	A	B
Thin residue	670	234	22.0	35.4	2,567	4,829	15	24
Thick residue	1,445	285	47.6	43.2	2,173	4,246	16	28
Mineral soil	145	48	4.8	7.3	3,862	11,250	22	48
Duff	237	12	7.8	1.8	4,388	4,167	19	33
Unburned	266	40	8.8	6.1	1,429	8,000	10	22
Rock	250	41	8.2	6.2	520	2,439	4	15
Prepared	25	0	0.8	0.0	5,200	0	36	0
All seedbeds	3,038	660	100.0	100.0	2,337	5,076	15	27

was 237 ± 498 with 30% of the sample plots being stocked.

In 1972 the white spruce seedlings, averaging 8 inches in height, were in most instances overtopped by intolerant hardwood species ranging from 6 to 10 feet in height. The principal hardwood species represented on the burn were pin cherry (*Prunus pensylvanica* L.f.), paper birch (*Betula papyrifera* Marsh.), yellow birch (*Betula alleghaniensis* Britton), and aspen (*Populus* sp.).

CONCLUSIONS

Control of the aerial seeding by elevating weather balloons at flight-strip centers along the base line supplemented by direct radio contact with the helicopter pilot was apparently successful in obtaining complete coverage of the burn. However, as indicated by the variation in the number of seeds caught on polyethylene flats and by the variation in stocking observed in the two regeneration surveys, an even distribution of seed was probably not attained. Better ground control of the flight pattern could have been achieved had parallel base lines been established at opposite ends of flight strips and flags on poles been used instead of weather balloons to mark the flight-strip centers.

First-year stocking percents on all types of seedbeds represented on the burn, except unburned seedbeds and seedbeds on exposed rock, were greater than that recommended by Smithers (1965) as being indicative of successful initial stocking for white spruce. The relatively high first-year stocking percents on a wide variety of seedbed conditions can be attributed primarily to above normal precipitation during the period of germination and seedling establishment. By the end of the sixth growing season, seedling mortality from insects, drought, washing, and frost heaving had reduced the estimated average number of seedlings per acre by 60% and resulted in one half of the area seeded being only partially stocked with white spruce seedlings.

Exposed mineral soil supported a greater average number of white spruce seedlings per acre at the end of the first growing season than any other seedbed condition represented on the burn. This emphasizes the importance of site preparation in successful reforestation by direct seeding. When, due to rough bouldery terrain, scarification of duff seedbeds to expose mineral soil is not feasible, sowing seed in prepared spots would provide greater assurance of success and be less wasteful of seed than aerial seeding.

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Silviculture treatment of seeded stands

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ABSTRACT

Density control is specifically applicable to and often the most urgent requirement of stands which have been established by seeding. Optimum density levels are essential if maximum merchantable values are to be obtained from lands devoted to fiber production. Although the improvement of understocked stands is possible through planting or seeding, it is often not practical and may be economically risky. On the other hand density reduction, both precommercial and commercial, can be biologically desirable and economically feasible if conducted at the proper time in the life of the stand. As a general rule maximum biological benefits accrue when proper spacing is achieved early in the life of a stand. Operational trials by the Canadian Forestry Service have indicated that thinning can be economically feasible also, if undertaken at an early age. In recent years mechanical, precommercial, strip thinnings have been the most common but such methods result in cleared corridors with dense, intervening residual strips of live trees. Research results have indicated that strip thinning is less desirable biologically than individual tree spacing. Currently, considerable work is being done in the development of more efficient mechanical row thinning equipment. Aerial strip thinning using herbicides has been tried with uncertain results to date.

A recent commercial row thinning in semimature jack pine was economically successful. A new harvester which can double as a thinner will be tested to determine if commercial thinning can be efficiently mechanized in Boreal Forest stands which have arisen following fire or seeding.

RÉSUMÉ

Spécifiquement applicable aux peuplements issus de graines, le contrôle de la densité en constitue souvent la plus urgente nécessité. Des degrés optionaux de densité sont essentiels à l'obtention de valeurs marchandes maximales des terres vouées à la production ligneuse. Quoique possible, l'amélioration des peuplements incomplets par plantation ou semis s'avère souvent peu pratique et éventuellement un risque économique. D'autre part, la réduction de la densité avant et durant le stade de production peut être biologiquement désirable et économiquement

opportun si elle est pratiquée au moment propice de la vie du peuplement. En règle générale, l'espacement convenable pratiqué au début de la vie du peuplement procure le maximum d'avantages biologiques. Des expériences effectuées *in situ* par le Service Canadien des Forêts est montré que l'éclaircie précoce peut être également opportune. Les éclaircies par bandes avant le stade de production étaient très courantes ces dernières années, mais de telles méthodes se sont soldées par des clairières alternant avec des bandes résiduelles d'arbres. La recherche a prouvé que, du point de vue biologie, l'éclaircie par bandes est moins désirable que l'espacement entre les arbres. Des travaux considérables sont en cours pour mettre au point un équipement mécanique procurant une meilleure éclaircie en lignes. Les résultats des expériences d'éclaircie aérienne par bandes au moyen d'herbicides sont encore incertains.

Une éclaircie par bandes récemment pratiquée dans un peuplement de Pins gris d'âge moyen au stade de production s'est révélée un véritable succès économique. Il sera essayé une nouvelle moissonneuse pouvant fonctionner aussi comme éclaircisseuse à l'effet de déterminer l'opportunité des éclaircies d'exploitation pratiquées mécaniquement dans les peuplements boréaux regénérées sur brûlis ou issues de graines.

INTRODUCTION

In considering the subject of this paper and ways of approaching it, I thought at first that I should deal with those silvicultural treatments which have exclusive application to artificially seeded stands. Further reflection made it apparent that forest management cannot be so neatly categorized, that most postestablishment treatments can be applied to a broad range of stand types and that the use of a treatment is not limited to stands which have been established by a particular method of regeneration. On the other hand, though, some forms of regeneration do create a more urgent need for follow-up treatment than others and some silvicultural treatments provide greater benefit when applied to stands arising from one regeneration method than to those arising from another.

In the case of seeding, the forester is commonly confronted with a major problem immediately upon the establishment of the stand. Stands so regenerated, either artificially or naturally, are seldom of a stocking [1] and density [1] that will result in optimum use of the site potential. Both understocking and excessively high densities are common and in both cases some form of postestablishment spacing treatment is essential if the maximum rate of merchantable growth is to be achieved. Although treatments such as cleaning, pruning, fertilization, etc., can be effectively applied, spacing control is specifically applicable to and the most pressing need of most seeded stands. This paper, then, will deal exclusively with that aspect of their treatment.

Forest management agencies generally stipulate minimum acceptable stocking levels below which complete retreatment of an area is often undertaken. The desirable maximum level of stocking is 100%, or approaching 100%, of the stockable area. However, minimum and maximum density levels are often overlooked or only vaguely defined, either because we are happy just to see a stand coming back or because of a "more the merrier-dominance will assert itself" approach. With some species in overly dense stands, there may be a tendency for individuals to outstrip the general growth of the stand but often a genuine potential for stagnation of growth exists. With lodgepole pine (*Pinus contorta* Dougl.), Smithers (1957) and others have emphasized that once stagnation sets in, it may be difficult to overcome, and the possibility of ever harvesting a merchantable crop from the stand becomes questionable. At the very least, time to harvest will be greatly prolonged by reduced growth rates. It is conceivable that a similar inhibition of growth occurs with other species, including jack pine (*Pinus banksiana* Lamb.), when they grow under greatly overcrowded conditions.

It is rather evident, as both world demand for fiber and international competition increase, that we can no longer afford to accept such losses. Eventually, we shall have to obtain maximum value from each acre of land. A move toward more intensive forest management will be essential and, for lands devoted to wood production, growing of trees at optimum densities [2] will be an important factor.

Current seeding methods result in stands with trees spaced in several distribution patterns (i.e., random, grouped or rowed). While most site preparation

[1] As defined in "Terminology of Forest Science. . ." (Anon. 1971).

[2] For the purpose of this paper, the somewhat theoretical concept of "optimum density" is defined as the minimum number of stems required to utilize the full growth potential of the site. In practice, this minimum number should be somewhat flexible and should reflect the type and quality of product for which the trees are being grown.

and seeding methods can be manipulated to allow a fair degree of control over final stocking, the direct control of density is less readily regulated. This, then, is the situation that generally leads to the consideration of spacing control or thinning if optimum use of site potential is to be realized.

FILLING IN

Filling in is undertaken when stocking is below acceptable minima and yet is not so low that a complete retreatment is warranted. It requires the regeneration of the open areas within an established stand through spot application, either by the placement of seed or by the planting of stock. The object is, of course, to bring the stocking of the area as a whole up to a desired level without creating an overly dense condition on those areas being filled.

To upgrade stocking by means of a ground technique, a systematic coverage of the area is required and each open area greater than a designated minimum size must be treated. Operational trials conducted by the Great Lakes Forest Research Centre have indicated that this process is generally quite costly (it can approach the cost of an original hand planting) and the cost advantage gained from the original seeding can soon be lost. In addition, the established stand, while understocked, may well be overly dense on the stocked portions and the forest manager may be faced with the necessity of exercising further spacing control in the form of thinning later in the life of the stand.

The decision to seed or to plant for the filling-in operation depends largely on the time that has elapsed since site preparation and seeding. Filling in by seeding requires a suitable seedbed. The original site preparation may be used if it is still acceptable, or a new seedbed may be prepared by scalping. Invasion by competing vegetation and the age of the established stand are also major considerations. If the invasion is proceeding at a rate which will severely restrict the new trees' growth before they can overtop the competition or if the time elapsed since the original seeding means that a significant size differential will occur between old and new seedlings, planting is the only alternative. However, even planting would be feasible only in the first few years after seeding.

From the above trials we have concluded that filling in by spot seeding or planting is a marginal undertaking and must be related to stand values. If the growth and value potentials of the stand are considered to be sufficiently high, some degree of filling in may be warranted but the undertaking seems economically risky.

The normal practice with jack pine in Ontario has been to reseed the entire area aerially if it is understocked after the first seeding. The timing of the reseeding has to be such that advantage can be taken of the previous site preparation but care needs to be taken also that adequate assessments are made and that sufficient time has elapsed since the initial seeding to allow most of the seeds applied at that time to germinate. There is a very real danger that an assessment made too early, say after one growing season, will indicate inadequate stocking. If a reseeding is then undertaken, it may well be discovered later that subsequent germination from the first seeding had been more than sufficient to bring stocking up to desired levels and that the reseeding was unnecessary. A reseeding under these conditions only adds to the cost of establishment and increases the need for future spacing control. Any survey made prior to reseeding should assess the unstocked areas carefully to determine if reseeding can achieve the intended goal. It may be discovered that insufficient suitable but unstocked seedbed exists to improve overall stocking materially. In such cases there is a disturbing tendency for the reseeding to do little more than add trees to the areas which are already stocked.

Given the foregoing information and a cost of aerial seeding for jack pine of \$5.00–\$10.00/acre (including cost of seed) (Robinson 1973), I think it is evident that, operationally, a well-conceived reseeding from the air is less costly than, and preferable to, manual ground filling in.

PRECOMMERCIAL THINNING

Once a stand of jack pine has reached the age of about 5 years, spacing control usually takes the form of density reduction, and unsatisfactorily stocked stands are either left or entirely reworked. In most jack pine stands successfully regenerated by seeding, the stocked areas support more trees than are desirable for optimum growth. Osborn's (1968) observation that "the timing of spacing control must be a compromise between economic and biological factors" now takes on special meaning. When is this time of compromise? Biologically, the sooner a stand can be put into an optimum spacing situation, the more opportunity it will have to utilize the full potential of the site to best advantage. This echoes Dahms' (1961) general observation that the real payoff from precommercial thinning comes from getting the crop trees in possession of the site at the earliest possible moment. Economically, this may not be so since the earlier in the life of a stand a cost is incurred, the longer it must be carried and therefore the greater the impact on the final net value of that stand. This, then, is where the compromise must be made. For jack pine the case is quite clear biologically but not so apparent from an economic standpoint.

HAND THINNING

In 1969 the Great Lakes Forest Research Centre undertook a series of precommercial thinning trials to determine 1) the stage in the development of a jack pine stand at which spacing operations can be carried out most economically, and 2) the most efficient nonmechanized techniques for treating stands of various ages. Jack pine was chosen for several reasons: because a great deal of research into the biological aspects of jack pine spacing has been conducted; because it is a major and commercially valuable Ontario forest resource; and because it frequently occurs in pure, even-aged stands of high density. However, the results of this series of trials may be applicable in part to other coniferous species.

It was decided that three age classes, representing three distinct size classes, between filling-in

Table 1. Site descriptions.

Age class	Location	District	Forest section [1]	Site class [2]	Moisture regime [3]	Soil
I (9 yr)	Benneweis Twp	Sudbury	B7	2 (est.)	1	medium sand
II (22 yr)	Panet Twp	Chapleau	B7	2	2	fine sand
III (33 yr)	Mickey Creek	White River	B8/9	2	2	fine sand

[1] Rowe (1959).
[2] Plonski (1960).
[3] After Hills (1952).

Table 2. Stand descriptions (before treatment).

Age class	Age (years)	Stocking (%)	Density (trees/ acre)	Dia range (inches)	Avg dia. (inches)	Avg height (feet)	Stand origin
I	9	88 [1]	5330	1-3	1	6	scarification and aerial seeding
II	22	96 [2]	4220	1-5	2	19	wildfire
III	33	96 [2]	2250	1-6	3	32	wildfire

[1] Percent of milacre quadrats having at least one tree.
[2] Percent of 1/640-acre quadrats having at least one tree.

age and commercial thinning age would be treated. Pretreatment site and stand data for each of the stands are given in Tables 1 and 2.

It was obvious that not all of the tools commercially available would be suitable for each size class and a series of small-scale trials was undertaken in two of the selected stands to assess the performance of a number of the tools. The most suitable were selected for use in the larger operational trials: brushcutters for the smallest size class, power saws for the intermediate size class and a hypohatchet–herbicide injection method for the largest. A companion trial using hand tools (Sandvik axes) was conducted in each of the stands to provide comparative data. Detailed work studies were conducted to identify the most time-consuming or inefficient aspects of the work with each tool (the areas where attempts to improve efficiency should first be concentrated) and, it is hoped, to provide the forest manager with sufficient data to enable him to estimate the cost of treatment for a broader range of stand conditions. Each trial was conducted under piecework contract using workers typical of those that forest managers might be expected to hire for the kind of work being done. Piecework rates were set to promote maximum productivity.

A suitable density (or spacing) level was selected for each age class based on the research information available. While no claim is made that they are optimal, the selected levels were 1210 trees per acre (6-foot × 6-foot spacing) for Age Class I and 682 trees per acre (8-foot × 8-foot spacing) for Age Classes II and III.

Although Riley (1973) has given a full account of the treatment methods and results, some reference to the latter is worthwhile. Post-treatment stand, production and cost information are given in Table 3. Figure 1 illustrates the cost for each treatment in graphic form.

1. The cost of treating Age Class I by either treatment was by far the least expensive. The brushsaw treatment was the cheapest of all at $15.92 per acre, a figure which includes a rather high assumed rental rate for the brushsaw. This rate could undoubtedly be reduced on a full-scale, operational basis, thereby reducing further the per-acre cost, or at least improving its cost in comparison with those of other treatments as labor rates, etc., increase with time.
2. For all classes, hand treatment was more expensive than the more sophisticated method in the same age class. Except for Age Class I where the cost differential is less than $2.50 per acre, the cost of hand treatment is much higher, approximately $23 and $27 per acre, respectively, for Age Classes II and III.

Table 3. Post-treatment stand, production and cost data.

Age class	Treatment	Treated area (acres)	Stocking (percent)	Density (trees/acre)	Avg dbh (inches)	Avg height (feet)	Desired spacing (feet)	Avg spacing A.T. (feet)	Labor (man-hours/acre)	Cost/acre[1] (dollars)
I (9 yr)	hand tools	12.4	80.9	1674 (5330)[2]	1	6	6	5.1	7.66	18.38
	brushsaw	28.6	79.0	1614	1	6	6	5.2	3.93	15.92
II (22 yr)	hand tools	1.4	86.3	864 (4220)[2]	2.9	24	8	7.1	27.14	94.99
	chainsaw	5.0	84.8	862	2.8	23	8	7.1	14.40	72.00
III (33 yr)	hand tools	5.0	90.7	1159 (2250)[2]	3.2	33	8	6.1	27.60	66.24
	hypo-hatchet	15.0	88.0	1125	3.3	33	8	6.2	6.91	39.64

[1] Including equipment, materials and supplies.

[2] Pretreatment density (trees/acre).

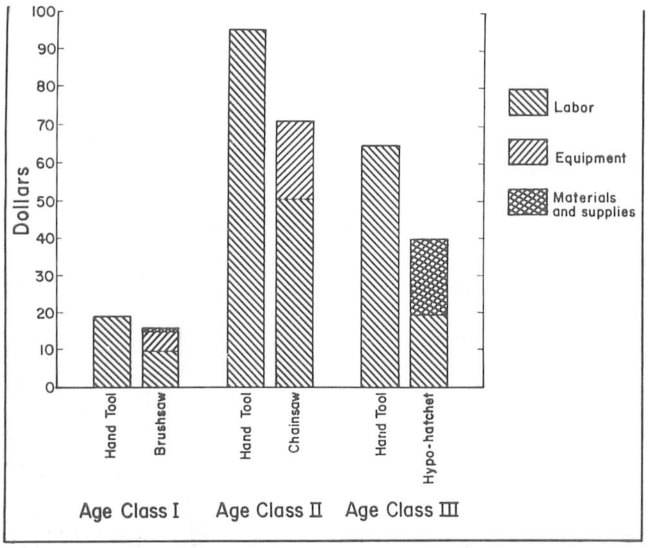

Figure 1. Per acre costs of precommercial thinning of jack pine.

3. The cost of the treatments is exorbitant in Age Class II, and at least for hand tools in Age Class III. Although the cost of the hypohatchet–herbicide treatment is much lower ($39.64 per acre) than those of the other treatments in these two age classes, it is still considered too costly to carry the investment through the remainder of the rotation.
4. The herbicide treatment, to be effectively carried out and to provide reasonable assurance that the desired spacing would be achieved, required a rather costly pretreatment crop-tree marking. This accounts for approximately one-third of the total cost of $39.64 per acre. The cost of the herbicide was approximately 45% of the total.
5. The brushsaw can handle trees up to at least 3 inches in diameter at point of severance, but it is most effective when stems are under 2 inches since it can then be used in a swathing manner and cutting is very rapid. The continuous motor noise is a major problem. With prolonged use there is a very real danger to the operator's hearing unless ear protectors are worn.
6. Hypohatchets can be used effectively only on trees larger than 2 inches dbh since the smaller stems are very flexible and do not offer sufficient resistance to the hatchet blow to cause ejection of the herbicide.
7. High ground fire hazards may be caused in Age Classes I and II by the treatments described. No such hazard is created by the herbicide treatment since the trees are left standing and will deteriorate slowly.

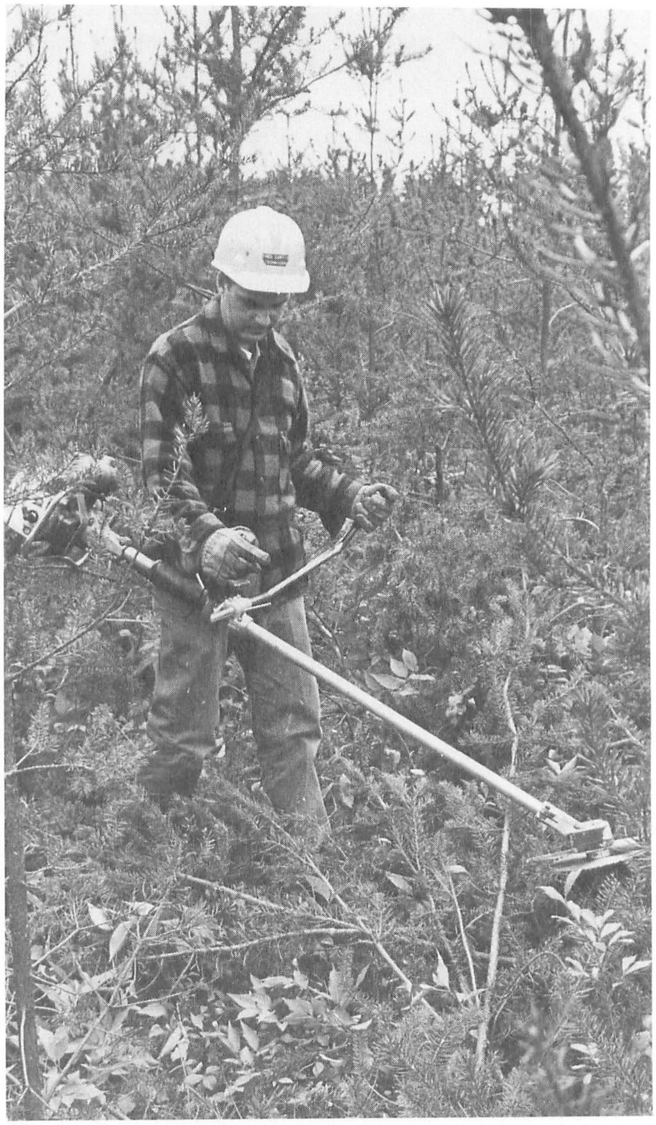

Figure 2. Brushsaw thinning in progress in Benneweis Township in jack pine. (Ontario Ministry of Natural Resources).

Figures 2-7 depict stand treatments as well as some operational aspects of the treatments conducted in these trials.

Figure 3. Brushsaw thinned condition, Benneweis Township.

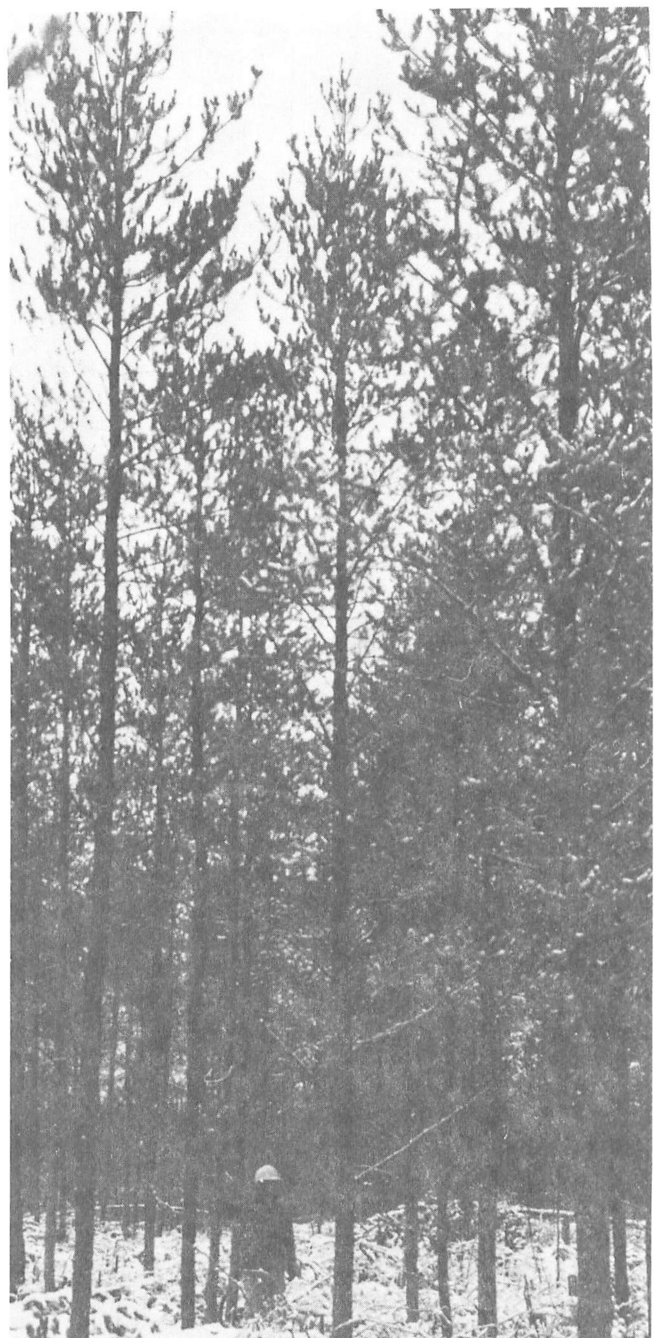

Figure 4. A 22-year-old jack pine stand thinned by chainsaw in Panet Township, Chapleau District.

Figure 5. A tree at the Mickey Creek site being treated by hypo-hatchet.

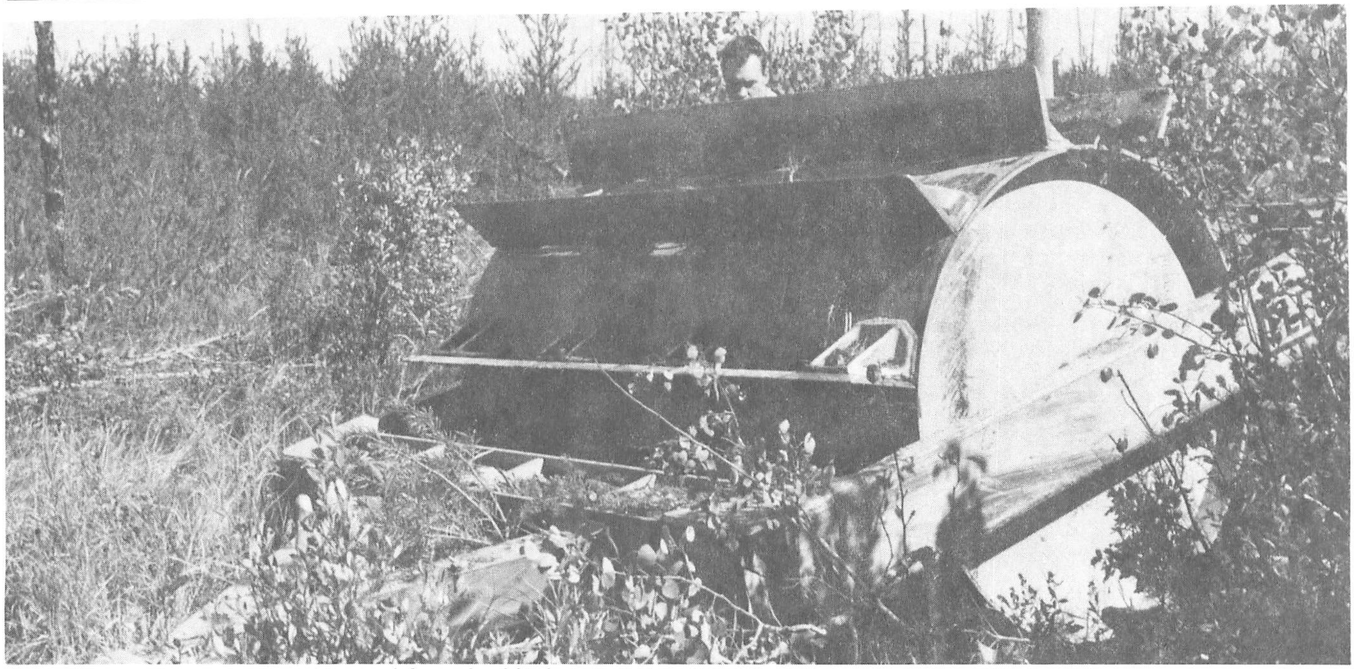

Figure 6. A chopper of the type used for strip thinning young lodgepole and jack pine in the Prairies.

Figure 7. Results of strip thinning by chopper in 9-year-old jack pine in Manitoba.

The results of these trials suggest that, if thinning takes place at an early age, costs can be kept at a reasonable level. It is evident that spacing operations may also be justified in terms of stand establishment costs. The cost of planting jack pine is about $48 per acre including the cost of stock (Scott 1968), whereas seeding plus thinning at about 10 years of age costs about $23–$25 per acre. (In both instances the cost of site preparation is excluded because it is common to both methods of regeneration). The stands resulting from a combination of seeding plus early thinning are equivalent to well-stocked plantations but their total establishment cost is considerably less. Thus it would appear that, even allowing for a greater possibility of failure, aerial seeding plus early spacing may be a more efficient method than planting for the regeneration of jack pine.

In each of the foregoing thinning treatments there is no immediate return on investment. Therefore, a comparison of these treatments centers on cost, time to maturity, and long-term benefits.

Numerous studies have been carried out to determine the effects of thinning upon the height, diameter and volume growth of jack pine. Although thinning does little or nothing to enhance height growth, the improvements in diameter and volume growth can often be quite dramatic. Unfortunately, few treated stands have been assessed at maturity, the only time when the impact of thinning can be fully determined. Thinning studies have usually indicated that, at harvest, merchantable volumes obtained from a thinned stand should be greater than those from unthinned stands. Of greater current significance from the industry's point of view is the increase in average stand diameter, which almost invariably results from thinning. Recent studies in the industry (Hannula 1970; Williams 1971) have illustrated the impact of volume per tree (i.e., tree diameter) upon the cost of producing a cunit of wood. Cost reductions per cunit can range from as little as 6% for each 1-inch increase in average stand diameter for larger diameters (8 inches increased to 9 inches dbh) to as much as 35% for smaller diameters (5 inches increased to 6 inches dbh). Even the former reduction can be the difference between a profitable and an unprofitable operation. Such reductions in wood processing costs are applicable (to a greater or lesser degree) to all conventional logging systems from power saw to sophisticated harvester. While the above examples are applicable only to processing to the primary landing, similar benefits will accrue to other processing operations right through to the mill.

An economic comparison of the three "non-manual" thinning treatments (Riley 1973) involving a calculation of internal rate of return showed that, with the saving gained at harvest from increased growth, the treatments of the youngest age class were the most economically attractive (See Table 4). In other words, if a manual, small-equipment approach is used, the most favorable time to thin economically coincides with the most favorable time biologically and, in this case at least, no compromise is necessary.

Table 4. Internal rate of return from thinning (in percent).

Site class	Merchantable volume/acre at 60 years [1] (cunits)	Age class I (15.92) [2]	II (72.00) [2]	III (39.64) [2]
3	14.8	2.7	—0.8	—3.8
2	23.1	3.6	+0.4	—2.1
1	31.8	4.3	1.3	—0.9

[1] From Plonski 1960.
[2] Cost per acre of thinning, in dollars.

MECHANIZED THINNING

Virtually all mechanical, precommercial thinning done to date, both operationally and on a trial basis, has been of a rowed or stripped nature. Given current thinking, this is likely to be the pattern for mechanical thinning in the future unless highly sophisticated, very large and very costly equipment, is introduced. Stripping may be the most productive method of achieving some form of spacing over large areas, but a review of work done indicates that often it has not been the most economical and seldom has it been the most biologically desirable method.

Most early machine thinning was done by tractor and blade. Treatment consisted in simply flattening strips through the stand to be treated, a rather crude technique with a number of undesirable side effects and uncertain biological results. Size of tree was relatively unimportant and almost any young-to-middle-aged stand could be treated relatively easily. Costs were often quite high.

Recognizing the difficulties associated with blade thinning, a number of governments, companies and researchers in Canada (notably in the prairies) and the United States have, in more recent years, investigated the use of drag discs and choppers for the row thinning of stands. Generally the size of tree which could be treated in this manner was smaller than that which could be treated by blade thinning. The results tended to be less damaging to the residual stand but strips were often less effectively cleared of living trees. Choppers seem to have had an advantage over discing in this regard as well as in cost.

Some agencies have attained notable success with drag equipment. An extensive strip thinning in Alberta using drum choppers in late winter on 20-year-old lodgepole pine severed most trees on the strip and caused little damage to the residual stand. Five-year assessment results show a high degree of response with only limited, mostly non-competitive, growth existing in the cut strips (Bella 1972).

Treatment times, and hence costs of the aforementioned mechanical methods (and of those which follow) vary widely with type of equipment, width of treated and untreated strips, stand density, tree size, terrain, etc. The various reports reviewed do not provide sufficient information to permit comparison of the results. However, production rates ranged from approximately ½ acre per hour to better than 2 acres per hour. The most striking impression one gets from these reports is that, in general, the people involved were not very pleased with the immediate results of the treatment. The most common complaints centered on damage to the residual stand and the incomplete kill within the treated strip.

Over the past few years considerable interest has been shown by the Canadian Forestry Service and by various companies in the development of row thinners which are mounted on conventional skidders or tractors. The most popular concepts are the front-mounted vertical beater and the front- and rear-mounted rotary mower. Although these machines are being heavily touted for use as thinners there appears to have been only limited application to date. Their main use has been in the area of brush clearing. Some operational use is being made of commercial machines in the Maritimes (particularly Nova Scotia) but little, if any, in Quebec or Ontario. Use in the United States also appears to be spotty.

At present the Forest Management Institute of the Canadian Forestry Service is developing a twinned, rotary mower thinner, rear-mounted on a conventional wheeled skidder (Fig. 8). Operational trials have been conducted in Newfoundland and the Maritimes and, most recently, northwest of Quebec City. Results typical of those achieved in the trials are shown in Figure 9.

The generally expected rate of production for this type of machine is in the order of 1 acre per hour and the Forest Management Institute has estimated that the Canadian Forestry Service mower can attain this. However, as noted previously, ground conditions and degree of coverage will be major influences on rates of production. As a general rule they are aiming for a cost of less than $25 per acre and as low as $10 per acre based on a 50% coverage of the area [3].

With these newer machines, damage to the residual stand is light compared to that caused by drag or blade thinning. Material on the treated strip is chipped and few trees survive the treatment. Provided

[3] J. D. Dunfield, Forest Management Institute, Canadian Forestry Service, personal communication.

Figure 8. The thinner mower being developed by the Forest Management Research Institute of the Canadian Forestry Service.

Figure 9. Results of row thinning in young jack pine conducted by the Forest Management Research Institute thinner mower.

the trees are not too large (4 inches dbh maximum), such equipment currently shows the greatest potential for row thinning and with refinement should be able to treat efficiently almost any area the power unit can traverse. In fact the use of such machines may be the only practical means of treating stands having average tree diameters in the 2 — 4 inch size range.

In terms of growth response, row thinning of seeded stands does not provide as good results as does individual tree selection (Steneker 1969). Overcrowding still exists in the "leave-strips" but trees are given more space than in the unthinned condition. Response decreases as distance from the leave-strip edge increases (Steneker 1969; Skilling 1957; Bella and DeFranceschi 1971). In some cases cross stripping has been practised to produce rectangles of residual trees. This approach more closely approximates individual tree spacing and allows for better growth response, but it can be expected to add considerably to the per-acre costs, since it requires a second coverage of the area.

AERIAL THINNING BY HERBICIDES

One potential method of thinning, for which only passing reference has been encountered in the literature, is the use of herbicides for aerial row-thinning. The only application of any kind, to the author's knowledge, is a combined experimental–operational spraying conducted in the Peshu Lake area of Ontario by the Sault Ste. Marie District of the Ontario Ministry of Natural Resources (then the Ontario Department of Lands and Forests), in 1968 and 1969, using Tordon 101 and a thickening agent. The operation was undertaken to reduce the very high density in jack pine stands (20–40 thousand stems per acre in many areas) resulting from the Mississagi fire of 1948. The burned area covered some 600,000 acres, much of which is inaccessible except by air and thus unavailable for ground thinning treatments.

The herbicide was applied by helicopter at different rates and in different spray patterns (strip and cross-strip). Operating techniques were adjusted to provide a tree-contact swath width of 7 feet, with two swaths per pass of the helicopter and an intervening unsprayed swath of 7 feet. The desired result would be alternation of killed and live rows 7 feet in width over the area.

At the time of writing no detailed follow-up assessment had been conducted although one is planned for the summer of 1973. However, information obtained from those involved[4] indicates that kill width may be satisfactorily controlled and that, at least at the highest application rate of 2 gallons of Tordon per acre, kill is reasonable. Although some further trials may be needed to refine the technical aspects, there appears to be some potential for the method, particularly in more remote areas.

Costs of these trials varied from $23 to $28 per acre but it is believed that the cost can be reduced to the point where it is at least competitive with those indicated for the thinning of the youngest age class in the Great Lakes Forest Research Centre hand trials. As with the Silvisar and hypohatchet treatment, the major cost resides with the herbicide and this may be a stumbling block to general use of the method.

COMMERCIAL THINNING

Commercial thinning, to be most beneficial, should be preceded by a precommercial thinning early in the life of the stand. In this way growth may be concentrated on an optimum number of trees, tree volume will increase at a faster rate and the commercial thinning will be possible at an earlier age. In practice, however, this combination of treatments has been the exception rather than the rule. Often only one or the other is conducted, if thinning is carried out at all. More often no treatment is undertaken and the stand is left until it is suitable for final harvest.

In a period of growing world demand and predicted strain on the supply of certain species in certain countries, Canada included, the need for intensive forestry practice and the maximization of production from our forested areas is becoming ever more apparent. While the advantages of early thinnings can be accepted in principle, the benefits to be derived are usually so long-term (beyond the practising life span of those implementing the treatment) that they seem highly idealistic, and numerous reasons can be given for spending the needed money in "better" ways. On the other hand, the benefits of commercial thinning are, at least in part, immediate and direct. Wood of utilizable size is available to the mill immediately, and at a time which is earlier than final harvest. This could be of considerable importance to a mill which, having to go steadily further afield to obtain raw material, is finding its wood costs soaring as a result of rapidly increasing transportation costs.

[4] W.C. Stevens, Regional Forester, Northeastern Region, Ontario Ministry of Natural Resources, personal communication.

In their cutting history, mills have often bypassed large stands of overly dense, semimature timber as being unmerchantable. If these stands can be thinned efficiently, they represent a new source of economical wood.

Although the silvicultural benefits resulting from commercial thinnings are not expected to be as great as those derived from early thinnings, growth will again be concentrated on a smaller number of stems and will result in a larger average stand diameter (and presumably, therefore, increased merchantable volume) at harvest. In addition, the volume removed will help to meet any increased demand for wood.

Still, commercial thinning is not commonly practised. Perhaps the economic or supply–demand crunch has not yet exerted sufficient influence. Perhaps commercial thinning has not yet been shown to be economically feasible or at least has not been presented in a manner which makes it sufficiently attractive.

In 1970 the Great Lakes Forest Research Centre undertook a two-stage approach to the problem in order 1) to determine the feasibility of commercial row thinning in the jack pine stands of Ontario's Boreal Forest, and 2) to investigate means by which commercial row thinning can be mechanized. Stage one, an operational row thinning using a conventional shortwood system, has been completed. A publication is currently being prepared on this work but at this time a short summary is in order. A 42-year-old jack pine stand, which appeared suitable for the purpose, was located in the Chapleau District of Ontario. (Pretreatment stand data are given in Table 5). Approximately 200 acres were strip marked to remove some 45% of the merchantable volume; 15 feet of cut strip alternating with 18 feet reserve strips. (This precut preparation cost $6 per acre for labor and $2.60 per acre for materials and supplies). With the assistance of the Chapleau staff of the Ontario Ministry of Natural Resources, a contractor was located to do the cutting and a cutting permit was issued to cover the work (minimum dues of $2 per cord). The contractor arranged with Eddy Forest Products of Espanola for a contract for 2000 cords of 8-foot wood at $27 per cunit F.O.B. (shipping point at Nemegos). All roads were constructed by the contractor at his expense. Using one- or two-man gangs with chainsaws, the trees were cut, limbed and bucked into 8-foot lengths and stacked on the cut strip for later removal to the established haul roads. Detailed work studies show that production ran at a rate of 0.5 cords per man-hour. Subsequently the wood was forwarded to skidways on the haul roads by front-end loaders. Still later the wood was truck hauled to a nearby siding and shipped by rail to Espanola. A summary of costs for each phase of the operation, total cost, revenue and net profit are given in Table 6.

Figures 10 and 11 illustrate the pretreatment stand condition and results achieved by the operation.

Overhead costs included stumpage, scaling charges, employment charges, supervision, strip marking costs, road construction and other miscellaneous costs. Road construction and forwarding costs were somewhat less than might be expected since the contractor owned the equipment outright and charged for it at a reduced rate.

This rather inefficient operation by a part-time contractor realized a substantial profit. How profitable might it have been if conducted more efficiently, say by a highly organized woods department using mechanical row thinners or if contracted out to a full-time jobber using similar equipment? This question remains to be answered and is the basis for the second part of the Great Lakes Forest Research Centre's investigations.

Eaton-Yale Ltd. of Woodstock, Ontario has successfully negotiated with the Australian manufacturer of the Windsor Harvester for the introduction of this machine into North America, and has scheduled testing of the harvester in various forest stands in eastern Canada in the spring and summer of 1973. At an early stage in the negotiations the Great Lakes Forest Research Centre held discussions with Eaton-Yale for the purpose of simultaneously developing

Table 6. Cost and revenue summary for commercial thinning operation, in dollars.

Cost [1]			
Felling, limbing, bucking, piling		8.00/cord	
Forwarding to roadside		1.44 "	
Hauling and rail car loading		3.50 "	
Overhead		4.82 "	
		Total — 17.76/cord	
Total cost of operation			33,765.50
Revenue [2]			
Total revenue from operation			44,403.90
Net profit (total)			10,638.40
Net profit (per cord, OMNR scale)	5.60		
Net profit (per cord, company scale)	5.11		

[1] Based on OMNR scale of 1901.21 cords.
[2] Payment based on E.B. Eddy scale of 2082.55 cords.

Table 5. Stand description before commercial thinning, Chapleau District.

Age (years)	Avg height (feet)	Avg dbh (in.)	Density (trees/ acre)	Trees/acre (4 in. + dbh)	Jack pine component: % of stems	Jack pine component: % B.A. (trees 4 in. + dbh)
42	41	4.5	1120	794	94	97

Figure 10. The Nimitz Township (Chapleau District) commercial row thinning. The residual strips indicate original stand density.

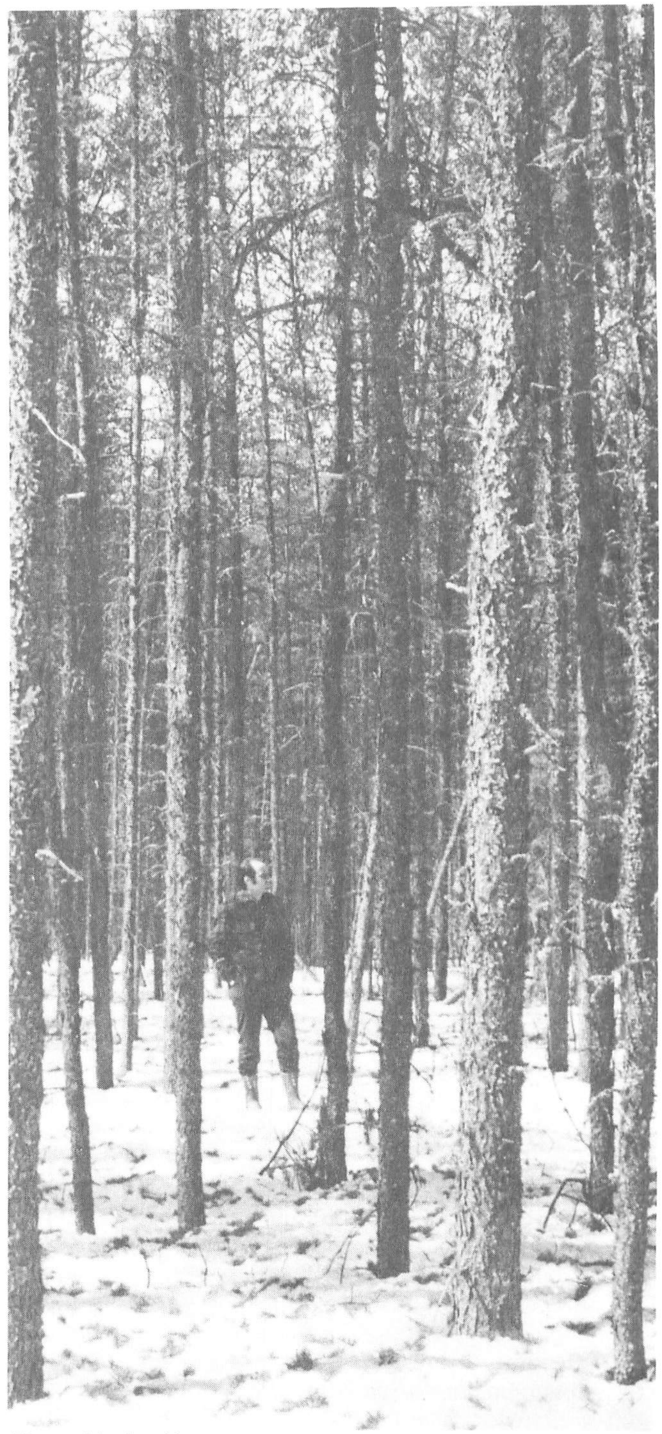

Figure 11. Looking across the unthinned rows of the Nimitz Township commercial thinning. The forester is standing in one of the cut strips.

this machine as a commercial row thinner for both plantations and natural stands of the Boreal Forest. If the early harvesting trials are sufficiently successful, at least one cooperative operational thinning trial will be made during 1973 on which detailed work studies will be conducted. With the 1970 row thinning information available for purposes of comparison, some indication of the feasibility of mechanized commercial row thinning may be obtained.

SUMMARY

Density control is the one silvicultural treatment most directly applicable to and most often required in seeded stands. The filling in of understocked stands can be quite costly and is not an attractive proposition. While much research and many trials have indicated the biological desirability of thinning in over-dense stands, the practice has not been widely applied, largely because of uncertain economic benefits and a pressing need to devote the greatest effort and funds to stand establishment. However, world demand, shortages of raw material, rising costs and demonstrated gains from thinning may well change this picture in the future.

Many precommercial thinning methods have been tried with varying degrees of success. The trend is toward mechanical row thinning using conventional bush equipment with specially developed attachments. With such machines large areas can be treated quickly and efficiently although most have some undesirable, but acceptable, side effects on the residual stand.

At least one manual spacing treatment, conducted with brushsaws in young jack pine stands, has been shown to be cost-competitive with machine thinning. The resultant stand is more desirable biologically, because of individual tree spacing, than the rowed pattern left by machine thinning, and there is little or no damage to residual trees. However, production rates are lower because the treatment is labor intensive. Because of this the brushsaw may well be restricted to areas that are not large enough to warrant bringing in a machine or are too rugged for efficient operation of a machine, or to localities where labor is plentiful but equipment is not. It is unlikely that other manual treatments will be acceptable because of high initial costs and lower long-term benefit.

Aerial application of herbicides to achieve stand thinning has yet to be investigated thoroughly although at least one operational spraying has been conducted with, as yet, indefinite results. There may be potential for this method in remote, presently inaccessible areas.

Commercial thinning can be profitable at least under certain conditions. Mechanization of commercial thinning may make it a more attractive proposition. While growth response over the short period remaining until harvest may be marginal, a commercial thinning has a number of other benefits including wood volumes obtained earlier in the rotation, an earlier return on stand establishment costs and the utilization of some trees which would otherwise be lost owing to mortality.

While thinning, both precommercial and commercial, is certainly no panacea and cannot be applied universally, the biological benefits have been fairly well demonstrated. What is necessary now is the development of efficient tools and techniques, and the assessment of benefit–cost relationships to identify those situations in which it can be applied most effectively. If this is done I believe that thinning will be shown to have a very definite place in the management of our forest.

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Direct seeding the spruces

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St. John's, Newfoundland

INTRODUCTION

Direct seeding has been employed as a means of reforestation in North America for many years, but it has never been used on the same scale as planting of bare-root nursery stock. It is, nevertheless, a most important and valuable reforestation technique, and it seems likely that its importance will increase rather than diminish in the future.

Most direct seeding operations in North America have involved pines — jack pine in the north, loblolly and slash pine in the south — or in the west, Douglas-fir. Spruce, chiefly white spruce and to a lesser extent black spruce, have been used generally on a smaller scale, especially in the U.S.A. This paper will summarize the information on direct seeding of spruce species, which has been presented at this Symposium and add some information based on the author's experience of direct seeding spruces in Newfoundland. Since much of the material which has been presented is of a general nature and not specific to any particular species, there will inevitably be some degree of overlap with the following summary paper on the pines.

A brief outline will be given of the statistics of direct seeding spruces in Canada and the United States. Some consideration will be given to the silvicultural and economic aspects of the decision whether to seed or plant. Most attention will be paid to the direct seeding operation itself, the factors which must be considered and the problems which may arise, at each stage from seed procurement through seed treatment, site preparation, seed application, germination and establishment, to stand treatment.

DIRECT SEEDING OF SPRUCES IN CANADA AND U.S.A.

Research on direct seeding has been conducted in Canada for over 70 years, but it has only been used operationally since the 1950's. During the decade ending in 1972, 247,000 acres were direct seeded. Of the total area seeded in Canada, 41% is in Ontario and 36% in Alberta; 86% has been carried out by the provinces, 13% by industry. Spruces account for about half the area seeded, with white spruce being the most commonly used species (42%); small amounts of black spruce (4%) and Norway spruce (3%) have also been seeded. Of the total area seeded, 50% has been on cutovers, and 26% on burned areas, but in recent years the proportion of cutovers seeded has increased to 76% while burned areas seeded have decreased to 8%. The results of direct seeding have been poor and results using spruces have been poorer than with pines. Most areas appear to have failed, although the data are largely incomplete, many factors are involved, and most seeding has been conducted in the last 5 to 10 years.

In Ontario the area direct seeded annually has increased more than tenfold, from 1986 acres in 1962 to 22,000 acres in 1971. Most of this area has been seeded with jack pine, but some white and black spruce is also used. Seeding accounts for 20% of the artificial regeneration in Ontario, However, with a breakthrough in techniques for seeding black and white spruce on cutovers, it is expected that direct seeding would increase to 40% of the artificial regeneration program.

In Alberta, 130,000 acres have been seeded since about 1959, mostly with white spruce (76%) or a mixture of white spruce and lodgepole pine (5%). Scarification with a variety of machines is usually performed and the seed is broadcast by cyclone seeder or applied by hand in pinches. Helicopters have been used for the last 5 years or so. Success has been very poor, with 83% of the area seeded having less than 20% stocking. Nevertheless, Alberta plans to use seeding more in the future, but with better guidelines.

In Saskatchewan, 876 acres have been seeded, some with white spruce, and in Manitoba about 6500 acres have been seeded, 62% with white spruce. Only one white spruce seeding project was successful in Manitoba; failures were largely due to a lack of adequate seedbed preparation.

Although only 5000 acres, or about 2% of the national total, have been seeded in Newfoundland, almost all that area has been seeded with spruces, chiefly black spruce with lesser amounts of white spruce and sitka spruce. A considerable number of direct seeding trials, using a variety of application techniques (spot and broadcast, aerial and ground), have been conducted on burned, cutover land with and without seedbed preparation. Success has been generally good, particularly with broadcast seeding.

In the United States, an average of 200,000 acres have been direct seeded annually since 1960, making up 14% of the total reforestation program. Some two-thirds of this area has been seeded by private agencies. There is a distinct regional pattern to direct seeding in the United States. Very little seeding is conducted in the Northeastern States, although the potential exists there, and 345 acres of a wildfire in Maine were seeded with white spruce in 1966 with some degree of success. Some white and black spruce seeding has been done in the Lake States. Black spruce seeding has been particularly successful in Minnesota on peat after broadcast burning of logging slash. This type of operation is likely to continue. Most direct seeding has taken place in the West and in the Southern States. In the West virtually all the seeding has been with Douglas-fir, apart from a little sitka spruce in California, and Engelmann spruce in Montana and Idaho. In the South, seeding of loblolly and slash pine predominates. In contrast to the optimistic situation in Canada, there is presently declining use of direct seeding in the United States, particularly by government agencies. This is largely the result of recently imposed restrictions on the use of chemical repellents to protect seed from small mammals and birds.

SEEDING VERSUS PLANTING – SILVICULTURAL AND ECONOMIC ASPECTS

A number of factors must be considered in reaching any decision as to whether to plant or seed. The economic factors are probably most strongly in favor of seeding, but the silvicultural aspects are also important.

Direct seeding has seldom resulted in stands with optimum stocking or density. Results are seldom predictable, particularly with aerial seeding. Understocking seems the most frequent problem: only 27% of the seeded area in Canada had more than 40% stocking at an average of 4 years, while only 29% of the area had more than 1000 4-year-old seedlings per acre. On the other hand, when seeding is successful, there may be a problem of overstocking. With spot seeding and machines such as the Bracke Cultivator, which sow several seeds on scalps, clumping of seedlings often occurs. If one seedling quickly becomes dominant in this situation, there is no problem, but if not, a very abnormal stand may develop. By contrast, spacing and density in a planted stand are highly predictable.

The biological requirements for germination and establishment of a direct seeded crop are much more rigorous than the requirements for satisfactory establishment of a plantation. In Ontario and elsewhere mineral soil seedbeds must be prepared, and the amount of slash, stones or vegetation on the site may make such preparation very difficult. Topography, soil moisture and vegetative competition after seedbed preparation may all limit the applicability of seeding. Planting of bare-root stock can be performed satisfactorily under a much wider range of conditions.

Another important consideration favoring planting is the increasing use of genetically improved seed. Since improved seed is more costly and is presently available only in limited quantities, most of it will be used to produce high quality planting stock for the immediate future at least.

On the other hand, seeding is a much faster operation than planting. Extensive areas such as wildfires can be broadcast seeded from the air very quickly. It is a flexible technique: quantities of seed can be stored for a number of years without serious loss of viability and are ready for use whenever required, but planting stock takes several months (in containers) or years (bare-root) to produce from seed, and can only be stored for a few months. In addition, the planting season is seriously limited in many areas by climatic conditions and unexpected drought or a late spring thaw may curtail it even more. Seeding is possible over a much longer period. Although most direct seeding in Canada has been performed in the fall, the use of snowmobiles with attached mechanical seeders is making winter seeding on snow increasingly popular.

There are other silvicultural reasons for favoring direct seeding, not least of which is the evidence from Ontario that after 5 years in the field, the height of seedlings (of jack pine) originating from seeding exceeds that of container-planted seedlings or bare-root nursery stock. Also, seeding produces a more natural-looking stand which may be an important factor in these days when the public is highly critical of any environmental disturbance.

Perhaps the biggest advantage of direct seeding is its cheapness compared to planting. Cost estimates given by different sources vary greatly according to region and the number of factors included, but seeding is seldom estimated to be more than half the cost of planting. Waldron estimated seeding costs in Canada in 1972 at $27 per acre, compared with $55 per acre for planting. In the Chapleau district of Ontario, the average cost per acre since 1967, excluding site preparation, has been $38.92 for planting bare-root nursery stock, $21.90 for container planting and $4.19 for seeding. In western Canada, even if three times as much seed were used as at present, seeding would cost only $20.50 per acre compared to $55 per acre for planting; these figures include the cost of scarification. In the Lake States seeding is less than one-sixth the cost of hand planting, and in the Pacific northwest planting is estimated to cost five times as much as seeding.

In assessing these figures it is important to remember the goal of reforestation. If the object is to achieve a specific stocking of a desired species within reasonable time limits, reseeding, replanting or other subsequent treatments are more likely to be required with seeding than with planting. With this type of objective and if there is a high probability of seeding producing the desired stocking, seeding will be economically preferable to planting if the cost of seed is relatively low. On the other hand, if the object is only to renew forest cover, even with seeding costs high and planting costs low, only a 40% probability of seeding being successful is necessary for seeding to be superior.

Many factors affect the choice of reforestation technique, including logging decisions, seed supply, seedling supply, capital budget and physical plant, manpower, administration, and laws and regulations. Most of these favor planting over seeding since planting is the accepted reforestation technique and present programs which are geared to planting cannot easily be altered.

Site preparation is probably the biggest single item involved in the cost of seeding. However, where site preparation is required for seeding, it is frequently also required for planting. Scarification currently costs about $16 per acre in western Canada and this figure will increase with the demand for greater mineral soil exposure.

The cost of application is probably the smallest element, varying from 75 to 90 cents per acre for aerial application to $1.50 per acre by hand. This differential is increased by the fact that 150 acres per hour can be treated by helicopter but only 2 acres per hour by hand or most mechanical ground application techniques.

It is clear that direct seeding will remain a valuable and much-used method of reforestation. Although considerable improvements in operational techniques are necessary, particularly for the spruces, to make the results of seeding as predictable as those of planting, the cost factor will preserve the comparative attractiveness of seeding.

THE DIRECT SEEDING OPERATION

Seed Procurement and Handling

Because of the large volumes of seed required in direct seeding, it is essential to have an efficient seed procurement and handling system so that seed is available as and when required.

Most provinces of Canada have a seed registration system so that each seedlot can be tracked from collection to eventual use. Ontario established a system of seed zones for collections in the 1950's, but the zones have been found too broad and are now being subdivided.

Where costly equipment is used to collect cones, a method for reliably forecasting the cone crop is needed. A method based on counting flower buds is best. For white spruce in central British Columbia a sequential sampling system has been developed in which female buds are counted on specifically defined trees in September of the year preceding cone harvest. Most spruce species do not produce good cone crops annually, and since the best yield and quality of seed are obtained in good seed years, it is preferable to plan big collections for those years. Cone collections should be made immediately prior to natural seedfall when most seeds are ripe. Cone maturity is checked by observing cone color, or using seed cutting or cone flotation tests. With species having serotinous or semi-serotinous cones such as black spruce, the exact timing of cone harvest is less critical and it may be delayed without appreciable loss of seed.

Most cone collections are made from trees felled in logging operations. Efforts are generally made to collect from the better stands and the best trees. In Ontario seed collection areas for black spruce have been selected and most seed will be collected there for the next few years. Since white spruce occurs chiefly in mixed stands it is more difficult to select seed collection areas for that species. At present there are 100 acres of black spruce seed production areas in Ontario. Seed production areas are also in use for white spruce in Alberta. These are young above-average stands that are silviculturally managed and fertilized. The present area of such stands will be doubled and most black spruce seed will come from them until seed orchards come into production. Ontario presently has 23 acres of black spruce seed orchards, but plans to increase this to 300 acres.

In seed production areas and seed orchards, cones must be collected from standing trees. Ladders are used most often, and an efficient system for supporting a 50-foot 3-part aluminum ladder by nylon guy ropes has been described by Lowry and Avard. Hydraulic high-lift equipment is of only limited usefulness within a forest stand. Tree shakers are being tried in British Columbia and Alberta for white spruce; they are smaller and more mobile than high-lift equipment, but lose efficiency as cones become drier and lighter.

After collection, cones are packed in burlap bags and shipped to the seed extraction plant where they are spread on trays in a cool well-ventilated area for pre-curing. Kiln extraction of seed is standard. After tumbling to separate the seeds, they are dewinged using either a brush or cement mixer. Cleaning is accomplished in a fanning mill, though some provinces also use a belt-cleaner or a gravity table.

Seed must be stored at carefully controlled moisture content and temperature levels. The optimum values for most spruces are 4-6% moisture content and 1-3°C. Under such conditions spruce seed can be stored safely for 10 to 20 years. Storage containers should be sealed: 1/8-inch polyethylene bags or glass bottles are used most often, but it should be noted that polyethylene is not impermeable to moisture.

Regular tests for seed viability are conducted by most agencies. A representative sample of seed is tested, mostly by direct germination on filter paper. Cutting tests, flotation or germination of covered seed in natural media are also used as alternative or supplementary methods. As yet X-ray examination of seed is not used on an operational scale in Canada.

Seed Predation Problems and Seed Treatments.

One of the biggest hazards in direct seeding is the consumption of seed in the field by small mammals and birds. Most study of this problem has been done in the west. Little mention is made of seed predation in Ontario and other parts of eastern Canada, although across the border in the Northeastern United States, seed predation is cited as a serious problem.

The extent of the problem in the west may be judged from the fact that 1 or 2 chipmunks and 24 mice per acre are sufficient to destroy 80% of seed sown. Deer mice and voles eat about 30% of their own weight every day. One deer mouse can eat about 2000 white spruce or 2100 black spruce seed in one night; the smaller the seed, the larger the number destroyed. Even the shrew, a "classic" insectivore, will eat white spruce and Douglas-fir seed.

Disturbance of the forest habitat alters the amount of food and shelter available for small mammals, which in turn causes changes in species and numbers present. Thus the first year after clearcutting, shelter and food are sparse, but as vegetation reappears, there is an increase in species and numbers of small mammals. Populations fluctuate between seasons and years, but it is unlikely that this fact could be used reliably to determine the best time for seeding. Prescribed burning does not eliminate populations, but results in improved habitat and food conditions in subsequent years and small mammals flourish, having survived the fire in unburned areas or burrows.

Studies involving radio-tagging of treated white spruce seed in Alberta have shown that almost 50% were destroyed between spring and fall. Of this number 71% were destroyed by mice and voles, 19% by chipmunks, 6% by shrews and 4% by insects. However, when seeds were sown in the fall and checked the following spring only 16 to 19% were destroyed and 28 to 36% germinated compared to 6% germination in the spring sowing study.

In contrast to this rather pessimistic picture, in Newfoundland there is only one species of seed-eating small mammal, the meadow vole, which is largely confined to grassy areas and thus is very infrequent on burned areas and cutovers. Successful seeding trials have been conducted in Newfoundland for the past 20 years without any form of seed protection.

In most areas of North America, treatment of seed to repel rodents and birds has been standard practice. The most frequently used treatment for a number of years has been various combinations of endrin, arasan, latex and aluminum dust or flakes. However, because of conflicting test results regarding the efficacy of endrin and arasan, and more particularly because of recently imposed legal restrictions on the use of endrin both in Canada and the United States, efforts are being made to develop new and more reliably effective repellent treatments. In the case of the United States, there is a noticeable decrease in the amount of direct seeding due to restrictions on the use of repellents. In Canada most direct seeding is done with untreated seed, in contrast to 5 or 6 years ago when 98% of seed used was repellent-treated.

The problem is to protect the seed from predation without inhibiting germination. Endrin is generally considered an effective rodent repellent, though possibly less effective in the field than in the laboratory. Arasan is a good fungicide and bird repellent but its effect on small mammals is questionable. However, some tests have shown that the endrin-arasan mixture reduces or delays germination, while other tests show that it has no adverse effect on germination. A recent Ontario test showed that arasan had no apparent adverse effect on black spruce germination. Tests are currently being conducted with a new repellent, R-55, which has had adverse effects on Douglas-fir and western hemlock germination, but has apparently little effect on black spruce.

Another approach to the repellent problem is to pelletize or encapsulate the seed. The repellent chemicals can then be applied to the outside of the pellet or capsule rather than directly to the seed coat. This idea also has the merit of making small seeds larger and more uniform, which facilitates precision sowing. Recent laboratory tests in Ontario showed that germination of pelleted black spruce seed was equal to that of non-pelleted seed. However, germination of encapsulated black spruce seed was only 50% compared to 100% for the untreated control. If pelletizing or encapsulating of coniferous seed proves satisfactory in the field, fertilizers and herbicides could be incorporated in or on the pellet or capsule as well as repellents.

Apart from protecting the seed or facilitating precision sowing, seed treatments are also used to help break dormancy, or to promote earlier germination. Stratification is the procedure used to break dormancy, but this is not normally required for black spruce. A wide variety of treatments have been tried to promote germination, including cold soaking, low doses of ionizing radiation, soaking in a trace element solution, nonionic surfactants, baby powder in a methyl cellulose sticker, intense short-duration radiation, microwave treatment, hydromulch seed mixture, and pulsed laser beams. Most treatments have improved germination characteristics for some species, but few of the treatments have practical value at present and few have been tested other than in controlled evironments.

Site Preparation

Most direct seeding operations in Canada are performed only after some form of site preparation. The object is to expose a favorable seedbed and to control vegetation growth. In most areas, and for most species, mineral soil is considered the best seedbed. However, there is some debate about the optimum degree of mineral soil exposure. In Ontario, Brown considers that 20-40% mineral soil exposure is best, particularly if prepared in strips, and that highly-scarified mineral soil is a poor seedbed; but Rudolph believes that increased scarification coverage may prepare better seedbeds, even if the equipment has to make two passes. In Alberta, Hellum suggests a need for more than 40% mineral soil exposure and stresses the need for even distribution of the effects of scarification. The amount of slash, stones and vegetation all affect the degree of site preparation possible.

There is some thought in Ontario that the soil should be allowed to settle for anywhere from a month up to a year after site preparation before seeding. In northwestern Ontario stocking of black spruce is generally less than 30% if sowing is done less than one month after site preparation, but increases to 69-85% for seeding conducted 1 to 2 months after site preparation. The delay allows the disturbed soil to finish settling and seed subsequently sown suffers only a minimum of movement and burying.

Over the years the use of site preparation has increased and has become progressively more sophisticated. Much early site preparation in Ontario was done by hand only, and in the west seeding was done on burns without seedbed preparation. Now bulldozer and blade are used in 54% of site preparation in Canada, and drag scarifiers such as barrels and chains in 30%.

In western Canada, slash burning and scraping with a bulldozer blade are used prior to direct seeding of Douglas-fir in British Columbia. Athens plows and bulldozers equipped with raker teeth are used to prepare seedbeds for cyclone seeding in Saskatchewan. In Manitoba where a lack of seedbed preparation is cited as one of the principal reasons for failure of direct seeding, Athens and middlebuster plows, bulldozers, and drums are all employed, and hand preparation is still used in some circumstances. Scarification is the rule before seeding in Alberta; Athens plows, Imsett scarifiers, bulldozer blades and Vee-blades are all used by government agencies, while drums and chains are preferred by industry. The last two are not satisfactory for white spruce.

The current emphasis in Ontario is on machines that both scarify and seed in one pass. The SFI scarifier and Bracke Cultivator, both of which can be towed by wheeled skidders, can prepare and seed 1000 scalps per acre and are used now for 1/3 of all direct seeding. A mechanical row seeder has been developed in which a seeding cone is trailed behind barrel scarifiers towed by a tractor. There is a need, however, to develop effective site preparation techniques for white and black spruce. The sites are small in area, only partly cut, and have a rapid regrowth of ericaceous shrubs and grass, especially in the case of white spruce.

In the northeastern United States a furrow seeder has been developed which is an effective single-pass seeder for stony ground and rough brush. It consists of a small crawler tractor which tows a fireline plow for seedbed preparation, and a modified agricultural seeder. This machine prepares a suitable ecological niche with less disturbance than some of the heavier equipment currently in use. This is an important point in these days of public criticism of any environmental disturbance.

In Newfoundland, the Rome discer, SFI scarifier, barrels and chains have all been tried as site preparation methods for direct seeding, with varying degrees of success. However, equally good success has been obtained without any site preparation by seeding black spruce on burned areas up to 4 years after burning. Rapid regrowth of vegetation on burns is not a problem.

Application Methods

Ground and aerial application methods have been used with approximately equal frequency in Canada. Spot seeding, using various hand seeders, or by hand, has been used on 46% of the total area seeded, ground broadcast methods using cyclone seeders, snowmobiles or hand scattering on 13% of the area, and air seeding, using helicopters about as much as fixed-wing aircraft, on 39% of the area. Currently, air seeding is used on 50% of the area seeded and hand seeding on only 10%.

Aerial seeding is a fairly recent development in most areas since the mid 1960's. The Brohm seeder which consists of a seed hopper, auger and slinging-tubes was an important Ontario government development. First designed for use in helicopters, it has since been modified for use in fixed-wing aircraft. The speed of the auger is variable and by this means the number of seed sown per acre is controlled. The Brohm seeder has been used in successful seeding operations on burns with white spruce in Maine and with a mixture of black spruce and jack pine in Newfoundland, as well as in Ontario. Helicopter seeding has also been used in British Columbia, Manitoba and Alberta. It was widely used in the Pacific northwest area of the United States until the recent drop-off in seeding there, which is partly blamed on the erratic results of air seeding. On the other hand, trials of air row seeding using encapsulated seed in the southern States may give air seeding new impetus.

The cyclone seeder has long been the most commonly used implement for ground broadcast seeding. In Ontario a motorized seeder has been designed for use on the back of a snowmobile, and with this apparatus up to 60 acres per hour can be seeded on snow. Good control of seed distribution can be obtained with this method. Other mechanical seeders such as the SFI, Bracke Cultivator, row and furrow seeders perform site preparation as well as seeding.

Sowing rates vary considerably. An average of 40,000 seed per acre has been used in Canada, but 33% of the area has been seeded with less than 10,000 and 31% with 10 – 20 thousand per acre. With the small-seeded spruces more seeds are used. The average rate for white spruce is 50,000 and for black spruce 60 – 80 thousand per acre. In Manitoba anywhere from 40 – 160 thousand white spruce seed per acre have been used. In Alberta the normal rate is 20 – 30 thousand viable white spruce per acre with germinability varying from 20 – 95%. However, it is suggested that three times as much seed should be used in future. In Ontario, 100 – 200 thousand black spruce per acre are necessary to produce full stocking when broadcast seeded after 40% mechanical scarification. From trials conducted in Newfoundland on burns, with and without site preparation, an average of 50,000 viable black spruce or sitka spruce seed per acre seems adequate to produce satisfactory stocking with broadcast seeding.

In seeding operations, difficulties are sometimes encountered in determining exactly how much seed was actually sown. In a helicopter seeding trial in Maine, estimates from seed trap counts suggested about 27,000 white spruce seed per acre were sown, but the weight of seed sown suggested about 76,000 viable seed per acre. The author has encountered similar discrepancies with the use of seed traps in both cyclone seeding and helicopter seeding trials in Newfoundland.

About 66% of Canadian direct seeding operations have taken place in the fall. In Ontario it is considered that the later seeding can be delayed in the fall the better. Spring sowing has been used in 16% of operations in Canada. Early spring sowing is generally thought to give as good results as late fall sowing. However, Brown suggests that spring sowing of black spruce will give maximum germination in the shortest time. Spring sowing, on fresh snow, is suggested as the best time for white spruce in Alberta. Winter sowing, used in 13% of Canadian operations, is receiving increased consideration because of the development of seeding methods on snow from snowmobiles.

Germination and Seedling Establishment

The three principal requirements for germination are heat, moisture and air. The optimum temperature for coniferous seed germination lies in the range 60–85°F. For white spruce, the temperature varies with different seed sources, the optimun temperature being related to the latitude of the seed origin.

Moisture is perhaps the most critical requirement, and insufficient moisture is one of the chief causes of poor germination. In an aerial seeding operation on a burned area in Maine, first year stocking of white spruce was better than average, largely due to above-normal precipitation during the germination period. A well-distributed rainfall is important, as heavy rains can wash seeds considerable distances especially on bare and steep slopes. Both moisture and temperature are normally optimum in spring, so that any sowing date which takes advantage of this (i.e. from late fall to early spring) should result in satisfactory germination.

A soil cover often improves moisture conditions and protects the germinating seed. However, only a thin layer of soil meets the requirements for small spruce seeds, so that they are more subject to high evaporation stress, large fluctuations in soil moisture and extreme surface temperatures than larger pine seeds which can safely be sown deeper.

The combination of seedbed and weather condition creates the environment in which germination takes place. Mineral soil is generally considered to be one of the best seedbeds for spruces. Its infiltration capacity, aeration, heat conductivity, and capillary action are such that it has good moisture retention and yet warms up fast. However, a mixture of mineral soil and organic matter, as is obtained by some forms of drag scarification, is considered by some to be superior to bare mineral soil because of the increased soil moisture retention capacity provided by the organic material. White spruce germinates better on mineral soil with a thin cover of trembling aspen leaves than on bare mineral soil.

Seedbeds of organic matter (litter, duff or humus) are generally poor. They may have high moisture content, but the moisture is not contained in surface films as in mineral soil and movement of moisture is slow. Thus the surface may dry and moisture fluctuations occur. Even after burning, organic matter is a poor seedbed. However, in the moist climate of Newfoundland, a shallow organic mantle (less than 3 inches) is often a relatively good seedbed for black spruce.

Moss is not a common seedbed in most areas as it is generally destroyed as a result of cutting or site preparation operations. Sphagnum moss is good for germination because of its moisture retention capacity. It is better than leaf litter for germination especially if it is scalped, but because of its rapid growth seedlings may be smothered. In a black spruce strip-cutting trial in Newfoundland, mineral soil was found to be three times better than patches of sphagnum moss. Feather moss, because it tends to dry out, is a poor seedbed. Polytrichum moss appears on areas of thin organic mantle within a few years of burning in Newfoundland, and it has shown in several trials to be an excellent seedbed. Rotten wood, though not always commonly encountered, is also a good seedbed.

While in the succulent stage, many seedlings perish as a result of high temperatures or lack of moisture in the seedbed. These two factors are strongly interrelated. Succulent seedlings are especially liable to direct heat injury. Temperatures of 120–130 F, which may mean 140–150 F at the soil surface, are lethal. Heavy seedling mortality during periods of summer drought associated with high temperatures occurs in many areas – with white spruce in British Columbia, Douglas-fir in California, and also in Ontario. In Ontario, one-third of the spring germinants are lost to desiccation during summer drought periods. Dry organic matter is a poorer seedbed in these respects than moist organic matter or mineral soil, because its thermal conductivity is very poor.

Some losses in the succulent stage are caused by precipitation. Heavy rain can wash and bury seedlings. On deep scalps, summer flooding may smother seedlings with debris. On the other hand, soil particles splashed up may protect succulent stems from the lethal temperatures of direct sunlight.

In the juvenile stage, drought can also cause problems, largely through soil desiccation, slow root development, rapid evaporation from organic matter and root competition. Spruce-seedling root-development is perhaps slower than other species and so soil moisture in the surface layers is of critical importance. The soil desiccation rate depends on the soil type, organic mantle depth, amount of rainfall, evaporation rate, and water table depth. Seedlings germinating on organic matter cannot survive long if their roots do not quickly reach mineral soil.

Partial shade helps to increase survival of a number of species, including white spruce and

Engelmann spruce. Shade helps to reduce the temperature, but it may have an adverse effect on the growth rate of Engelmann spruce.

Competition from vegetation can be a problem, especially on cutovers and on the best sites. Spruces probably suffer more than pines, because of their slower height growth. Competition is a common problem when conifers are spot seeded under thinned out hardwoods. Scarification may help to reduce the competition but its effect is temporary and the regrowth may soon cause even greater competition. The life of a seedbed depends on the rate of reinvasion by vegetation. We are fortunate in Newfoundland in having a very slow rate of vegetative regrowth, especially on burns, which permits seeding of black spruce with satisfactory results without site preparation up to 3 or 4 years after wildfire.

Some seedling losses may occur through frost heaving, especially on wet sites, although it is possible that frost heaving may be a help by thinning out dense seedlings on a mineral soil seedbed. It is estimated that more than 75% of new seedlings are frost heaved during the first winter in the northeast United States. Any organic covering on the soil should help to reduce heaving.

Finally it is interesting to note a few species comparisons from the Cochrane District of Ontario. There, spruce do not germinate and survive as well as pines, but black spruce germinates and survives better than white spruce, particularly from spring sowing.

Treatment of Seeded Stands

The silvicultural treatments which may be applied to direct seeded stands after establishment are mostly designed to regulate spacing to obtain the maximum merchantable growth rate. Since seeding seldom results in a stand of optimum density, the density may be increased by filling in, or reduced by spacing or thinning.

Filling in is required when stocking is below the minimum acceptable but complete retreatment is not needed. The open areas can be regenerated by spot application of seed, or planting, depending on the time since initial seeding. If the seedbed is still receptive and vegetation and the established stand do not present competition problems, reseeding may be possible; otherwise planting will be necessary, but even then it will only be possible for a few years. Filling in from the ground is worthwhile only if the potential growth and value of the stand are high. Complete aerial reseeding is possible and cheaper, but runs the risk of creating overstocked conditions on some areas without improving stocking on others.

Reduction of stocking may be accomplished by thinning, either precommercial or commercial. Since most of the operational experience described at this Symposium has been with jack pine, this paper will touch only very briefly on this topic. In the author's experience of direct seeding black spruce in Newfoundland, overstocking is seldom a problem requiring treatment. The only possible exception is in seed-spotting where sowing 15 or more seeds in one spot on a good site has produced dense clumps of 10 or more seedlings. Hand thinning at an early stage would appear to be the best solution, but has not been attempted.

Precommercial thinning can be accomplished by hand thinning using any of a variety of tools, by mechanical row thinners, or by aerial application of herbicides in strips. Brush saws, power saws, or hypo-hatchets that inject herbicides may be used in hand thinning depending on the size of the trees, but the best results are obtained by thinning early. Mechanical row thinning does not produce as good results, in terms of growth on the residual stems, as individual tree selection. Overcrowding still exists in the residual strips and although cross-stripping is possible, it greatly increases the total cost of the operation. Aerial application of herbicides in strips appears to have some potential, but the herbicide is a major item of expenditure.

Commercial thinning is clearly beneficial. It gets usable wood out of an otherwise immature stand, and concentrates growth on fewer remaining stems with a resultant increase in the average diameter. The growth response may be marginal, but the earlier availablility of wood and the earlier return on the investment at establishment are clearly valuable.

CONCLUSIONS

Operational direct seeding of spruces in Canada is confined largely to white spruce in the Prairie Provinces and black spruce in Ontario. There is much less seeding of spruces than of pines, chiefly because of erratic results with spruces. This may be due to the smaller size of spruce seed, the slower establishment and growth of spruce seedlings, or the lesser suitability of spruce sites, particularly cutovers, for direct seeding because of poor seedbeds and vegetative competition, or it may be due to combinations of these factors.

Considerable research is being conducted, much of it in Ontario, in attempts to improve techniques for direct seeding the spruces. What is most required, perhaps, is improved site preparation – a definition of exactly what conditions are required to obtain optimum germination and establishment of spruces, and then the development of site preparation techniques to obtain these conditions. The development of effective repellents and seed encapsulation methods will also improve the efficiency and results of direct seeding.

For the future? Seeding spruce has considerable potential. Though the use of seeding is unlikely to exceed planting, it will be an important ally of planting in reforestation.

Pine summary

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INTRODUCTION

The first thing that became obvious to me as I read over the papers for this symposium was the great variability, the conflictions, in results of apparently similar seeding projects and research experiments. About the only points on which there is almost complete agreement are that site preparation is essential and that small seed-eating mammals are a serious problem.

Seeding results are often erratic. We usually don't know exactly what happens to the seed. If we treat the seed, we are not sure what effect the treatment has on the seed viability, or on the mammals, birds, insects or fungi that the treatment was meant to protect the seed from. We are still not sure of the best time of year to seed, or even how long after site preparation we should seed. There are many differences of opinion about the number of seeds per acre we should use, and what the problems of understocking, high density, or clumping of regeneration will be. There is a lot we don't know, and a lot more we disagree about.

A very hopeful aspect of this symposium is that it is bringing to light the large amount of work that is being done on a research and an operational scale to help improve the results from direct seeding. Work is going on to improve the quality and supply of seed, to improve site preparation techniques, and to develop better application methods. There is research on seed and seedling losses, seed treatments, timing of the seeding and tending of the crop.

All this makes me very optimistic that before too long we will be able to take a lot more of the elements of risk out of seeding. In any event, there is strong evidence that, in spite of our professed ignorance, we know enough now to improve considerably the results of direct seeding.

PRESENT USE OF SEEDING

	Approximate Annual Acreage Being Sown 1972	Trend
Canada	30,000 acres	Increasing
Alberta	10,000 acres (mostly white spruce)	Increasing
Ontario	20,000 acres (mostly jack pine)	Increasing
Others	small	
Quebec (1973 only)	6,000 acres jack pine	Increasing
United States	225,000 acres	Decreasing
Pacific N.W.	about half of all seeding (mostly Douglas Fir)	Decreasing
South	most of remainder (mostly pines)	Increasing
Minnesota	small amount (mostly jack pine)	Increasing
Others	mostly small	

SEEDING SUCCESS

Seeding success has tended to be variable, even erratic. We have been plagued with failures or excessively high density. We have been told quite bluntly that direct seeding does not work.

Assessment in Canada is available for less than half of the seeding, and it is difficult to draw reliable conclusions. There is always a lag in getting assessment results, though, and success seems to be improving.

Jack pine seeding has produced a milacre quadrat stocking of 40% or more in only half the projects assessed. Even with this relatively low standard of success, jack pine has shown much better results than spruce. The Ontario standard is 70% stocking, which makes the situation appear even worse.

ALTERNATIVES

What are the factors that help a forest manager choose direct seeding, or not choose it, for a specific site?

A decision can not be made unless there are fairly clearly defined objectives. These may be stated in economic terms, but there will be biological objectives and limitations as well. Cost is a major consideration of course, but it is only part of the total story. A simple type of objective is to reach a stated level of stocking and density on as many acres as possible at the least cost.

There are some basic biological limitations before seeding can be considered on a given site:

1. suitable distribution of rainfall
2. the site must be amenable to suitable seed bed preparation
3. there must be adequate available soil moisture
4. there must not be too much vegetative competition, or it must be subject to suitable control.

Some of the advantages of direct seeding are:

1. low requirement for labor and supervision
2. done during low work-load months (Ontario)
3. can be repeated easily and cheaply, although the success of re-seeding is open to question
4. convenient where access is poor
5. helps assure a more natural root system.

There are also come serious disadvantages of direct seeding:

1. understocking, high density, and clumping are common
2. cannot yet take advantage of the best genetically improved seed
3. less suited to intensive forest management
4. may lose 2 or 3 years time (this appears to be regained in jack pine in Ontario by the sixth year).

There are a lot of factors for careful consideration before choosing to seed. Sometimes the immediate cost advantage outweighs other silvicultural or economic limitations, and sometimes the fear of failure prevents the manager from risking seeding. One should plan for the most favorable expected results in terms of the objectives and the cost, and not try to avoid all risk.

GENETIC CONSIDERATIONS

Great gains are possible by practicing genetics in the regeneration of the forest, and conversely, great losses may be incurred by neglecting genetics.

Simple attention to provenance can improve growth and resistance to frost, insects and diseases. Seed collection areas can be used to provide better seed to replace low quality stands and raise the average quality of regeneration. Seed production areas in jack pine, after roguing, can increase growth 5 – 10%. Tree breeding and seed orchards have a potential for increasing jack pine production 15 – 25%. Some authorities in the southern United States believe the southern pines can be improved much more than this.

There are problems with jack pine in non-destructive cone collection. The cones are very difficult to remove without serious damage to the branch. This will probably mean additional costs in the way of greater care in collection, or more seed orchards will have to be established. In any event, technology and money should be able to solve this problem.

At present the lowest priority for use of any improved seed is in direct seeding. This is understandable when improved seed is scarce and direct seeding of jack pine is wasteful of seed in terms of quantity as well as success.

Perhaps I might suggest, though, that we may be too cautious in our decisions. The amount of improved seed that can be made available in a given time is largely a function of money and effort.

Ontario costs for jack pine seed from a known site region, treated with arasan, latex and aluminum flakes is as follows:

	Per kilogram	Per acre (20,000 viable seeds)
jack pine seed	$58.04	$4.25
treatment	1.10	.10
Total	$59.14	$4.35

The cost of tree planting may be thirty to fifty dollars per acre greater than for direct seeding. This gives us a tremendous margin, some of which could be used for the genetic improvement to give shorter rotations and larger diameters. By the time some of this improved seed is available, our results from direct seeding should be much better.

The cost of seed from a seed production area is estimated to be no more than double the present seed costs. We have no estimate of seed orchard costs.

SEED PROCUREMENT AND HANDLING

Seed procurement is becoming much more critical as silviculture programs increase. This is particularly true for the pines where large increases in direct seeding, with a rather prodigal use of seed, are occurring. More development is needed in cone crop forecasting and mechanization of cone harvesting. A broader use of seed registration is also needed.

The pines show few problems in regular collections. They are usually plentiful, have a fairly high frequency of seed years, and the seed extracts easily and stores well.

Perhaps some additional emphasis should be put on field storage, that important time after the seeds have been coated and shipped but before they have been disseminated. Sometimes in Ontario they are kept for several months, and even over winter, in field offices with limited refrigeration facilities. This may lead to a serious loss of viability.

Our management objective should not be to maximize the acres treated per pound of seed, but conversely, we should control our seed collection by our management objective.

SEED LOSSES TO SMALL MAMMALS

The number of small mammals in a forest usually increases significantly 1 or 2 years after logging, wildfire, or prescribed burn. These mammals may destroy a lot of seed and frequently are reputed to be the cause of direct seeding failures.

Actual facts have been hard to obtain in the past because it has been difficult to trace the seeds to find out what happened. Recent developments in the use of radio tagging of tree seed are supplying more information.

In Ontario we have tended to believe that rodents are only a minor problem in our jack pine seeding program. This belief can not be too sincere since to be on the safe side we have treated our seed anyway, and are continuing research on the use and effect of repellents.

SEED TREATMENT

Various treatments to improve germination have been tried. Stratification and cold soaking are the two commonest, but the danger of damage to the seed during handling and seeding probably offsets any advantages. Jack pine does not require stratification, but there is some evidence that loblolly pine can benefit by stratification after seed coating.

The most important seed treatment is coating with various repellents. The commonest coating is arasan, latex and aluminum powder. Endrin was also generally used but it has been barred in Canada for some time and is becoming much more restricted in use in the United States.

Arasan is used as a fungicide and bird repellent and may have some rodent repellent qualities. Endrin is a rodenticide and rodent repellent. Latex is a binder only. Aluminum powder is a lubricant and a bird repellent. The effect of these materials on the seed germination and on rodents and birds seems to be quite variable. This variability of effects of seed treatments was frequently stressed. In Canada, average stocking with jack pine increased from 27% where there was no seed treatment to 42% with arasan only and 48% with endrin and arasan; it appears that seed treatment helps, however, even with seed treatment there is still seed loss, probably to small mammals.

A new rodent repellent, R-55 is being tested and offers some hope as a replacement for endrin. There is no indication that it is being tested on the pines yet. With the increasing use of pines in direct seedings, this testing should be started quickly.

Pelleting and encapsulating are two other treatments that may be useful for direct seeding. They result in a larger, uniform round ball which may be more resistant to damage and more amenable to precision seeding. Repellents, fertilizers, herbicides and other materials might be used with these treatments. Perhaps a hormone to speed up the rate of root growth in the first few days could be tried.

SITE PREPARATION

Everyone agreed that site preparation is necessary for successful direct seeding. There did not appear to be many conflicts in the type of site preparation, either. Results are best from seeding on mineral soil. They are much poorer on mixed humus and mineral soil and on light burns. Stocking is almost non-existent where there is no disturbance at all.

Mechanical scarification appears to be best although the well named "dip and dive" method which produces deep trenches and scalps is poor. Hand scalping is usually poor. I could add that jack pine can tolerate very severe scarification and often succeeds on heavily bulldozed areas such as landings and road sides. This is borne out by average stocking figures of 69% where bulldozer blades are used for site preparation.

Many types of equipment are used, with the more common ones being bulldozer blades with or without teeth, V-blades, various ploughs, various drags, and fire. A more recent development is to combine the seeding device with the scarifier. The more common types are the furrow-seeder, the mechanical scalper and seeder such as the brackecultivatorn, and seed drums attached to drag scarifiers.

APPLICATION OF SEED

Many methods are used. Aerial broadcasting by helicopter and fixed-wing aircraft have probably accounted for most of the seeding. The fixed-wing aircraft are more commonly used now. Ground broadcasting was often done using a cyclone seeder but now a Brohm seeder on a snowmobile is becoming popular. Hand seeders are still used, but are losing ground to more mechanized methods. The combination scarifiers and seeders are a newer development which shows promise.

The sport and row seeders use less seed but may induce clumping of regeneration. The broadcast seeders avoid clumping but use more seed and may lead to excessive density.

Seeding success in jack pine does not seem to be influenced to any clear degree by the type of seeding or the equipment used.

TIME OF SEEDING

Most jack pine sowing in Ontario is done in the fall. This pattern has developed owing to less pressure from other work and better availability of aircraft.

Assessment results in Canada show a clear preference for spring and early summer seeding, with April, May and June being best. There is some difference of opinion as to the success rating of late winter seeding.

Another factor that should be considered in the timing of the sowing operation is the amount of settling of the seed bed after scarification. There is some evidence that seeding should be delayed 1 or 2 months and perhaps even up to 1 year after the site has been prepared. This opinion is offset by the evidence of acceptable success from the combination scarifying and seeding machines now being used. There are advantages to covering the seed lightly and this occurs when seeding in loose soil, but there is also a danger of deep burying or washing of the seed. The answer to the apparent conflict may lie in the texture of the soil, the slope of the seed spot, and the type of site preparation equipment.

RATE OF SOWING

Sowing rates vary widely. In jack pine the best success in Canadian experience has been with rates of 20,000 – 30,000 seeds per acre. Most aerial seeding has been done at rates of 10,000 – 30,000 seeds per acre. Rates have gradually decreased and now 20,000 and even 15,000 seeds per acre are the commonest rates.

Sowing rates for spot or row seeding are usually 5,000 – 10,000 seeds per acre. The rate of success may be slightly better than for broadcast seeding.

The proper rate of sowing is very dependent on the degree and quality of the site preparation.

GERMINATION AND ESTABLISHMENT

The major factors affecting germination and establishment of seedlings should come as no surprise. Adequate moisture, protection from lethal temperatures and release from excessive competition must be provided. Frost heaving on some sites is also critical.

Many of the contributing factors, such as distribution and amount of rainfall, can not be controlled. A better understanding of the site factors can allow us to make better choices of sites for direct seeding, and help us adapt our site preparation and release efforts more effectively. These site factors are probably the cause of a great deal of the variability and conflicts in the results of direct seeding.

A performance study in Ontario compares seeding, container planting, and bare root planting in jack pine. It is of interest to note that seeded jack pine catches up in height growth to bare root stock during the fifth year.

TENDING

Density control is often stated to be the most urgent need in stands established by seeding.

A common problem with jack pine is too few seedlings, so filling in must be considered. A second seeding must be done soon, before the effect of the site preparation is lost and before too much competition develops. It should not be done too soon or additional germination from the first seeding may make the stand too dense. Frequently a second seeding will increase the existing density but will not fill in the missed areas. Filling in by planting can be very costly.

In general, filling in is costly and chancy and should be avoided if at all possible.

High density is another common problem and it may lead to serious loss of growth and stagnation in the denser parts of a jack pine stand. Pre-commercial thinning may be needed to improve the spacing. The earlier the spacing control is carried out, the sooner the trees can take advantage of the additional growing space. If the work is delayed, costs to space the larger trees may rise, but interest rates are charged for a shorter time. There must be careful studies of costs and results.

Hand thinning with power brush-cutters is a reasonable economic compromise if done when the stand is about 10 years old. Costs rise considerably in older stands.

Research is continuing in fully mechanized methods of thinning in older, larger stands. Various types of row thinning are being tried. There has also been some work done on chemical thinning with aerial application.

At a later stage in the rotation, commercial thinning may be used. The purpose would tend to be to use wood closer to the mill and salvage wood which might otherwise be lost, rather than to promote extra growth.

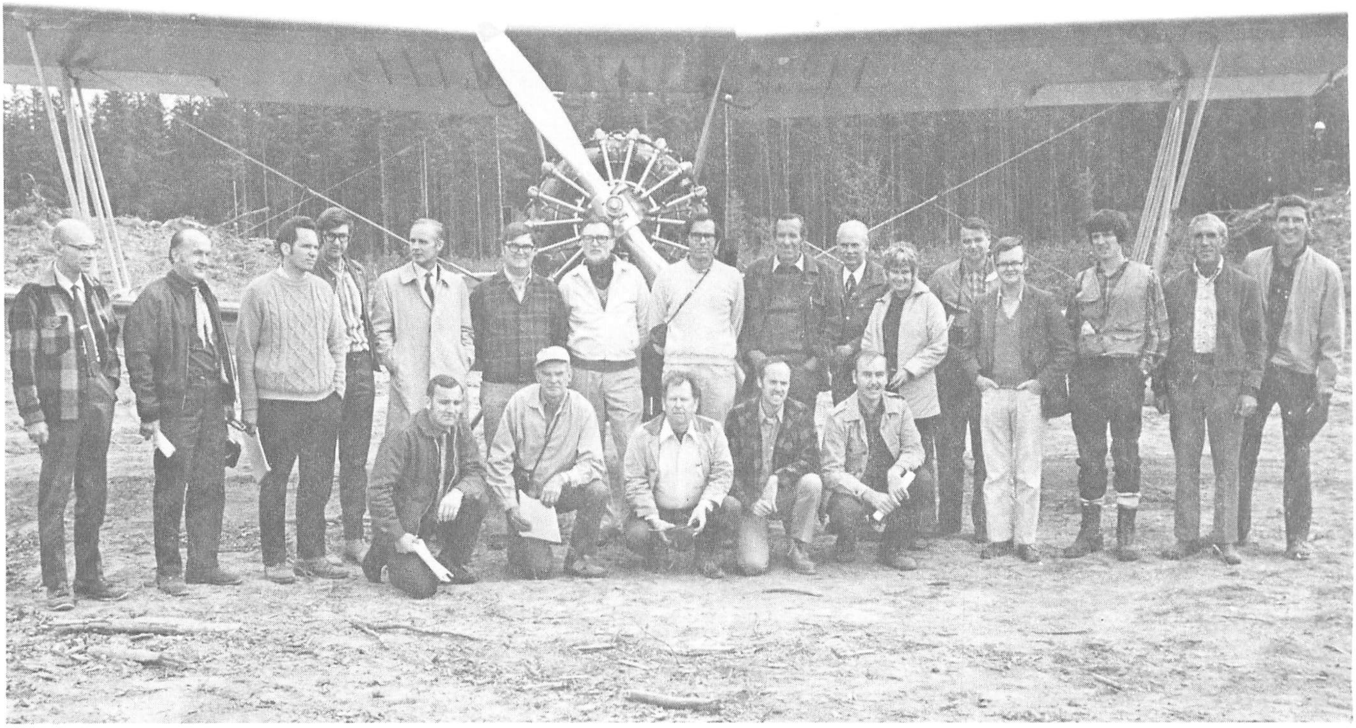
Under present operating systems even a small increase in the average diameter of the trees being harvested can reduce logging costs significantly. The benefits from various tending practices can be well worth the cost of further study and trials.

There is still room for doubt about the need for spacing and thinning in jack pine. A careful study of the objectives should be made. Do we want large trees of high quality, or just fiber? Do we want to make the best use of limited capital or of limited land?

THE FUTURE

Most speakers have made a few suggestion of what the future could hold. Some changes and developments that I think we might expect are:

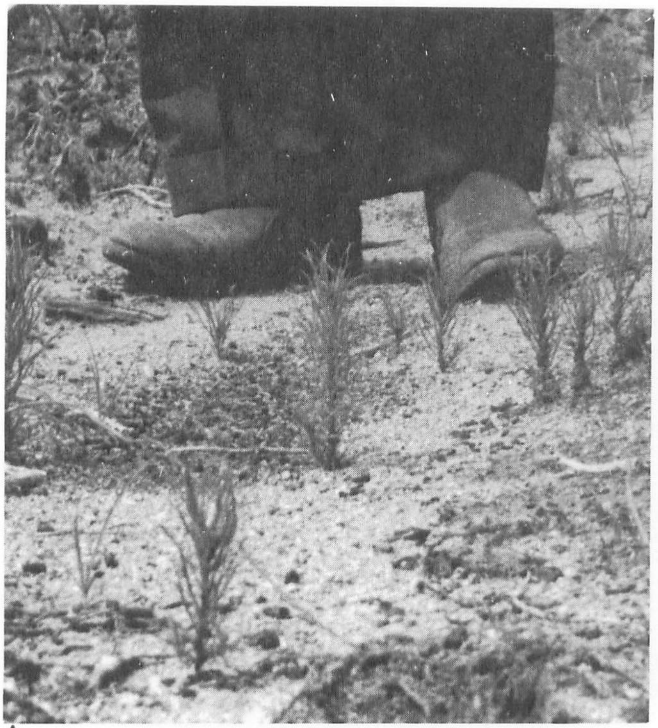
1. Pine seeding will increase. It is not just this year's or this decade's fad.
2. Seeding results will improve considerably just by better use of presently known techniques, particularly site preparation.
3. Tree improvement through genetics will be applied to a greater extent in seeding as techniques of seeding improve and as improved seed becomes available.
4. Better rodent repellents will become available. These will further improve the success of seeding and will influence the increased use of the technique. There is a sort of positive feedback mechanism at work between success, amount of seeding done, and the amount of research in further improvements of techniques.
5. Seed treatments will be developed to allow for precision seeding, proper timing of germination, and the use of herbicides, fertilizers, and other additives.
6. The combination scarifier-seeders will come into more general use, probably as precision, row seeders.
7. Spring sowing of jack pine will become standard, rather than fall sowing.
8. Pre-commercial thinning will become satisfactorily mechanized and will come into more general use; particularly on good sites for high quality products.
9. In the long term future, seeding will be used much less as forest practices become greatly intensified. This prediction may be wrong if swathing of young trees becomes a widespread practice.



Photographs from demonstrations at the Direct Seeding Symposium, Timmins, Ontario, Sept. 11, 12, 13, 1973.

Speakers, members of program committee and session chairmen, Direct Seeding Symposium, Timmins, Ontario, September 11, 12, 13/73. (Standing) R. Griffin, A. Radvanyi, K. Cleary, L. Riley, J. Walters, R. Waldron, J. Fraser, A. Demers, R. Grinnell, F. Robinson, M. Rauter, J. Cayford, J. Richardson, A. Vyse, D. Worgan, R. Haig. (Kneeling) A. Papineau, J. Scott, H. Abbott, J. Arnott, J. Rudolph. *(Ont. Ministry of Natural Resources).*

A.— Jack pine seedlings in second growing season after aerial seeding.
B.— Seeded.jack pine stand 6 years of age, 6,000 stems per acre.
C.— Thinning dense 8-year-old jack pine stand with a brushsaw.
D.— Seeded jack pine stand immediately after thinning to 1,600 stems per acre at 8 years of age. Cost of treatment, $15.00 per acre.


A.


B.

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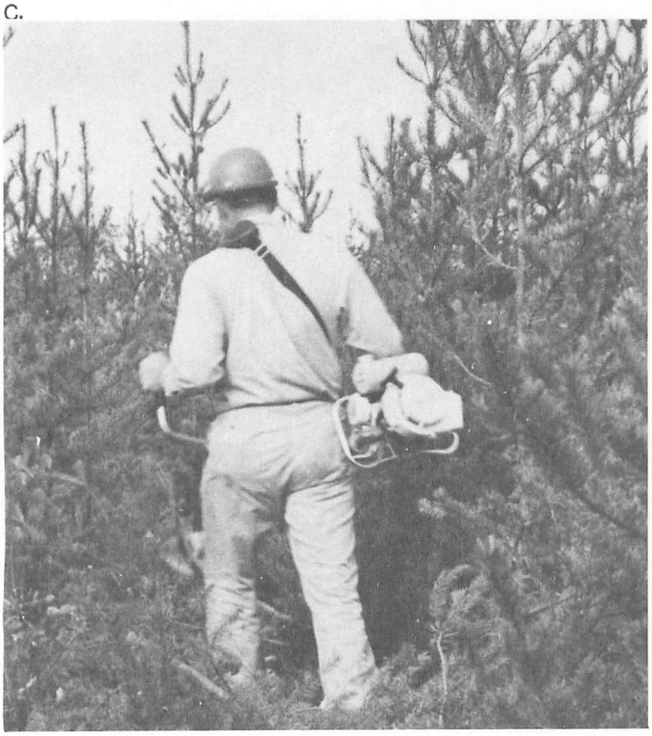
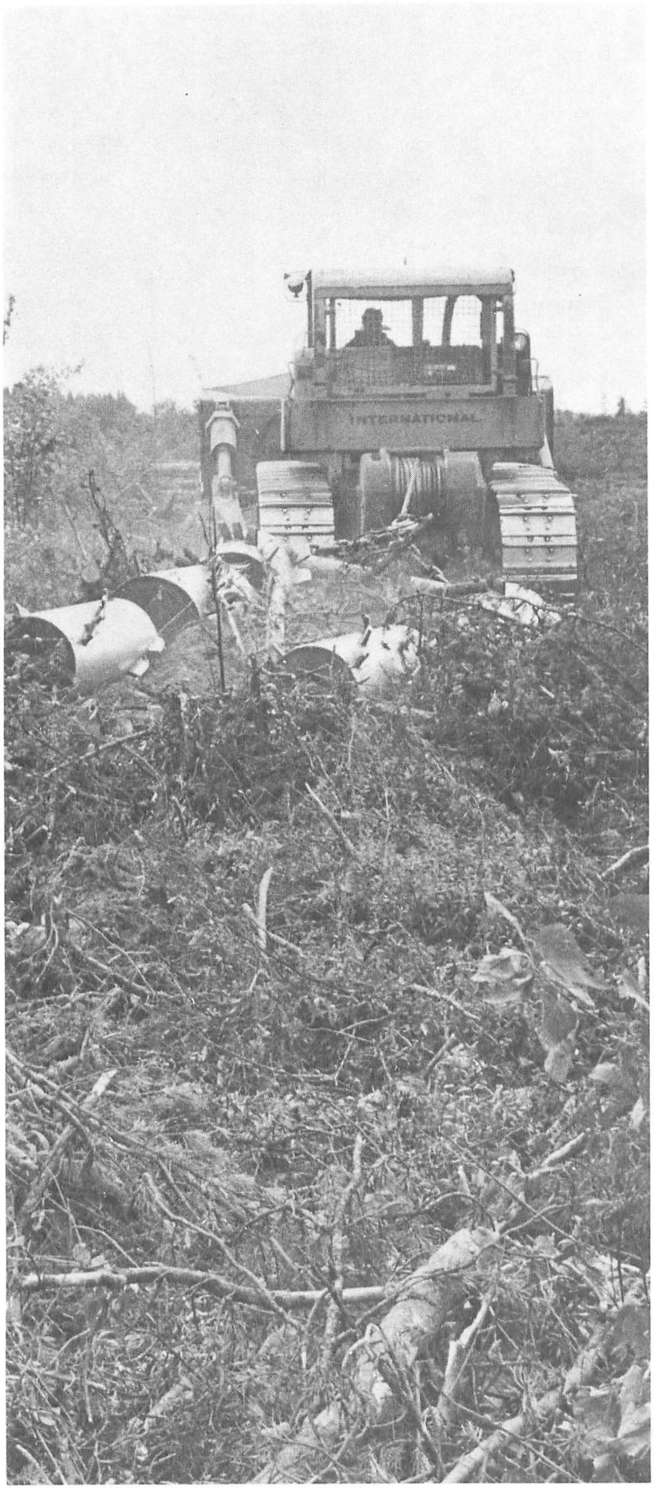
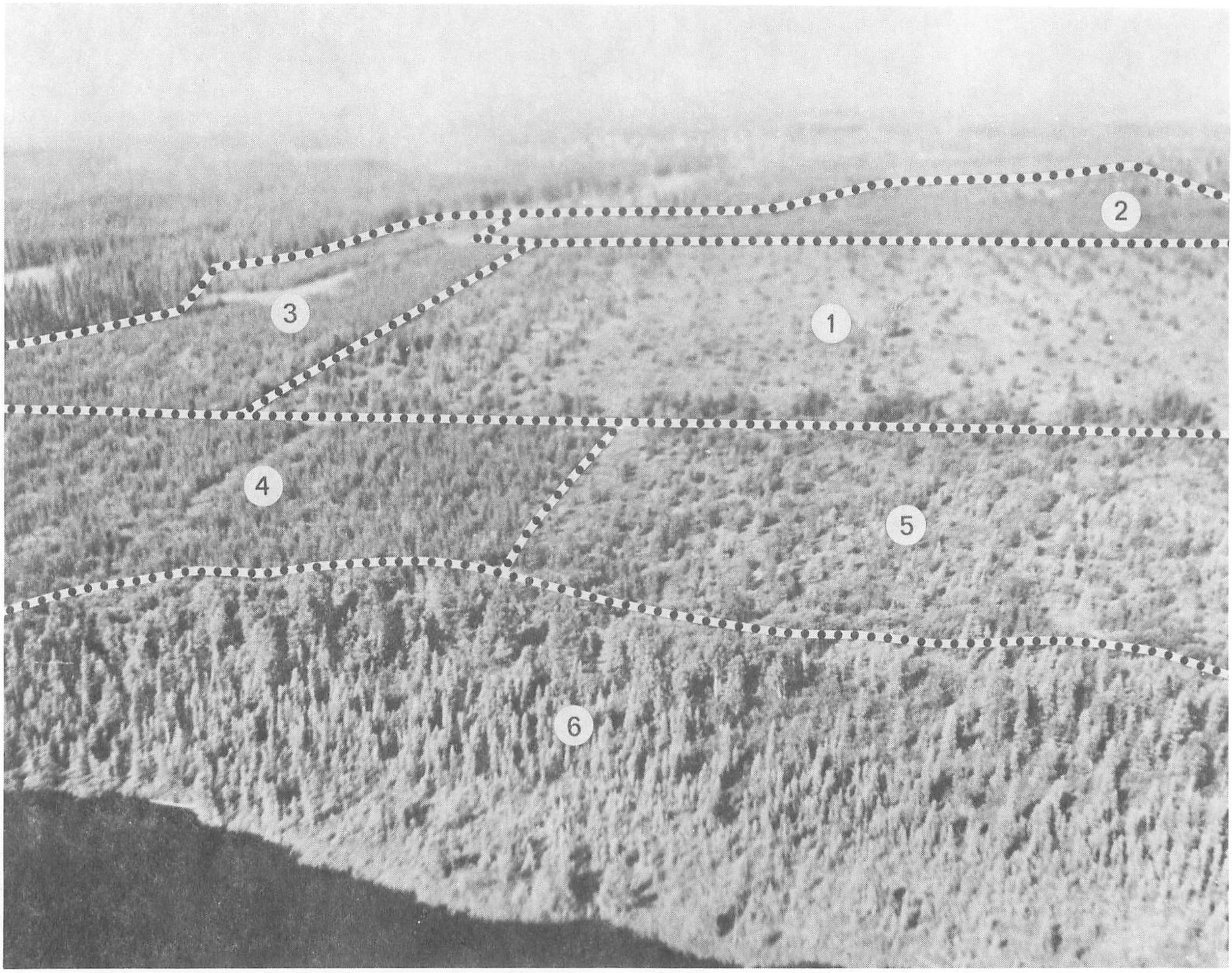


D.


Shark-finned scarifier in Voorman Township for (*Ontario Ministry of Natural Resources*).

Snowmobile seeder designed by Swastika District of the Ontario Ministry of Natural Resources.



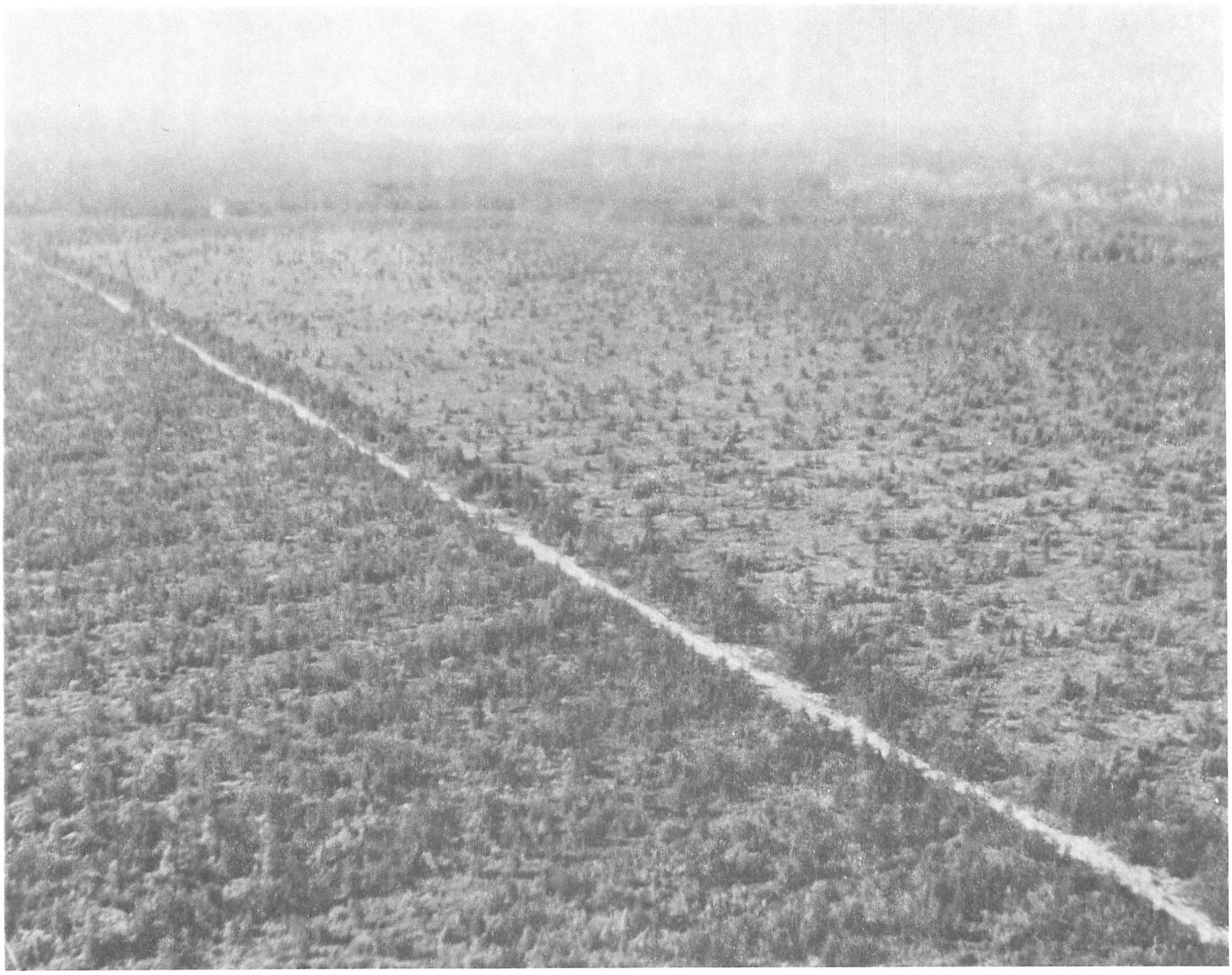


Direct seeding of jack pine, Area A, Benneweis Township. Site preparation in 1961 using detachable teeth mounted on a bulldozer blade.

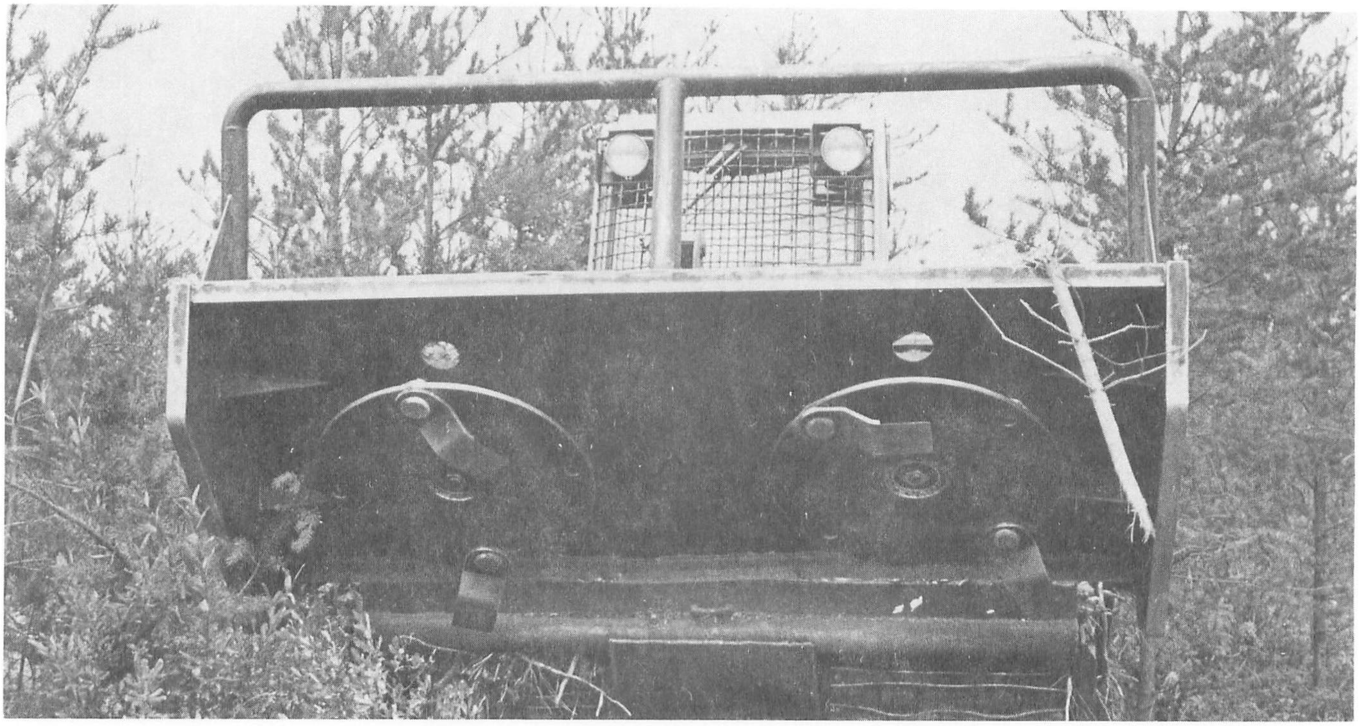
Direct seeding in 1962, both by aircraft and by hand.

1. Control, no site preparation, hand seeding 2 to 5 seeds per spot.
2. Aerial seeding, 40,000 viable seeds per acre.
3. Aerial seeding, 20,000 viable seeds per acre.
4. Aerial seeding, 10,000 viable seeds per acre.
5. Hand seeding 2 to 5 seeds per spot.
6. Shoreline reserve.

(Ontario Ministry of Natural Resources)



Direct seeding of jack pine, Area A, Benneweis Township. The control area with no site preparation and hand seeding at a rate of 2 to 5 seeds per spot is in the center of the picture. The area in the foreground was site prepared and hand seeded at a rate of 2 to 5 seeds per spot. (*Ontario Ministry of Natural Resources*).



Bombardier brush cutting machine. (*Ontario Ministry of Natural Resources*).

Seven-year-old jack pine regeneration, aerial seeding by helicopter in Area B, Voorman Township. (*Ontario Ministry of Natural Resources*).