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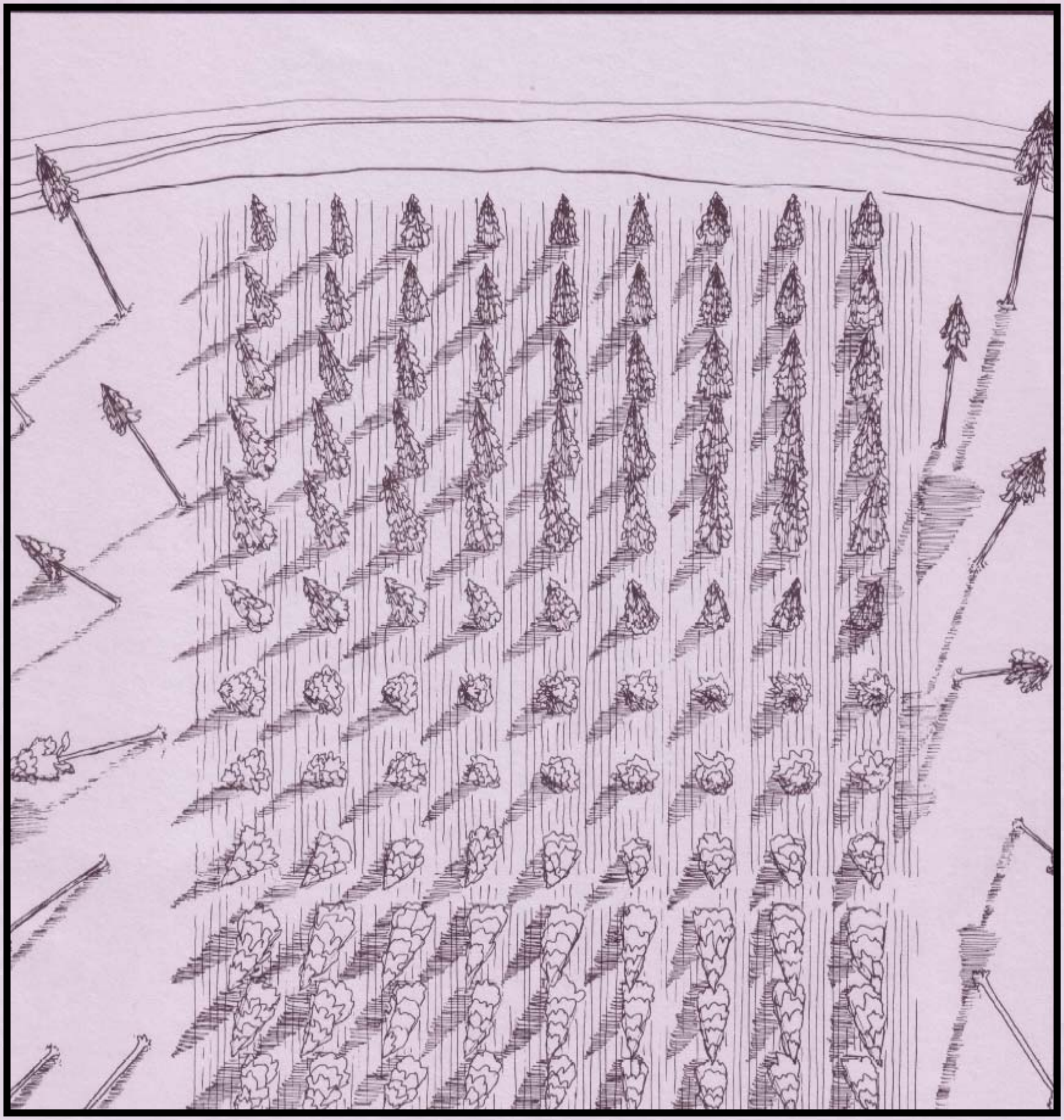
The Yield Advantages of Artificial Regeneration at High Latitudes



THE YIELD ADVANTAGES OF ARTIFICIAL REGENERATION AT HIGH LATITUDES

Proceedings of the

Sixth International Workshop on Forest Regeneration

Edited by

Mayo Murray

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FOREWORD

Edmond C. Packee

The Sixth International Workshop on Forest Regeneration at High Latitudes took place during a period of transition for the forest industry worldwide. The economic slump in the forest products industry had bottomed-out; the planting approach to forest regeneration was being questioned, primarily, but not solely for economic reasons; the future of the workshops on Forest Regeneration at high latitudes was being examined; and changes were in progress within the School of Agriculture and Land Resources Management at the University of Alaska-Fairbanks.

The economic slump in the forest industry began in North America in 1981. The profits of the previous decade evaporated overnight. The concept of sustained yield forest management was being challenged for economic reasons. In the North American west and north, funds simply are not available for long-term investment in forest stand management. Tree planting, one of the more expensive long-term forestry investments, is being scrutinized more closely. Alternatives, including planting of seeds in stead of seedlings, encouragement and acceptance of natural regeneration, accepting longer regeneration periods, and even accepting non-satisfactory levels of stock, are being considered.

Hence, the workshop on "The Yield Advantages of Artificial Regeneration" was most timely. The Workshop group approached this issue from two directions possibly the most important was a field tour of industrial forest lands to observe and assess operational plantations and natural stands. J.D. Irving Ltd. provided access to their operation near St. Leonard, New Brunswick. Their intensively managed forest contains some of the most extensive acreage of spruce plantations in eastern Canada as well as examples of natural stands. The presentation of formal papers addressed the advantages of artificial regeneration and ways of economic evaluation. From both the field observations and the formal papers, artificial regenerations, although fraught with problems, has yield advantages across a large range of sites under a broad range of conditions.

This was the sixth international workshop focusing on forest regeneration at high latitudes. Workshop locations and topics, past and planned are listed on the following page.

The School of Agriculture and Land Resources Management of the University of Alaska-Fairbanks initiated this series of workshops in 1979. However, if it were not for the many cooperators, the workshops would not have succeeded.

Because of the circumpolar interest involving three continents and the international effort, association with an internationally recognized organization was deemed desirable. At the Edmundston, New Brunswick workshop, the group decided to seek IUFRO (International Union of Forest Research Organizations) affiliation. In January 1985 IUFRO affiliation was obtained within Division 1; the group was recognized as Working Party S1.05-12, "Silvi-

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Year	Location	Topic
1979	Fairbanks, Alaska U.S.A.	General problems related to forest regeneration in the circumpolar north.
1980	Umea, Sweden	Forest regeneration problems in Sweden.
1982	Hinton, Alberta, Canada	Forest regeneration problems in north west Canada.
1981	Prince George, British Columbia, Canada	Management of lodge-pole pine in the boreal forest.
1983	Fairbanks, Alaska, U.S.A	Forest classification at high latitudes as an aid to forest regeneration.
1984	Edmundston, New Brunswick, Canada	The yield advantages of artificial regeneration of High Latitudes.
1985	Lulea, Sweden	Forest regeneration at northern latitudes close to timber line.
1986	Ft. St. John, British Columbia, Canada	To be announced.
1987	Finland (tentative)	To be announced.

culture and Management of Northern Forests." Hence, the workshop to be held in June 1985 in Umea, Sweden will be the first as a IUFRO organization.

Finally, there have been changes at the School of Agriculture and Land Resources Management of the University of Alaska. Mr. Anthony F. Gasbarro's responsibilities as Extension Forester have in creased. "Tony", as we all know him, was the prime organizer of the first five workshops and was the individual who held the group together. He is to be applauded for his efforts. In 1983, I joined the Agricultural and Forestry Experiment Station of the University of Alaska. Slowly, I have been assuming the responsibility of the workshop and group. This has been a year of transition and the forthcoming year will equally exciting.

At this time, I would like to sincerely thank the organizers and hosts of the Edmundston, New Brunswick workshop: Dr. David Winston of the Canadian Forestry Service, Ottawa, Ontario, and Mr. Peter Etheridge of J.D. Irving Limited, Sussex: New Brunswick and his colleagues from St. Leonard, New Brunswick for their considerable efforts. Also appreciated are the time and efforts of the authors of the papers in this publication.

EXPERIENCES AND RESEARCH ON YIELD IMPACTS OF ARTIFICIAL REGENERATION AT HIGH LATITUDES IN FINLAND

Mauri Timonen and Martti Varmola

Abstract.-- Artificial regeneration has been used in Finnish Lapland from the 1910's. It is normally used on sites where natural regeneration will not succeed. The most promising results have been achieved when converting thick-moss spruce stands to pine stands. However, extreme conditions have caused partial or total failures especially on high altitudes.

RESEARCH AREA

Finland lies in Fennoscandia between latitudes 60° and 70° N. The southernmost coast belongs to the Central European hemiborealic zone, and the other parts to the borealic zone. The borealic zone changes to the subarctic zone in the northernmost part of Lapland. This paper is mainly concerned with the yield impacts of artificial regeneration in Finnish Lapland, i.e. the north-borealic zone between latitudes 66° and 70° N (fig. 1).

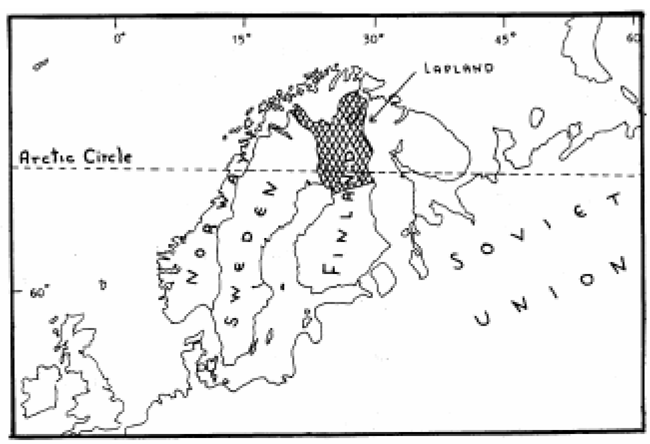

Figure 1.--The geographical location of Lapland, the research area.

CLIMATE IN LAPLAND

The climate in Lapland is cool, but thanks to the proximity of the Gulf Stream and the warm winds coming from the south-west it is more favourable than in parts of Siberia, Alaska or Canada, for instance, lying on the same latitudes. The mean temperature for June is +14° - +16° C (+57°- +61° F) and for February -13°- -10° (9°- 14° F). The length of the growing season, i.e. the period

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during the year when the daily mean temperature is above +5° C (41° F), is 120 - 145 days. The mean effective temperature sum during the growing season, using the same threshold value, is 500-900 d.d. The timberline lies roughly along the 550 d.d. line and at a height of 400 m (1300 ft) above sea level. The annual precipitation is 400 500 mm (160 - 200 in) of which almost half is snow. The climate is very humid, owing to the fact that evaporation in the summertime is even smaller than the precipitation.

Fluctuations in the climate are strong. The annual growth of the forests may vary by 30 - 40 % from the long term mean index. The magnitude of the fluctuations are the greater, the further north the regions are situated.

TREE SPECIES

Scots pine (Pinus silvestris L.) is the most important tree species in Lapland. It covers about 70 % of the forest land and also grows further to the north than Norway spruce (Picea abies Karst.). In addition to these two conifers there are a cou ple of broad-leaved trees which have some commercial importance. Pubescent birch (Betula pubescens Ehrh.) is common especially on peatlands, but it is used mostly as pulp wood. Silver birch (Betula pendula Roth.) grows on sites of the best forest type. European aspen (Populus tremula L.) grows even further to the north than Scots pine, but the timberline is covered by mountain birch (Betula tortuosa Led.) which, however, has no commercial importance.

THE HISTORY OF ARTIFICIAL REGENERATION IN LAPLAND

Forests have been regenerated artificially in Lapland from the beginning of this century. Most of the activity was originally of an experimental nature. Already in the 1910's sowing experiments were made with pine above the timberline even, and owing to the favourable conditions they have grown remarkably well. However, artificial regeneration work was not started on a large scale until the beginning of the 1960's.

The most problematic question in Lapland has been the regeneration of old spruce stands. They often grow on rather moist sites of the Hylocomium-myrtillus type (HMT-type), (Cajander 1949). The old stands are without exception seriously decayed and their growth has ceased.

Alredy in the 1920's promising results were achieved in HMT forests following clearcutting, prescribed burning and changing the tree species to pine. The decisive research effort concerning the problem of regeneration was undoubtedly made by Prof. G. Siren. His doctoral dissertation, pres ented in 1955, dealt extensively with the development of thick-moss spruce stands. He came to the conclusion that spruce stands of the thick moss type represented, in the north, a degenerative secondary stage of the rather fertile Myrtillus type, the potential fertility of this secondary phase being higher than it is at the present.

Converting thick-moss spruce stands, by means of clearcutting and reforestation into their fertile primary stage was from then on the principal aim of forestry programmes affecting Lapland (Leikola 1979). Thus the regeneration method involving clearcutting, soil preparation and sowing, and later on planting with pine became the most popular one. In the 1960's the new method was particularly unsuccesfull on high elevations, where severe damage appeared in the plantations. The main reasons were the exceptionally cool summers, which led to epidemics of various fungal diseases and the use of seed of too southern an origin which could not withstand the extreme weather conditions in Lapland. In the 1960's, after the first serious outbreaks of damage, it was thought that a thorought site preparation method, plowing, would improve the soil conditions. This resulted in it be coming the most popular method of site preparation. During recent years, however, plowing has frequently been criticized as being a method which is too drastic. It has also been used on sites where a lighter method would probably have been sufficient.

As mentioned above, carrying out artificial regeneration on a large scale is a relatively young, less than 30 years old practice in Lapland.

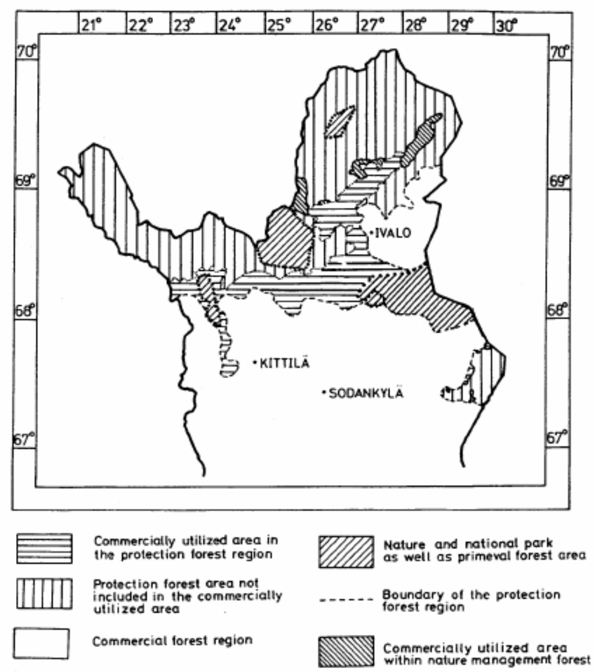

Figure 2.--Land-use classes and protection areas on forestry land in Lapland.

Thus we do not yet have enough results about the yield advantages. Most of the experiments have concentrated on developing different methods which can be used in artificial regeneration. Nowadays the most important question is how to produce viable conifer plantations with a good rate of growth. In conifer plantations established in 1965-1975 by private owners, for instance, only 1/3 of the trees were still capable of further growth in 1983. Thus it is a little difficult to talk about yield advantages, when the main question is how to succeed in regeneration at all. In order to be able to discuss the possible yield advantages of artificial regeneration we first have to assume, however, that the reforestation result is satisfactory.

THE RESULTS OF ARTIFICIAL REGENERATION ON THE POLAR TIMBERLINE

The northernmost pine plantations in the protection forest area were inventoried in 1978. This large area of over 3 million hectares (7,4 million acre) acts as a buffer zone between the fully stocked forests and the tundra (fig. 2). About half of the protection forest area is under commercial utilization. Both the timberline of pine and spruce lie within this area (fig. 2). Over 23 000 ha (57 000 acre) of forest have been established in the protection forest area since the 1910's (Pohtila and Timonen 1980). Reforestation work was earlier carried out through direct seeding, but more recently through planting. Almost all of the reforestation work has been done with pine.

The reforestation result in the protection forest area was quite satisfactory, even better than that in the southern part of Lapland. The mean number of all types of seedling was 1771 trees per hectar (717/acre), of which 45% were natural seedlings. About 1 000 seedlings per hectar (405/acre) (57 %) were classified, on the average, as being capable of further development. Regionally the number of seedlings varied from 730 to 1520 per hectar (297 - 620/acre) (fig. 3).

The oldest plantations growing on the timberline and north of it were over 60 years old. During this period fluctuations in the macrocli mate and the density of plantations were observed. The warm period in the 1930's had brought about better results and the cold 1960's poorer, on the average.

Some other interesting results were found: The number of stems in plantations at altitudes of over 300 m (980 ft) above sea level was clearly lower than in plantations under 300 m. No differences were found between the number of trees in planted and in sown stands, but the transplants had a greater diameter in the planted stands. Plowing was found to improve the success of reforestation. The effect of slope was a positive factor. Stoniness, small mounds and depressions had a negative effect on the success of forestation.

In the light of the stem number, the fact that the result of artificial regeneration above the timberline was surprisingly satisfactory, is an interesting phenomenon (fig. 3, Pakanajoki and Utsjoki area). The development of the cultivations was slow. Dominant height at the age of 60 years was only 6 meters (20 ft) and volume $6 m^3$ /ha (86 cu.ft./acre).

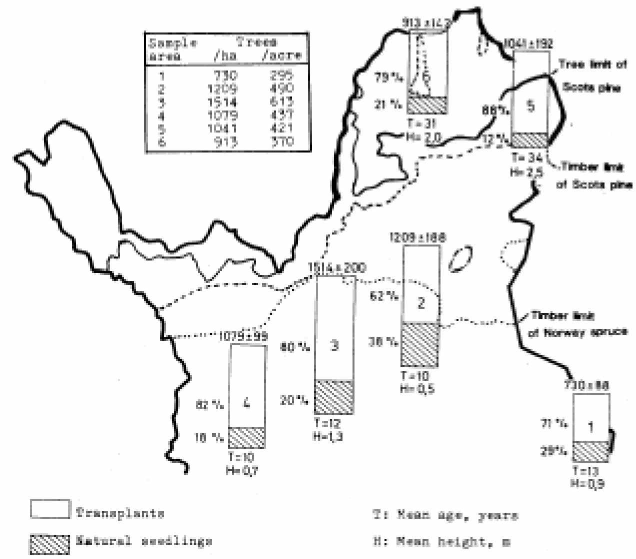

Figure 3.--Number of satisfactory young trees in sample areas: 1 = Tuntsa, 2 = Laanila Vuotso, 3 = Sammalselka, 4 = Kittila, 5 = Pakanajoki and 6 = Utsjoki.

YIELD ADVANTAGES

Vuokila and Väliaho (1980) have discussed the yield advantages between natural and cultivated forests. Their conclusions were based on the idea that all necessary thinnings are carried out in accordance with the yield and growth models for coniferous plantations in Finland. The yield estimates and conclusions may be too optimistic when applied to Lapland, because the material of the models is mainly based on the forests of southern Finland. The natural conditions in the north are very extreme, which means a loss in total yield. However, their growth and yield tables give the best information about the maximum yield advantages during the whole rotation period in Lapland.

Yield differences between artificial and naturally regenerated stands

According to Vuokila and Väliaho, conifer plantations do not produce more in terms of volume than natural stands when grown on sites of the same type, provided that both are managed from the very beginning. In practice the advantage of artifical regeneration can be seen as a quantitative rise in wood production. On good sites especially, there are no real alternatives to artificial regeneration, because natural regeneration is not usually successful on such sites. An in crease in wood production can also be expected if a natural stand originates with openings or it is so uneven that part of the site potential is initially left unexploited.

In conifer plantations there will be a "volume growth loss" in comparison to natural stands. This is due to the wide spacing at the seedling stage and to the strong decrease in the growing stock at an older age. While the stem number at the end of the rotation period in natural stands is over 1 000 stems/ha (400/acre), the corresponding figure is only 400-500 stems/ha (160-200/acre) in commercial forests.

As regards the total volume yield, it would appear that natural regeneration should always be used, whenever possible, in reforestation work . This presupposes that the seedling stock is fully established within a reasonable period of time. In the case of spruce, planting is the only proper method. As regards pine, on the other hand, direct seeding is preferable to planting on sites poorer than the average. On better sites also pine should be planted. The advantage of direct seeding in comparison to planting is the better subsequent quality of the growing stock.

Depending on the site, natural normal, untreated pine stands produce 0,6 - 1,2 m^{3}/ha/year incl. bark (8,6 - 17,2 cu.ft./acre/year) more timber than plantations (fig. 4). Although, proportionally, the loss in a plantation is greatest on poor sites, it is important also on all sites. If we take into account only the growing stock remaining at the end of rotation period, plantations with thinnings gives a greater yield of 0,5 - 1,2 m^3 fha/year incl. bark (7,1 - 17,2 cu.ft./acre/year).

Yield advantages of artificial regeneration on certain sites

The advantages of artificial regeneration on certain sites have to be sought from the structure of the yield, rapid development of the trees and shortening of the rotation period. The wood production of cultivated forests can be guided in the desired direction by applying different thinning programs, developed by Vuokila and Väliaho (1980).

Artificial regeneration is an efficient means of producing sawlog trees and very large-dimensioned timber. According to Vuokila (1970), 900 log stems/ha (360/acre) can be achieved on sites with site index H_{100}=24 (H_{100} = the dominant height at the age of 100 years) during the rotation period by applying repeated moderate thinnings. Using a selection type thinning it is possible to obtain a practical maximum of 1100 - 1200 log stems/ha (450 - 490/acre).

In artificial regeneration, an initial low stem number coupled with intensive silvicultural ly activating low thinnings accelerates the diameter growth in a way which cannot easily be achieved in natural regeneration. The production of logs of 750/ha (300/acre) is, however, lower than the normal level. This yield is 70 % of the maximum to be achieved in practice. As a result, however, the timber is larger-sized than average, particularly in the final felling.

Every year which is gained in growing a new plantation means an increase of one percent in the wood production during the next 100 years on the same site. In many cases, however, artificial regeneration shortens the rotation time by 5 - 15 years in comparison to natural regeneration under Finnish conditions (Putkisto 1980). In addition to this, intensive low thinnings shorten the rotation time by 15 - 20 years (Vuokila 1980).

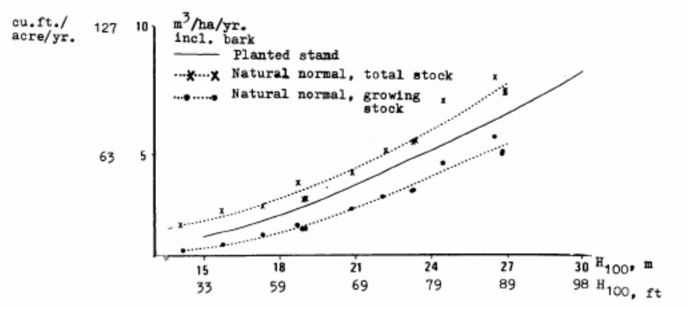

Figure 4.--The mean annual volume growth of cultivations during the rotation time as a function of site index (Vuokila and Valiaho 1980) compared to the corresponding growth values of the total and growing stock in natural normal forests (Ilvessalo 1975) according to Vuokila (1982).

Artificial regeration of Hylocomium-myrtillus site type forests

One very interesting question is the possible yield advantage that can be achieved by converting the old HMT-type spruce stands into pine stands by direct seeding or planting. According to Ilvessalo (1937), a spruce stand on a site of the HMT-type grows very slowly, and reaches a dominant height of 11m (36 ft) in 100 years, 18 m (59 ft) in 200 years and 20 m (66 ft) in 260 years. Gustavsen (1980) classified HMT-type spruce forests in the site index class H_{100}= 12 - 15 m. However, Vuokila and Väliaho (1980) have classified pine plantations on HMT-type sites in the site index class H_{100} = 21 m. The difference between naturally regenerated spruce and artificially regenerated pine stands is remarkable. Ilvessalo (1937) quotes a yield of only 64 m^3/ha (915 cu.ft./acre) for spruce whereas Vuokila and Valiaho (1980), depending on the type of thinning program used, report a yield of 410 - 490 m^3/ha (5900 - 7000 cu.ft./acre) for pine in 120 years. In the figures presented by Vuokila and Väliaho the stands must be fully-stocked and they must not have suffered from any damage.

Problems of artificial regeneration in Lapland

Artificial regeneration is a very useful tool for forest management, since all the work can be scheduled precisely. Natural regeneration is much more difficult in this respect. In spite of the advantages of artificial regeneration there are also some drawbacks that restrict its use in practice in Lapland. Two important problems are discussed.

One of the main problems is the difficulty of regeneration at high altitudes. Climatic fluctuations, unsuitable seed origin and other factors may cause partial or total failures of reforestation. In some difficult areas the establishment of a plantation may take years, sometimes decades. In such a case, the plantation may not be fully established until the next warm period occurs. The very best regeneration methods for these extreme conditions have presumably not yet been developed. The establishment of a new forest at high altitudes may well succeed with time, but it may in volve considerably high costs.

Attention has been drawn to the deterioration of the technical quality of the wood sites throughout the whole of Finland. Wide spacing in plantations increases branchiness, which weakens the use of stems as high-quality lumber. In practice this problem can be avoided by the selection of proper tree species or by pruning, if a stand already exists.

As a rule, artificial regeneration methods work well enough to ensure the rotation of tree generations.

CONCLUSIONS CONCERNING THE ADVANTAGES OF ARTIFICIAL REGENERATION

The first role of artificial regeneration is the establishment of new forests. Natural regeneration is the main method in cases where the conditions are favourable. Artificial regeneration has to be used when natural regeneration gives unsatisfactory results. Its advantages are of course the greater, the more it helps to establish and complete new stands.

The second role of artificial regeneration can be found in individual forests. On certain sites it is not possible, in practice, to in crease wood production by artificial regeneration. Its advantages can be found in the improvement of the structure of the yield, the development of trees and the shortening of the rotation period.

The most promising results with artificial regeneration in Finnish Lapland have been achieved when converting thick-moss spruce stands to pine stands. Changing the tree species from spruce to pine can increase the total yield manyfold. This, however, is more theory than practice, because the growth losses due to failures in regeneration, damage during the rotation period and fluctuations in the climate may be significant. The failures are most probable at high altitudes.

Increasing the dimensions of the growing stock and striving for high technical quality are conflicting production targets especially on good sites. In order to guarantee high-quality forests in the future pruning and other methods are being developed.

Artificial regeneration is a popular method in establishing a new forest. It is used on sites where natural regeneration will probably not succeed. It seems to work in Lapland, on the timber line and above it. However, it is recommended to be used only when the other methods available do not work enough well.

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THE IMPACT OF ARTIFICIAL REGENERATION ON ROTATION AGE IN NORWAY SPRUCE AND SCOTS PINE AREAS IN NORWAY

Martin Sandvik

ABSTRACT: The possibilities for natural regeneration are considered related to site quality and altitude. The most fertile sites have to be artificially regenerated. On medium and poor sites natural regeneration may be achieved. The effect on rotation age reaches from -6 to +40 years compared to artificial regeneration. Lodgepole pine survived and grew better than Scots pine at high altitudes.

INTRODUCTION

The effect of artificial regeneration on rotation age depends primarily on the conditions for natural regeneration created by the climatic and edafic factors. Climatic factors are decisive in flowering induction and seed maturation as well as germination and seedling establishment. Site quality affects the germination and establishment processes mainly by vegetation competition and drainage conditions. This article is dealing with some observations and experimental results concerning the variability in conditions for natural regeneration of Picea abies and *Pinus silvestris* in Norway. Figure 1 shows Norway situated from 58° to 71,5°N, with the native conifers growing primarily in the southeastern and the central parts of the country. The timber line is reaching 1,000 meters above sea level in the southern central Norway at its maximum, and decreases rapidly towards west coast and more slowly to the north. Nearly 1/3 of the total forest area of Norway is situated close to the timber line where low summer temperature restricts natural regeneration most heavily.

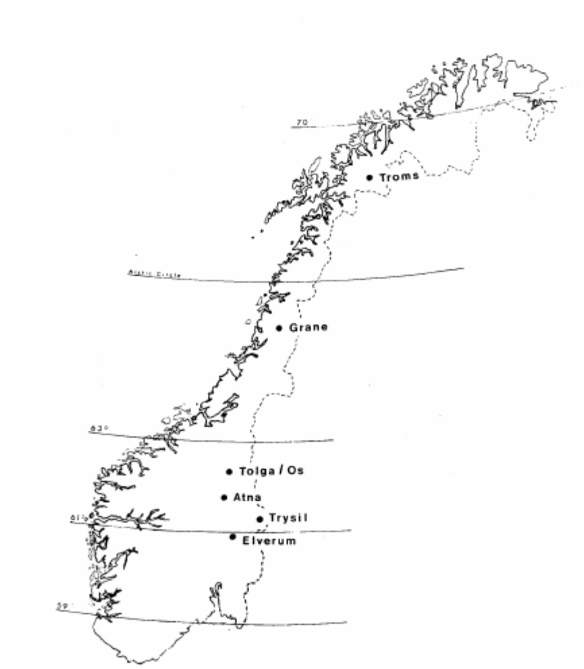

Figure 1.--Distribution of the experimental plots described in Norway.

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FLOWERING AND SEED MATURATION

In Norway spruce the induction of flower buds depends on a fairly high temperature producing a water deficit in the current year shoots within a rather short period in early summer. Cone and seed development the following year is most depen-

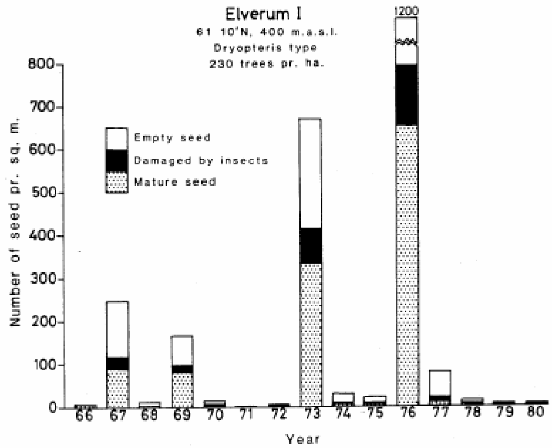

Figure 2.--Seed harvest in spruce shelterwood.

dent on the heat sum between the flushing in spring and the first frost in the autumn. The probability for these temperature requirements to be fulfilled in two subsequent years is obviously decreasing with both latitude and altitude. It is also an experience that the temperature requirement for flower induction is more frequently met than the heat sum requirement for seed maturation the following year in the marginal areas for spruce forests. Approaching the timber line 20 - 30 years may elapse between seed years of any significance in the regeneration process (Mork 1969). Also at lower altitudes seed production in spruce occurs periodically with increasing intervals towards the north. Figure 2 is reproduced from Skoklefald (1983) and illustrates the seed years at a locality in south ern Norway from 1966 to 1980. In this part of the country seed years may occur with 3 to 8 years intervals. It is a common feature that pollination and seed quality are positively correlated with the flowering intensity.

In Scots pine seed years are more frequent than in Norway spruce as seen from figure 3 (Skoklefald 1983). This behaviour may depend partly on the fact that the pine forest usually occupies the most dry and poor soils where water deficits are easily introduced during warm days in early summer, and where restriction of vegetative growth by nutrient shortage is most pronounced.

GERMINATION AND EARLY DEVELOPMENT

Germination conditions are strongly dependent on the site quality. On the best sites spruce germinants are easily outgrown by the vigorous ground vegetation. With a stem-wood production potential of 10 - 20 m^3/ha a year, those sites are considered as obligate planting areas in Norway. Natural regeneration of spruce is most easily raised on medium sites belonging to the ***Dryopteris*** type, either as in advance regeneration towards the end of the

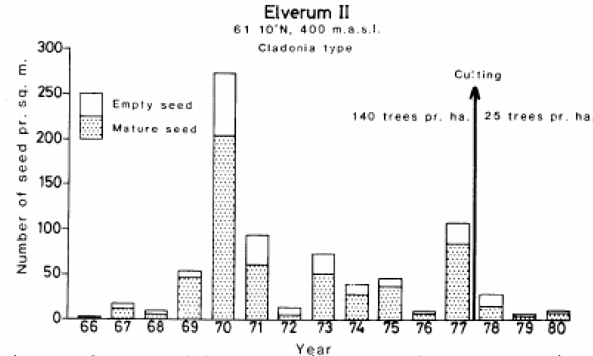

Figure 3.--Seed harvest in a seed tree cutting of pine.

stand phase or after a shelterwood cutting. Results from regeneration studies carried out by Skoklefald (1983) in the southeastern part of the country and by Bergan (1971) in North Norway are presented in figures 4 - 10.

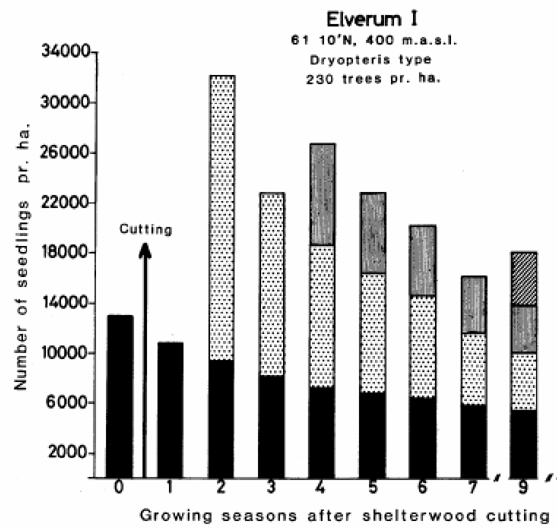

Figure 4.--Germination and mortality among seedlings from different seed years.

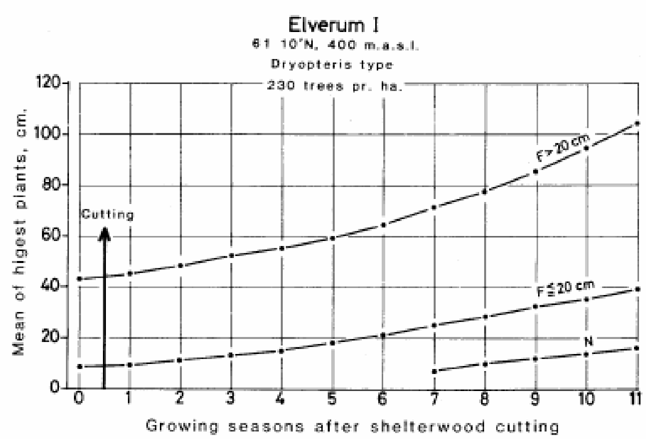

Figure 5.--Mean of highest plant in each 2 x 2m square. F = advanced regeneration. N = regenerated after shelterwood cutting.

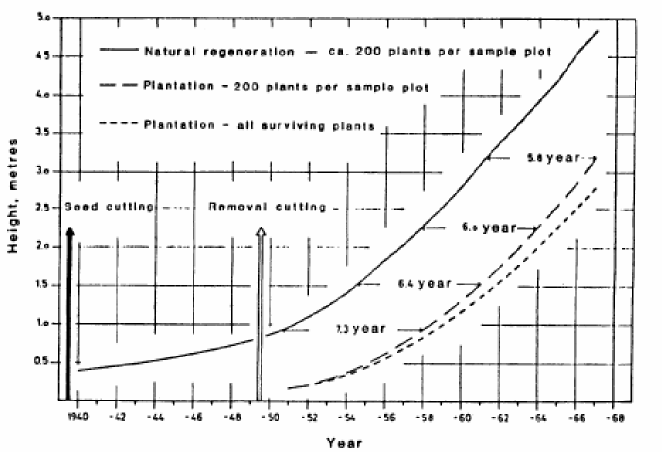

Figure 6.--Height growth of natural regeneration of spruce established before shelterwood cutting compared to seedlings planted just after shelterwood removal. Each sample plot = 900 sq.m.

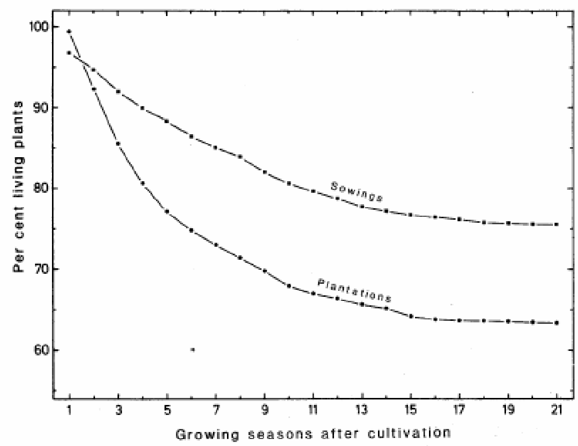

Figure 7.--Survival of planted 2 + 1 bareroot seedlings of Scots pine compared to per cent patches with living plants after direct seeding.

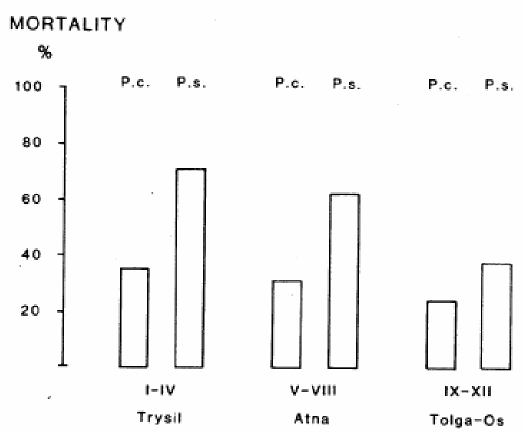

Figure 8.--   Mortality 7 years after comparative planting of lodgepole pine (P.C.) and Scots pine (P.S.) on 12 experimental plots in 3 different areas at high altitudes in southern Norway.

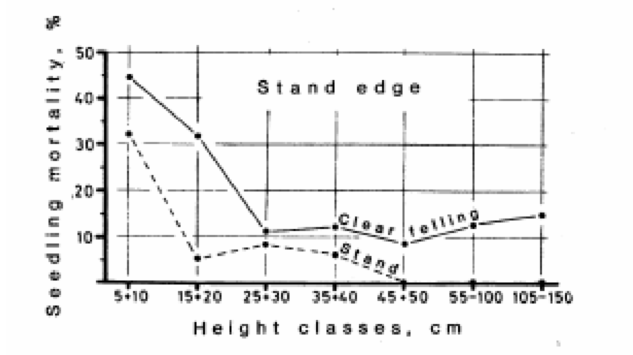

Figure 9.--Mortality among seedlings of different height classes after clear-cutting of stand edge. Regeneration on previously clearfelled area compared to regeneration within stand edge.

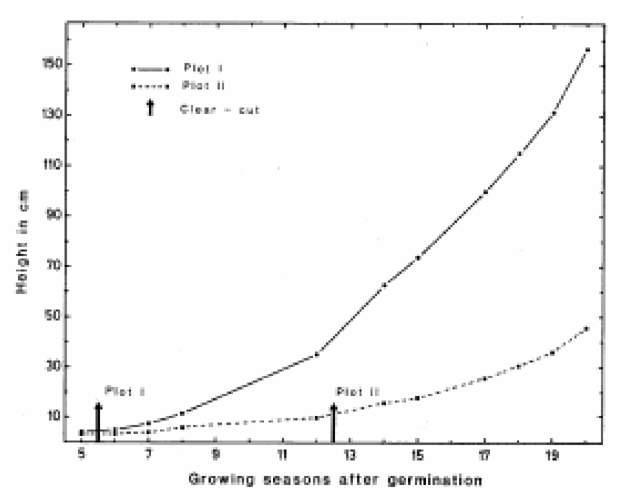

Figure 10.--Height growth of Scots Dine seedlings after removal of the shelterwood at age 5 (Plot[1]) compared to removal at age 12 (Plot II) in Troms county.

By comparing figure 4 and figure 2, both from the same stand, it is seen that a rich seed harvest some years after the shelterwood cutting contributed less to the natural regeneration than a poor to medium seed harvest just after the cutting. Germination and seedling establishment were adversely effected by an increased competition from ground vegetation following the shelterwood cutting.

Attention should be payed to the contribution from the in advance regeneration and to the effect of different height classes on the rotation age.

At cutting age 11 (fig. 5) the development of in advance regeneration from the height class ≥20 cm was at least 15 years ahead of seedlings established during the shelterwood period.

Bergan (1971) in his study compared the development of in advance regeneration on a ***Dryopteris*** type with seedlings planted just after shelterwood removal (fig. 6). The in advance regeneration was 20 - 25 years old at the time of planting. At a plantation age of 16 the height development of the in advance regeneration was approximately 6 years ahead of the planted seedlings. No additional regeneration occured during the shelterwood period in this case. It is concluded from these experiments and others that in advance regeneration above 20 cm in height - even if the vitality of the plants looks poor - will secure the establishment of a new stand when the spacing is acceptable. On the other hand, where in advance regeneration is missing at the end of the stand phase, a seed year has to occur within 3 - 4 years after shelterwood cut ting if a successful regeneration should be expected. Later on exposure of mineral soil by scarifycation would be a prerequisite for germination and seedling development. By scarification in a cone year, natural regeneration may succeed also on the *Myrtillus* type where a thick humus layer otherwise obstructs germination and seedling establishment.

The less fertile *V*accinum type is most frequent on sediments and moraine areas in the lowland. In southeastern Norway mixed stands of spruce and pine are easily established, with spruce as in advance regeneration supplemented by pine during an edge regeneration or seed tree period.

In Troms, Bergan (1981) observed that natural regeneration mainly occured in advance of seed tree cutting even in pure pine stands of the *Vaccinium* type. He also registered a higher freqency of empty scarified patches after planting of 2 + 1 bare rooted Scots pine seedlings than after direct seeding in a comparative study in the same area (fig. 7). At age 20, however, the height development of planted seedlings was 4 - 5 years ahead of direct seeding.

The poorest sites occur as *Cladonia* type in arid regions in the inland and as *Calluna* type in more humid climate in the coastal regions and at high altitudes in southeastern Norway. These types are typically pine areas. On the *Cladonia* type in advance regeneration is a common feature which may give rise to new stands at lower altitudes. At high and harsh areas - in the so-called mountain forest - both natural and artificial regeneration of Scots pine are frequently and heavily injured by fungi as *Phacidium infestans* and G*remeniella abietina.* This makes regeneration investments a hazardous one on those areas as far as Scots pine is concerned.

On the more wet *Calluna* type a thick rawhumus layer and the height and density of the ground vegetation offer very poor conditions for germination and seedling establishment. This type occurs also on shallow soil at low altitudes. Owing to the poor site quality the stand density is usually low, and Scots pine is often mixed with starving trees of Norway spruce. A clear cutting of spruce combined with a seed tree cutting of pine followed by scarification seems to be the most reasonable regeneration method on this type in the lowland. During the last decay, however, increasing attention is paid to afforest clear felled areas on poor sites with *Pinus Contorta* also in Norway. This is particularly put in practice at high altitudes where regeneration of *P*inus *Silvestris* is experienced to be heavily injured by the abovementioned fungi.

In figure 8 is presented average mortality 7 years after planting of *Pinus contorta* and *Pinus Silvestris* on 12 experimental plots at high altitudes in southeastern Norway (Dietrichson & Tutturen 1983).

In addition to the higher survival, lodgepole pine is expected to increase the yield by 20 - 30% and decrease the rotation age even more compared to established Scots pine.

REMOVAL OF SHELTER AND SEED TREES

During shelterwood or seed tree removal, logging operation and slash cover will cause a loss of seedlings. Factors affecting this loss may be shelterwood density and amount of slash, seedling height and the logging season. An example from a study on spruce shelterwood carried out in southeastern Norway by Skoklefald (1967) is shown in table 1.

Table 1--Seedling mortality in per cent on slash-covered and slashless ground after shelterwood removal Spruce

Time of felling	Slash cover (cm)	Height Classes (cm) 5+10	15+20	25+30	35+40	45+50	55+100	Total mortality (≤100cm)
Autumn	0	36.4	16.7	0	0	0	3.7	8.2
	10-25	31.3	24.4	24.0	23.5	12.5	0	22.5
	30-50	81.3	52.8	64.7	40.0	50.0	36.8	54.5
Winter	0	25.0	17.5	12.5	0	0	5.8	10.3
	10-25	44.4	22.2	40.9	11.1	40.0	37.5	31.3
	30-50	66.7	80.0	80.0	50.0	66.7	19.4	48.4
Spring	0	8.3	32.3	11.1	5.9	4.6	8.2	12.7
	10-25	50.0	17.7	0	0	0	0	9.1
	30-50	-	-	-	-	-	-	-

Seedling smaller than 25 - 30 cm are easily wasted during and after shelterwood removal. Mortality increases considerably with increasing amount of slash which also leads to a more irregular spacing. Felling season usually has less influence than suggested in table 1. The same detrimental effects of logging operations are also experienced when edge regeneration is applied instead of shelterwood cutting (fig. 9).

Bergan (1981) studied the effect of pine shelter wood on seedling growth in Troms.

At age 20 the height development was depressed by 6 years in rotation age when the shelterwood period was prolonged from 5 to 12 years (fig. 10) The difference in shelterwood yield, which was not observed in this case, has also to be considered when the best time for shelterwood removal is calculated from an economical point of view.

CONCLUDING REMARKS

Natural regeneration of Norway spruce and Scots pine is most profitable when occuring in advance towards the end of the stand phase. The seed lings height is critical for the survival after clear cutting and should be at least 20 - 40 cm, depending on the stand density and the amount and dispersal of slash. The vitality of in advance spruce regeneration may be increased by a shelterwood period of 5 - 6 years. Experimental results from the northern part of Norway indicate a shortening of the rotation age by 5 - 6 years for this regeneration compared to regeneration by planting 2 + 2 bare rooted spruce seedlings.

On medium and poor sites with limited competition from the ground vegetation - i.e. on the ***Dryopteris*** and ***Cladonia*** types - a successful natural regeneration may be achieved by a shelterwood or seed tree cutting. Rotation age is then expected to be prolonged by 5 - 10 years in the lowland and until 40 years at high altitudes compared to plantations of vigorous seedlings. A successful breeding strategy may add years to these differ rences. On poor sites at high altitudes in Norway, afforestation by lodgepole pine seems profitable when established at a density of approximately 1,000 tress/ha.

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DEVELOPMENT OF WHITE SPRUCE PLANTATIONS AT THE PETAWAWA NATIONAL FORESTRY INSTITUTE CHALK RIVER, ONTARIO

W.M. Stiell

ABSTRACT: Growth and yield characteristics are reported for white spruce plantations established 1922 to 1940, mostly on old field sites. Main research was in thinning and the development of yield tables for unmanaged stands, based on site index and initial planted spacing. A widespread root rot, Polyporus tomentosus has caused significant mortality in some plantations.

INTRODUCTION

Location and Description

The Petawawa National Forestry Institute is located in the Ottawa River Valley, within the Middle Ottawa Section L.4c of the Great Lakes-St. Lawrence Forest Region (Rowe 1972), at 46°00'N latitude and 77°26'W longitude. The climate is continental and sub humid with consequent extremes of heat and cold. Some relevant statistics are as follows:

Mean annual temperature	4.3°C	(39.7°F)
Extreme maximum temperature	38.9°C	(102.0°F)
Extreme minimum temperature	-40.6°C	(-41.1°F)
Minimum frost-Free period	ca 100 days	
Average growing season	136 days	
Average total precipitation	82.2cm	(32.4 in)
- Falling as rain	61.2cm	(24.1 in)
Average snowfall	210.4cm	(82.8 in)

The institute area may be considered lowland, ca 90 to 275 m (295 to 902 ft), and is generally undulating to flat. The entire area is underlain with Laurentian gneiss and granite. Six major landforms can be distinguished: (i) ridges and hills of shallow till; (ii) low ridges and hills of water-worked, more sandy till; (iii) broad rolls of moulded, loamy till; (iv) terrace out wash and delta sand plains; (v) sand dunes; and (vi) lakebed sands and silts. The dry climate and sandy landforms favour the natural occurrence of pine species.

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Forest History

The first forest exploitation was in the extensive stands of white and red pine then [1/] prevalent. Following logging and fire the second growth forest (post 1878) was predominantly mixed in character and represented numerous species. Conifers included white, red, and jack pine, black and white spruce, tamarack, balsam fir and white cedar; and hardwoods trembling and large-tooth aspen, white and yellow birch, red and sugar maple, beech and basswood.

Some of the Institute lands were cleared for settlement, with further associated fires, but generally they proved submarginal for agriculture. In 1904 the area was purchased from the Ontario Government by the military authorities, and privately owned lands within it were all expropriated by 1910. In 1917 the Canadian Forestry Service, at the request of Dept. National Defence, took over management of the forest on the military lands--about 260 km^2 (100 mi^2) , and a few years later embarked on a program of forest research; this program still continues on a more limited area of 98 km^2 (38 mi^2).

One of the early forestry efforts was to plant up the abandoned fields which had been standing fallow since 1910; later poorly stocked old burns were reforested as well.

Planting Sites

The commonest plantation soils are waterlaid sands and gravels (some interbanded with or overlain by lacustrine silts or windblown sands), and moulded tills which overlay bedrock--usually for a depth of a few metres. These soils are some what acid about pH 6 in the upper 7.5 to 10 cm (3 to 4 in). They are weakly podsolized, and have poorly developed profiles with L, F, A2, and B horizons, usually farmed to an As B type. Fertility is low, but foliar analysis indicates that windblown materials contain more available nutrients. Parent materials are chiefly siliceous, with small amounts of feldspar and biotites. At the time of planting, the old fields were free of tree growth, with the exception of occasional volunteers. They supported a herbaceous cover which had formed a moderately heavy sod or, on the drier sites, a blueberry--sweet fern (<u>Vaccinium</u>-<u>Comptonia</u>) type of vegetation.

About 9% of these plantations were in pure stands of white spruce, with 34 stands being planted from 1922 to 1940. The object of these test plantations was to find out how the species would perform on the soils in question, and at various spacings, and growth and yield studies made in them is the subject of this paper.

TREE IMPROVEMENT

A separate program, which will merely be touched on here is tree genetics and breeding. Small trials comparing the growth of white spruce from Petawawa, Quebec and the Maritimes were planted in 1922 and 1936, but it was after 1949 that there was a major expansion in research on the genetics of this species. This work included the study of variation among provenances grown from seed collected in stands throughout the range of white spruce, the study of variation among individual trees in a single stand, and the testing of progeny from the controlled breeding of selected trees. The provenance research, which involved large-scale trials not only at Petawawa but elsewhere in Canada and the United States of America, has identified some provenances giving superior performance over a wide range of locations where they were planted. Notably, this apparent superiority, so far to age 30 years or less, is exhibited by provenances from locations in the Upper Ottawa Valley, such as Beachburg and Douglas. Results of other research have shown that there is also a large amount of genetic variation in growth rate among individual trees. Present research places greater emphasis on the development and testing of effective ways to harness the variation in this species for the production of genetically improved planting stock for use in forest renewal now and in the future.[2/]

GROWTH AND YIELD OF TEST PLANTATIONS

Sample Plots

First observations in the plantations were taken at a young age, involving systematic samples of survival and total height in a certain proportion of rows. The main vehicle for research however are permanent sample plots (PSPs) of which ca 60 were ultimately established in white spruce. On each of these every tree is permanently identified with a numbered tag at breast height, its position mapped and its measurements recorded separately.

PSP measurements are usually carried out at lO-year intervals, although as-year remeasure ment may be made for short-term growth determination. Characteristically at measurement, d.b.h. is taken on all trees with a diameter tape, and a smaller, systematic sample is taken of tree height and form class. Special purpose measurements, e.g. crown length and width, diameters at other points on the stem, or cone counts may be taken on a subsample. Observations are now accumulated in the field with a Datamyte recorder. Compilation is carried out by com puter, and includes the solution of parabolic equations for height/diameter relationships and

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[1/] Scientific names of tree species are those in R.C. Hosie's <u>Native Trees of Canada</u>, 8th ed. (Fitzhenry & Whiteside, Don Mills, Ont., 1979).

[2/] Information provided by Dr. Gordon Murray, Tree Breeding and Tree Genetics Project, Petawawa National Forestry Institute.

the calculation of tree volumes from volume tables. The data are printed out in stand tables which give numbers of trees, basal area, total volume and merchantable volume for each 2-cm diameter class, as well as sub-totals and per plot and per-hectare totals. Biomass of individual tree components and of the whole tree may also be calculated.

Growth Characteristics

Height growth of plantation white spruce at Petawawa does not appear to be consistently related to physiographic site, as defined by soil parent material or moisture regime (Hills and Pierpoint 1960), with plantations over the range of moisture regimes encountered (1 to 5) being found in every site index class (Stiell and Berry 1973). Considerable variation in early height growth is found, with time to reach breast height ranging from 6 to 12 years. That within-stand variability is sustained was shown in one sample of plantations, from 1.5 m (5 ft) to 9 m (30 ft) tall where the coefficient of variation in aver age height was almost constant at ca 31% (Stiell 1955). Height growth, therefore, cannot be predicted with much assurance before a stand age of 15 to 20 years. Owing to shade tolerance of the species, large numbers of smaller trees survive long after the crowns have closed over them, ultimately succumbing to suppression.

The range of diameters in a stand is likewise quite wide and increases with mean diameter at breast height. About a 25.4-cm (10-in) spread is not unusual in plantations with mean dbh of 12.7, 15.2 or 17.8 cm (5, 6 or 7 in). The mean is strongly influenced by stocking level, increasing with wider spacings.

Closed canopies are extremely dense, shading out nearly all ground vegetation. In these conditions the ratio of the live crown length to total height can exceed 50% for dominant trees, and dead branches below the crown can persist in a sound condition for at least 25 years. Oven-dry foliage weights of up to 25 kg (55 lb) were found for individual crowns, and 14,515 kg/ha (12,950 lb/ac) (Stiell 1969).

Root excavations in thinned and unthinned parts of a 39-year-old plantation growing on deep sands showed mean radial spread of laterals up to 78% of the height of a dominant tree 17.1 m (56 ft) tall. The laterals, mostly occurring in the top 0.3 m (1 ft) of soil, were still increasing at ca 0.3 m/yr. Taproots and sinkers were common, descending as deeply as 3 m (10 ft). Intertree grafting was common in both parts of the stand (Grose 1968).

Insects and Diseases

Four main pests have concerned these plantations. An outbreak of spruce budworm (Choristoneura fumiferana Clem.) in the late 1960's and early 1970's was successfully controlled on research areas by annually spraying them with chemicals from the air. A root rot Armillaria mellea (Vahl ex Fr.) Kummer has killed potential crop trees at scattered points throughout the plantations. A stem canker Cytospora kunzei Sacc. is prevalent and recurs in managed plantations even after thinning infected trees. This canker, observed to be self-limiting in a number of instances, is not considered to pose much of a threat at Petawawa.

Much more serious is the root rot caused by Polyporus tomentosus Fr. This disease, wide spread in the boreal forest, and identified in planted white spruce from Saskatchewan to Nova Scotia and Prince Edward Island is spread by root-to-root contact (Whitney 1977). Death of trees in groups often occurs. There does not seem to be natural immunity and all sizes of trees can be affected although the smaller ones succumb more quickly. The fungus grows slowly, taking at least 15 to 20 years to kill a tree after infection. At Petawawa the disease usually does not appear in plantations less than 25 or 30 years old. There is no feasible control measure yet.

Volume Tables

Since pure stands of white spruce rarely occur in the natural forests of central Canada a study of tree taper and volume was undertaken for the plantations, involving the felling and sectioning of 455 trees. Tables of total cubic volume, merchantable cubic volume, and board foot volumes, as well as taper curves by I-in dbh and 10-ft height classes, were prepared (Berry 1969). A cubic-metre version of the total volume table for trees 4 to 22 m tall and 4 to 40 cm in diameter was subsequently derived (Berry 1980). These tables are directly applicable to plantation trees.

Yield Tables

Accumulated plot data have been used to develop yield tables for untreated plantations by 5-year age classes, based on site index and initial planted spacing. Utilizing data only from those plots showing high initial survival and in which virtually all subsequent mortality has been due to mutual competition, these tables have passed through several editions, having been updated and extended after successive remeasurements (Stiell and Berry 1967 and 1973, Berry 1978).

The general method of construction was to estimate stand parameters at successive ages according to regressions relating them to various combinations of dominant height and spacing (trees/ha) (Stiell 1973). The first step was to prepare a set of anamorphic site index curves showing dominant height in metres for SI Classes 15, 18, 21, and 24 m (49.2, 59.0, 68.9, and 78.7 ft) at base age 50 years from planting. Next, a set of survival curves, based on initial spacing and dominant height, was generated by predicting numbers of trees dying from suppression for each I-m increase in stand height. At each 5-year interval, basal area and total volume were calculated from regressions relating them to the numbers of trees and dominant height of the stand at that age. Mean diameter was calculated

Table 1 – Yield table for unmanaged white spruce plantations (site index 21)

Age from plant-ing (years)	Domin-ant height (m)	Average height (m)	Planted spacing (m)	Trees per ha (no.)	Mean d.b.h. (cm)	Basal area/ha (m^2)	Volume/ha		Mass/ha		
							Total (m^3)	Merch (m^3)	Total tree (t)	Total stem & bark (t)	Merch stem & bark (t)
20	8.4	6.4	(1.25	5820	7.40	25.1	88	43	44	37	18)
			1.50	4160	8.28	22.4	78	44	39	33	19
			1.75	3148	9.08	20.4	70	44	35	30	19
			2.00	2467	9.83	18.7	64	43	32	27	18
			(2.50	1600	11.28	16.0	54	42	27	23	18)
			(3.00	1111	12.62	13.9	47	39	24	20	16)
25	11.0	8.5	(1.25	5175	9.14	34.0	152	102	76	65	44)
			1.50	3774	10.19	30.8	135	96	68	57	40
			1.75	2920	11.13	28.4	124	95	62	53	41
			2.00	2340	11.99	26.4	114	91	57	49	39
			(2.50	1591	13.65	23.3	99	86	50	42	37)
			(3.00	1111	15.38	20.6	87	79	44	37	34)
30	13.6	10.7	(1.25	4477	10.94	42.1	226	176	113	96	75)
			1.50	3312	12.15	38.4	203	162	102	86	69
			1.75	2613	13.19	35.7	186	154	93	79	66
			2.00	2137	14.16	33.6	174	148	87	74	63
			(2.50	1526	15.89	30.3	155	138	78	66	59)
			(3.00	1111	17.71	27.4	138	127	69	59	54)
35	15.9	12.8	(1.25	3790	12.72	48.2	295	245	148	126	105)
			1.50	2867	14.02	44.3	267	224	134	114	96
			1.75	2298	15.16	41.5	247	212	124	105	90
			2.00	1918	16.16	39.4	233	205	117	99	87
			(2.50	1426	17.91	35.9	210	191	105	89	81
			(3.00	1093	19.66	33.2	191	176	96	81	75)
40	17.9	14.8	(1.25	3230	14.40	52.6	355	302	178	151	128)
			1.50	2480	15.82	48.7	324	279	162	138	119
			1.75	2022	17.02	46.0	303	267	152	129	114
			2.00	1715	18.04	43.8	286	252	143	122	107
			(2.50	1320	19.78	40.5	261	238	131	111	101)
			(3.00	1053	21.40	37.9	242	223	121	103	95)
45	19.5	16.4	(1.25	2782	15.95	55.6	402	342	202	171	145)
			1.50	2180	17.41	51.9	371	323	186	158	137
			1.75	1804	18.63	49.2	348	306	174	148	130
			2.00	1551	19.64	47.0	330	294	165	141	125
			(2.50	1227	21.35	43.9	304	277	152	129	117)
			(3.00	1009	22.85	41.4	284	261	142	121	111)
50	21.0	18.0	(1.25	2414	17.50	58.1	446	379	224	190	161)
			1.50	1917	19.02	54.5	413	359	207	176	153
			1.75	1606	20.24	51.7	388	341	195	165	145
			2.00	1403	21.25	49.8	371	330	186	158	141
			(2.50	1139	22.89	46.9	346	315	173	147	134)
			(3.00	960	24.30	44.5	325	299	163	138	127)
55	22.1	19.2	(1.25	2148	18.79	59.6	476	405	239	203	173)
			1.50	1817	19.95	56.8	449	391	225	191	166
			1.75	1536	21.19	54.2	425	374	213	181	159
			2.00	1302	22.48	51.7	401	357	201	171	155
			(2.50	1075	24.06	48.9	376	342	189	160	146)
			(3.00	921	25.41	46.7	356	328	179	152	140)
60	23.2	20.5	(1.25	1928	20.07	61.0	506	430	254	215	183)
			1.50	1572	21.61	57.7	473	412	237	201	175
			1.75	1349	22.83	55.2	449	395	225	191	168
			2.00	1202	23.79	53.4	432	384	217	184	171
			(2.50	1010	25.29	50.7	406	369	204	173	157)
			(3.00	880	26.57	48.8	388	357	195	165	152)

Table 2 - Total production, merchantable m^3/ha (ft^3/ac), after three thinnings from below

Residual basal area, m^2/ha (ft^2/ac)	18.4	(80)	25.3	(110)	32.1	(140)	Control	
Thinnings 1958 + 1968 + 1978	148.9	(2128.0)	140.3	(2005.0)	109.0	(1557.8)	0.0	(0.0)
Mortality 1958-78	2.4	(34.3)	5.4	(77.2)	4.2	(60.0)	24.5	(350.1)
Volume 1978, after thinning	140.8	(2012.2)	194.8	(2783.9)	241.2	(3447.0)	310.4	(4436.0)
Total production	292.1	(4174.5)	340.5	(4866.1)	354.4	(5064.8)	334.9	(4786.1)

according to the corresponding numbers of trees and basal area/ha. Merchantable volume was derived as a percentage of total volume. Ovendry biomass of the whole stand (kg/ha) was determined by multiplying total volume by basic wood density and by a factor to take into account bark, branches and foliage; and mass of the stem plus bark was taken as the product of total volume and wood density, increased by 10.3% to allow for bark (Alemdag 1983). The various regressions, or their constants, have been modified after each remeasurment as the additional data indicated.

The latest tables (unpublished) project values to age 60 years from planting, and are the first to include biomass values. Table 1 shows an example for a better than average site index class. In these tables, wider planted spacing (fewer numbers of trees) consistently shows greater mean dbh and smaller total volume/ha, and after ingrowth is complete, smaller merchantable volume as well. These differences become less important with age. For example plantations established at 2.0 x 2.0 m (ca 7 x 7 ft) appear to give a good compromise between dbh and branch thickness. At age 60, for 51 21, merchantable volume/ha at this spacing would be 93% of that at 1.50 x 1.50 m (5 x 5 ft), yet require planting of only 56% as many trees.

Thinning Trials

A number of thinning experiments were established, the first in 1958. These all involved thinning back to fixed basal areas (with control plots) at 10-year intervals, but used different marking methods (Berry 1974, Stiell 1980).

General trends were the same, with natural mortality heavily reduced in thinned stands. Despite wide growth variation between individuals in a dbh class, larger trees in each residual basal area consistently grew more in diameter than smaller ones; average growth for a given dbh class was greatest at lowest residual basal area; and growth in all circumstances was lower after the second treatment.

Of the residual basal areas tested, volume growth was similar at 25.3 m^2/ha (110 ft^2/ac) and 32.1 m^2/ha (140 ft^2/ac), but was reduced at 18.4 m^2/ha (80 ft^2/ac) and also on the controls. Pruned crop trees released by removal of competing dominants or codominants developed epicorrnic branches which would have to be removed if production of clear lumber was the objective. Table 2 shows results of thinning from below, after three treatments.

Future Development

The Polyporus root rot has led to significant mortality in a number of stands. As a result, those sample plots affected have had to be rejected for growth calculations. Lacking a direct control method for the disease, prognosis for the remaining stands is open to question.

Owners of badly infected plantations may find it advisable to clear cut them at a relatively early age--perhaps 40 to 50 years when the MAI of merchantable volume culminates in any case. Like wise, thinning under these circumstances is not likely to have much appeal if the potential of larger trees so produced will not be realized.

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GROWTH AND DEVELOPMENT OF LARCH IN NEWFOUNDLAND

J. Peter Hall

ABSTRACT: Larch occurs widely throughout Newfoundland's boreal forests on a wide variety of sites and becomes established naturally after most types of disturbance. It grows faster and produces wood of higher density than other native conifers on most sites. Exotic species of larch have shown in plantation trials to grow even faster than native larch and to have considerable potential as reforestation species.

THE FORESTS OF NEWFOUNDLAND

The island of Newfoundland covers III 000 km^2 of which 100,000 km^2 is land area; of this 38 000 km^2 is productive forest land (Milne and Munro 1981). Productive forest land is defined as that producing at least 35 m^3/ha at rotation. About three-quarters of the forest land is owned by the Crown, the remainder is owned by the two pulp and paper companies on the Island; Abitibi-Price and Bowater Newfoundland Limited. Over 80 percent of the growing stock comprises conifers and 87 percent of the wood harvested is for pulpwood.

The climate of the Island is typically boreal with cold winters, cool summers, late springs with the possibility of frost every month of the year. Rainfall is adequate for the growing season and there is normally a moisture surplus throughout the year (Damman 1983). The climate is moderated to a large degree by Haritime influences.

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Most soils are derived from glacial tills and the underlying strata are mostly Palaeozoic sediments with varying amounts of intrusives. In eastern Newfoundland the underlying rock is mostly late-Precambrian sediments and volcanics. Profiles in most forest soils are podzols or humic-podzols. In western and central Newfoundland bogs and fens are common. In eastern Newfoundland soils tend to be thinner with bogs and wetland areas more common than in central Newfoundland.

Most of the productive forest land and nearly all areas under intensive forest management are located in three of the boreal forest regions described by Rowe (1972); Corner Brook (B28b), Grand Falls (B28a) and Avalon (B30) (fig. 1). The dominant species in the Corner Brook and Avalon sections is balsam fir (Abies balsamea (L.) Mill.) and in the Grand Falls section both balsam fir and black spruce (Picea mariana (Mill.) B.S.P.) predominate. Other species commonly found throughout the forests are white birch (Betula papyrifera Marsh.), trembling aspen (Populus tremuloides Michx.), white spruce (Picea glauca (Moench) Voss) and larch (Larix laricina (Du Roi) K. Koch). Larch, however, consists of about two percent of the total merchantable growing stock (d. Khalil 1972). Several other species occur

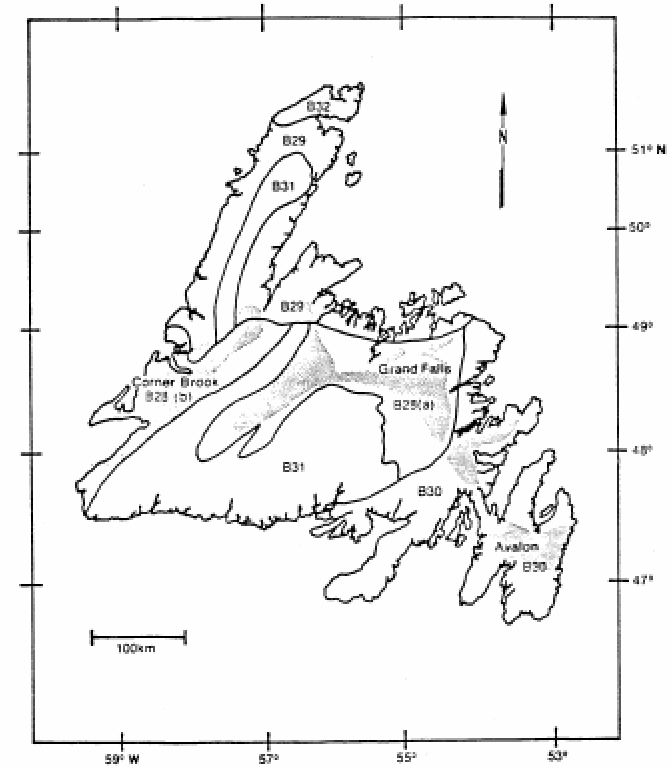

FIGURE 1.

NEWFOUNDLAND SHOWING FOREST SECTIONS (ROWE 1972) AND NATURAL DISTRIBUTION OF LARCH.

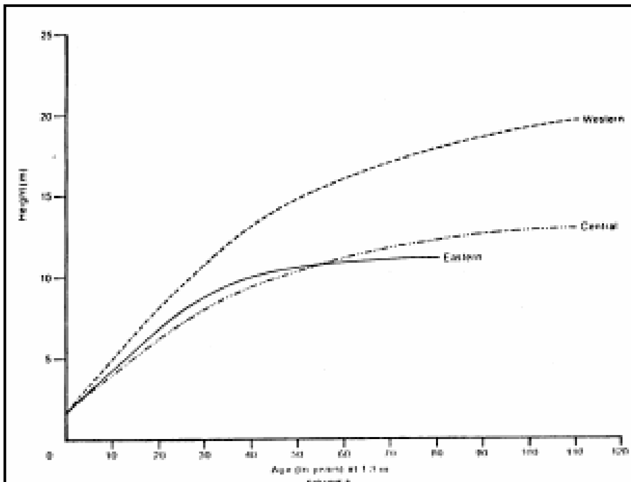

FIGURE 2.

AVERAGE GROWTH RATE FOR BLACK SPRUCE, WHITE SPRUCE, AND BALSAM FIR FOR EASTERN B30, CENTRAL B28(a), AND WESTERN B28(b) NEWFOUNDLAND.

sporadically but are of no economic value because of their scarcity. Growth of the dominant black spruce and balsam fir is variable with the best growth occurring in the Corner Brook section and the slowest in the Avalon section (fig. 2). Climatic differences among the three sections are small; rainfall and temperatures are similar (except for total rainfall) (table 1). The most significant difference is that of the average windspeed in the Avalon section which results in increased exposure and also adversely affects growth.

Table 1--Climatic data for the three major forest sections in Newfoundland

Climatic factor	Forest Section: Avalon B30	Grand Falls B28a	Corner Brook B28b
Mean annual rainfall (mm)	1 445	937	940
Mean rainfall May to September (mm)	457	406	432
Average annual wind velocity (kph)	23.8	20.8	15.2
Mean temperature May to September, ^{o}C	12.8	12.8	12.8
Mean daily maximum temperature July, ^{o}C	21.1	22.2	22.2
Mean number of frost free days	116	103	96
Degree days above $5^{o}C$	2 000	2 000	2 000

GROWTH OF LARCH IN NATURAL STANDS

Although larch occurs naturally throughout the productive forest areas it tends to be concen trated in central and eastern Newfoundland (fig.1). Pure stands of larch occur occasionally but it is most frequently found as scattered individuals in black spruce or black spruce-balsam fir stands. It grows under almost any forest conditions and one noticeable occurrence is on sites which have been mechanically disturbed for road construction or rights-of-way. All stands of larch in Newfoundland post-date the larch sawfly (Pristiphora erichsonii Hart.) epidemic of the 1880's which destroyed nearly all the larch stands in eastern North America (Webb and Drooz 1967).

An increased interest in larch in Newfoundland during the past decade has resulted in the initiation of studies on its distribution, growth and yield, possibilities of its use as a reforestation species and the potential for genetic improvement. Several exotic larch species are also being tested on various forest sites.

Part of the increased interest in larch is a result of the shrinking supplies of wood and the realization that greater utilization of forests includes harvesting species which had been considered non-merchantable for pulpwood. It is also becoming apparent that larch can be pulped with no reduction in product quality at least in quantities likely to be harvested with spruce and fir (Hunt 1979, Balatinecz 1982).

During the past decade a program of artificial reforestation has been underway in Newfoundland with the overall aim of increasing the black spruce component of pulpwood forests. Black spruce is the most desirable species currently in use because of its excellent pulping qualities and its relative resistance to insects and diseases. (It is, however, declining in relative abundance. This decline is a consequence of improved fire protection programs and of clearcutting practices. The major source of natural black spruce stands is regeneration following wildfire; after clear cutting balsam fir dominates the natural regeneration.) The reforestation program envisions the planting of six million seedlings in 1984, ten million in 1985 and for planting to remain at this level or increase in the future. There is therefore an opportunity to introduce other species into the program to increase forest productivity. Larch as a native species, biologically well adapted to Newfoundland, is an excellent species for testing in this way.

Larch has long been recognized as a fast-growing species; faster than its associates on most sites and for this reason it would seem to have high potential as a reforestation species (Fowells 1965, MacGillivray 1969). Much the same relationship was found when growth and yield data were collected for productive sites in Newfoundland where comparisons were made with black spruce and balsam fir (fig. 3). At the age of 50 years the superiority of larch over spruce and fir is about 2.5 m in height growth (Roberts and van Nostrand 1984). This translates into a significant economic increase when applied to a reforestation program.

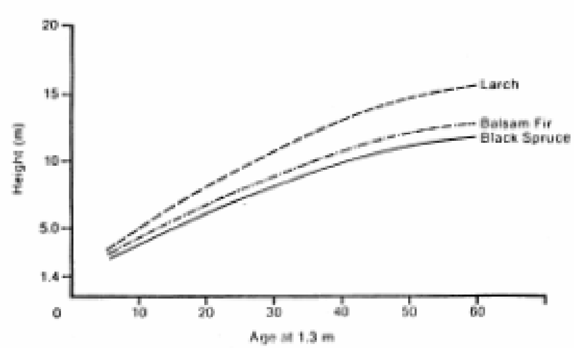

FIGURE 3.

HEIGHT AGE CURVES FOR LARCH, BALSAM FIR, AND BLACK SPRUCE (ROBERTS AND VAN NOSTRAND 1984).

An analysis of three mixed black spruce larch stands in central Newfoundland showed similar trends (table 2). In all stands the larch has grown at a faster rate than the spruce and so have produced more biomass annually per tree (kg of dry matter per year). The increase ranged from 8 43 percent for stands at approximately rotation age (40-60 years). The data suggest an increased potential yield from using larch in reforestation programs.

A factor as important as rapid rate of growth of wood is that of specific gravity. The specific gravity of larch is normally greater than that of either black spruce or balsam fir (.49 compared to .36 or .34) (Panshin et al. 1964). Studies of wood specific gravity in Newfoundland black spruce stands were begun in 1980 and recently have been extended to larch and other species. The specific gravity of black spruce and larch in natural stands averaged .41 and .47 respectively. The range of specific gravity among trees within the stand. as expressed by the coefficient of variation, is about twice as great in larch stands as in black spruce stands 1/. This greater variability within the stands provides an excellent opportunity for selection of superior individuals in a tree improvement program.

The data from natural stands show that larch grows faster than black spruce, produces more dry matter per unit of time than black spruce and hence shows considerable potential as a reforestation species.

GROWTH OF PLANTED NATIVE AND EXOTIC LARCHES

Exotic species are normally incorporated into reforestation programs because of some failing with the native species; either the native species cannot supply the needs of the forest industry or they have severe insect or disease problems. In Newfoundland the native species meet the demands of the forest industries for fibre but exotics

1/ Hall, unpublished data.

Table 2--Comparison of the growth of black spruce and larch in three mixed stands in central Newfoundland.

Stand	Age at 1.3 m	Diameter at 1.3 m	Average total height	Biomass 1/ kg/yr./tree	% increase over black spruce
Glenwood - Larch	45.7	22.0	14.7	3.06	8.1
Black spruce	52.9	20.4	14.9	2.83	
Grand Falls - Larch	46.1	21.1	15.7	3.00	31.6
Black spruce	43.5	17.5	13.2	2.28	
Millertown Jct. - Larch	50.4	20.4	15.3	2.52	43.2
Black spruce	58.0	18.9	13.9	1.76	

1/ Source: Lavigne 1982.

were introduced to determine if other species were adaptable which would yield more fibre and consequently have greater economic value than the native species. Various species have been intro duced from Scandanavia, western Europe, the USSR, Japan and western North America. Species chosen were from boreal or sub-boreal forests and it was thought that they would be reasonably adaptable to the Newfoundland climate. The species tested were primarily from the genera already native to Newfoundland - Pinus, Picea, Larix and Betula (Hall 1982). Locations of various test sites are shown in figure 4.

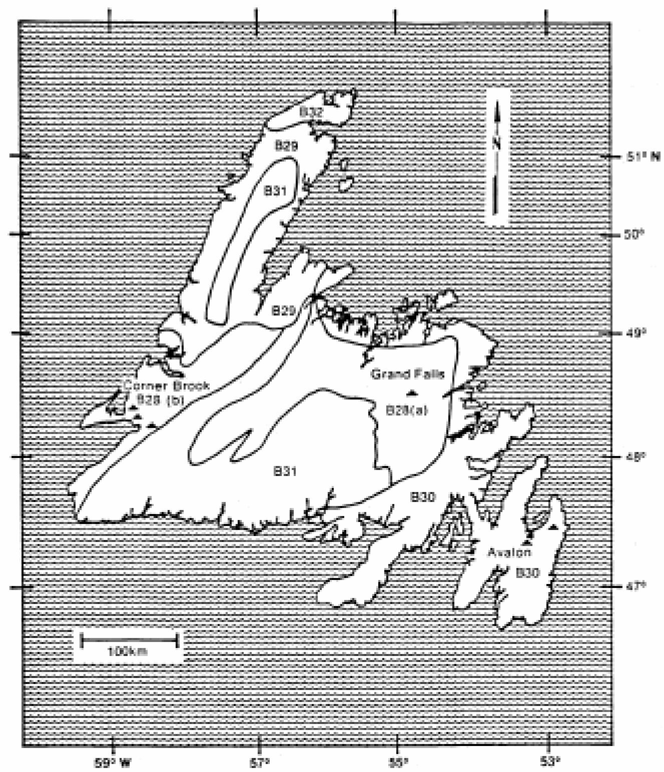

FIGURE 4.
NEWFOUNDLAND SHOWING FOREST SECTIONS AND LOCATION OF TEST PLOTS.

Western Newfoundland, Corner Brook Section

The largest species trial is located at Bottom Brook in western Newfoundland and is now nineteen years old. The plantation is on a rich mixedwood cutover which was burned after clearcutting in 1966. Several other exotics were planted on the site; the fastest growing of them grew at a similar rate as black spruce (Hall 1982). When the larches are compared to planted black spruce or white spruce or the exotic red spruce (P. rubens Sarg.), it is evident that they are superior in height growth and yield per tree dry matter production (table 3). Best growth was achieved with Japanese larch (L. kaempferi (Lam.) Carr.) followed by European larch (L. decidua Mill.). Variation within the seedlots were large with the tallest trees as much as 2 m taller than the mean for the plot. Some of the differences may be due to competition from natural regeneration of white birch which was present for a few years after planting. Both larch species have high within-provenance variability which could be exploited in a tree improvement program (Cook 1966).

Other trials in western Newfoundland have shown similar trends. A trial on a ploughed peat bog after 15 years from seed also shows Japanese larch to be outgrowing all other species; native black spruce, exotic Scots pine (Pinus sylvestris L.), Sitka spruce (P. sitchensis (Bong.) Carr) and Norway spruce (P. abies L.). The height of Japanese larch averaged 2.35 m, the pine 1.31 m and the spruces less than 1 m (Hall 1982). The severe exposure of the site restricted growth rates but the larch was by far the most successful species.

Another trial on a cutover at higher elevation (365 m) and exposed to onshore winds consists of a species trial of native larch, Japanese larch, Siberian larch (L. sibirica Ledeb.) and hybrid larch (L. eurolepis Henry). At ten years from seed the hybrid larch (2.0-2.2 m) is significantly better than all other species with the Japanese larch and native larch at about the same height (1.7 m) (Hall 1984, in press).

Table 3--Comparison of yield of native and exotic larches and spruce in western Newfoundland

Species	Seedlot No.	Origin	Average total		Yield per tree (kg dry matter)
			Height (m)	Diameter (cm)	
Japanese larch	129	Germany	6.51	11.4	24.0
" "	130	"	6.74	10.8	22.8
" "	139	Honshu, Japan	6.96	12.1	27.8
European larch	102	Central Europe	5.60	10.1	17.8
	134	Germany	6.24	10.1	19.2
Larch	27	Eastern Nova Scotia	5.88	7.6	11.1
Black spruce	59	Central Newfoundland	3.73	5.7	7.7
White spruce	24	Eastern Nova Scotia	3.48	5.8	6.0
Red spruce	26	Central New Brunswick	4.19	6.8	10.4

1/ All larch yields calculated using larch (L. laricina) equations, red spruce yield calculated using black spruce equations (Lavigne 1982).

Table 4--Comparison of yield of native and exotic larches and black spruce in central Newfoundland

Species	Seedlot No.	Average Total Height (m)	Average Total Diameter (cm)	Yield per tree (kg dry matter)
Japanese larch	129	4.31	6.6	6.3
" "	130	4.56	6.9	7.2
European larch	102	3.24	4.2	2.2
" "	134	3.11	4.8	2.7
Larch	27	5.72	7.2	9.7
Black spruce 1/	-	4.70	7.5	10.6

1/ Natural regeneration on the site was measured for comparison.

Larches have therefore consistently outgrown native spruces in these tests in western Newfoundland. Japanese larch shows considerable promise as an exotic and there is the possibility that other species and or hybrids may also have promise.

Central Newfoundland, Grand Falls Section

One species trial, also 19 years old, is represented in central Newfoundland. This plantation was established on a site which had been clearcut, then burned by wildfire in 1961, six years before planting commenced. The site rapidly became stocked with black spruce, white birch, trembling aspen and pin cherry (Prunus pensylvanica L. f.) with the wetter areas dominated by alders (Alnus spp.). Many of the exotic species soon became overtopped and only the planted pines and larches were able to maintain themselves in the stand. Native larch had the greatest height growth but the black spruce has the largest yield per tree (table 4). The comparison made is with black spruce natural regeneration as no planted spruce was available. Japanese larch is the fastest growing of the exotics and although trees have grown well (maximum height was over 7 m which was taller than any of the black spruce), the average height is less than that of the native larch. It is not possible to determine if the slower growth rate of the exotic larches is due to species differences or to effects of variable degrees of competition. Further testing will be needed to assess the potential of larch growing on similar sites.

Eastern Newfoundland, Avalon Section

A third plantation also 19 years from seed was established on a clearcut balsam fir site near St. John's. The dense balsam fir on the site suppressed most of the exotics except for the larches which outgrew it (Hall 1982). All larches outgrew native black spruce. Among the larches the European and native larch grew at about the same rate with the Japanese larch slightly superior to both (table 5). It is risky to extrapolate from small amounts of data such as these but there is at least a good indication that larches have reforestation potential in eastern Newfoundland too.

A second plantation was established on a barren land site on the Avalon Peninsula which had not been forested previously. Native larch was planted along with black spruce, white spruce, Scots pine and Jack pine (P. banksiana Lamb.). (Jack pine though a common boreal species is not native to Newfoundland.) After fifteen years the larch had outgrown the spruces by a wide margin (4.1 m compared to 1.2 m) (Hall 1982). The pines were intermediate with the Jack pine outgrowing the Scots pine (3.3 m compared to 2.7 m). The performance of larch on this site suggests that it has considerable potential for afforesting barren lands - certainly more so than black spruce or white spruce.

SILVICULTURAL IMPLICATIONS

1. In natural stands larch outgrows black spruce and produces more dry matter annually than does black spruce.
2. In planted stands larch has outgrown black spruce in most tests. Exotic larches especially Japanese larch and hybrid larch have outgrown native larch and spruce.

Table 5—Comparison of yield of native and exotic larches and black spruce in eastern Newfoundland.

Species	Seed lot no.	Average height (m)	Total diameter (cm)	Yield per tree (kg dry matter)
Japanese larch	129	3.78	6.3	5.8
"	130	4.38	7.7	9.6
"	139	3.84	6.1	5.6
European larch	102	2.93	5.7	4.0
"	134	3.54	5.6	4.5
Larch	27	3.54	5.9	4.9
Black spruce	25	2.47	3.2	3.2

3. The wide tree to tree variability in growth, development and wood quality in native and exotic larch means that there is an excellent opportunity to enhance productivity by selection and breeding (Loo *et al.* 1982, Park and Fowler 1983). Significant gains can also be made through inter-specific hybridization.

4. Results obtained in Newfoundland are consistent with those obtained elsewhere (Cook 1966, Vallée 1982). It is therefore with some assurance that they are recommended for inclusion in reforestation programs.

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BOREAL ENERGY PLANTATION R & D WITH SALIX SPECIES

Alexander Robertson

ABSTRACT: In the last decade short-rotation willow plantations have become an attractive, high-yielding, biomass energy source in cool climatic regions. Preliminary results at Pasadena, Newfoundland show that 28.5 t $DM/ha^{-1}/yr^{-1}$ with an energy equivalent 513 GJ/ha^{-1}, can be achieved in the boreal forest region. While high yields are expected in the more productive forest areas of Newfoundland, the paper stresses the need for biogeographical and bio-meteorological research that will examine the fundamental problems of establishing energy plantations in areas characterized by thin soils and a high mean annual wind speed.

INTRODUCTION

Both Federal and Provincial Government policies in Canada advocate the use of forest biomass as a major renewable energy source. These policies create an obvious need for a sustained fuelwood management program to ensure continued and reliable sources of forest biomass. Implicit in such .a program are the socio-economic benefits through the expansion of a specialized forest biomass industry and spin-off technologies.

As a result of these policies the use of fuelwood has increased dramatically in the last decade. In Newfoundland, for example, there was 168% increase in fuelwood consumption in 1983. Of the 3 million m^3 of wood harvested on the Island, fuelwood accounts for roughly 25% (Northlands 1984a). The pulp and paper industry in Newfoundland utilized approximately 50 000 m^3 of fuelwood (van Nostrand pers. comm.) and households consumed the remaining 700 000 m^3. Overexploitation of the forests for household fuelwood in 'non-commercial' zones has become a serious problem in Newfoundland. The problem is especially critical on the Avalon Peninsula where the annual allowable cut (AAC) is 112 000 m^3 and in 1983 the fuelwood consumption alone was estimated at 196 000 m^3 (Northlands 1984b). Also, the forest has deteriorated to a patchwork of immature stands (Wilton 1984) which cannot meet future demand for fuelwood due to the long rotation age required for coniferous forests to reach merchantable volumes.

To alleviate the pressure on existing forest resources, short rotation energy plantations offer an alternative source of biomass energy. This paper discusses a developing boreal energy plantation research and development project based on willow coppice.

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WILLOWS AS ENERGY BIOMASS

In terms of economic and environmental resilience willow energy plantations have a distinctive advantage over coniferous boreal forest and that is their high yields at an early age. Also, willow plantations can be established with ease from cuttings and harvested repeatedly on a 2-3 year rotation with a minimal energy input.

Because willows (Salix) is a predominantly northern genus, with a wide ecological amplitude and high genetic variability, they are admirably suited to cool, northern climates. Very few, if any, willows are strictly aquatic; the majority of species are to be found on moist, well-drained alluvial soils. Most are pioneer species on unstable or disturbed sites; in fact, the more common species are best known as ruderals along roadside embankments and abandoned farmlands.

In Eurasia, willows have been widely cultivated since early Greek times for fuelwood, construction manufacturing, pharmaceuticals, amenity planting, erosion control and, more recently, for short rotation energy plantations (Robertson 1984a). Apart from ornamental planting and shelterbelts, willows have not been widely cultivated in North America.

In Newfoundland, research to evaluate willows for agroforestry and community shelterbelts began in 1981. This included the collection and aquisition of willow clones in Europe and eastern North America. To date, about 180 clones have been acquired. The collection represents clonal material that could be adapted to a broad range of sites in Newfoundland. These sites range from comparatively sterile sand dunes and disused gravel pits; rich, well-drained alluvial soils; poor, shallow and stony soils characteristic of barren regions; and drained peatlands. In 1982, under the ENFOR (Energy From The Forest) programme administered by the Canadian Forestry Service, emphasis shifted to the potential of willows for biomass energy and the project was broadened to reflect the full scope of research and development necessary for establishing economically viable energy plantations. Consequently, preliminary screening has concentrated on clones which have potential on medium quality forest cutovers in central and eastern Newfoundland where there is a reasonably good chance of success and, of course, where there is an existing demand for fuelwood in the form of wood chips.

YIELDS

The preliminary screening of clones is being conducted at the Canadian Forestry Service Nursery at Pasadena, western Newfoundland. The climate and soils offer the best growing conditions on the Island. The soils are well-drained, sandy loam on a fluvio-lacustrine fan. The growing season usually begins about mid-May although it is not uncommon for buds to flush in late April or early May during brief warm, dry spells. Shoot elongation of most willow clones ceases at the end of October.

The willow clones at Pasadena are planted in stooling beds at a density of 30 000/ha^{-1}. This is the same density planned for energy plantations. Although the project is still in its infancy, (which necessitates coppicing yearly to build up the planting stock), some preliminary results have been obtained to indicate the potential productivity. Table 1 shows the productivity and energy value from annual coppice of 2- and 3-year-old stools of selected clones. Figure 1 shows a 3-month-old stand of _Salix viminalis_ shoots from 3-year-old stools which eventually produced 28.5 t DM/ha^{-1}, or 513 GJ/ha^{-1} (i.e., without foliage).

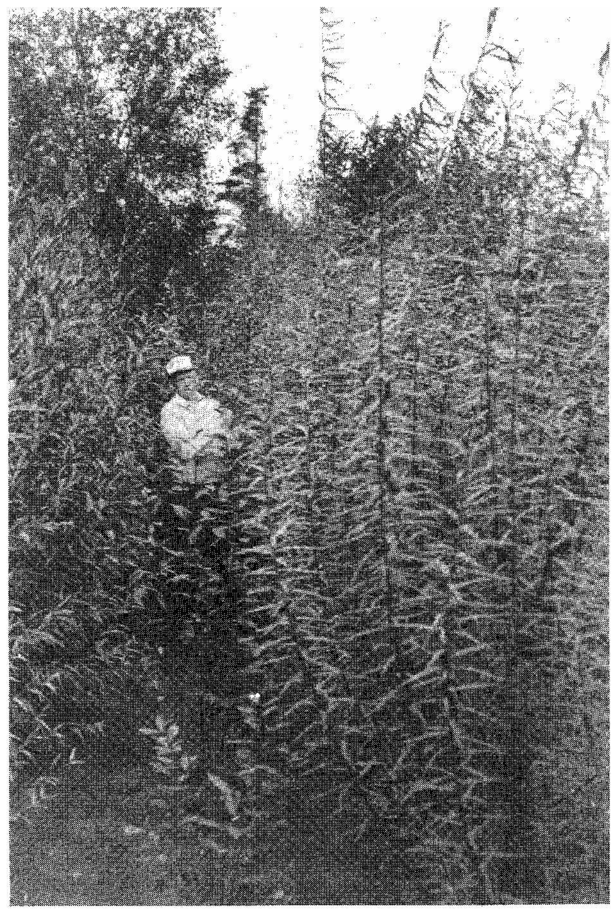

Figure 1.--A 3-month-old stand of _Salix viminalis_ shoots from 3-year-old stools at Pasadena, Newfoundland. This stand eventually produced 28.5 t DM/ha-^{1} with an energy value of 513 GJ (without foliage).

Although no data is yet available for coppicing on a 2-3 year rotation it is reasonable to assume that 15 t DM/ha-l/yr-^{1} (270 GJ/ha-l/yr-^{1}) is practically feasible under field conditions in western and central Newfoundland because of the similarity in climatic conditions. Elsewhere in Newfoundland, especially the Avalon Peninsula, characterized by poor soils and a high mean annual

Table 1--Productivity and energy value of 2- and 3-year-old stools of selected willow clones coppiced yearly in early spring prior to bud-burst at Pasadena, Newfoundland (based on a density of 30 000 stools/ha^{-1})

Species	Clone No.	Annual yield: 2nd year stools t DM/ha^{-1}	2nd year stools GJ/ha^{-1}	3rd year stools t DM/ha^{-1}	3rd year stools GJ/ha^{-1}
Salix viminalis	082	13.4	241	28.5	513
S. alba (Italy)	5016	12.9	232	20.2	364
"	5017	7.9	142	24.0	432
"	5018	7.7	139	24.4	439
"	5019	4.6	83	8.2	148
S. alba (Romania)	5020	3.3	59	12.8	230
"	5021	2.7	49	10.5	191
"	5022	2.8	50	9.8	176
"	5023	7.0	126	15.8	284
S. fragilis	5004	12.8	230	21.0	378
"	5005	8.1	146	16.5	287
"	5010	6.0	108	21.0	378
"	5011	10.6	191	18.0	324
S. nigra	5002	9.5	171	13.5	243
"	5002	9.5	171	17.0	306
"	5009	8.7	157	9.0	162

wind speed (Robertson 1984b, Wilton 1984) productivity is difficult to estimate. In some of the sheltered and more fertile sites, e.g., in the Salmonier area, 10 t DM/ha^{-1}/yr^{-1} (180 GJ/ha^{-1}/yr^{-1}) may be possible.

R & D PRIORITIES

In 1984, funding by ENFOR increased considerably to enable the establishment of experimental plantations and expand the level of basic research. R & D currently underway include:

Plantation Establishment

Four sites in central and one in eastern Newfoundland are currently being developed for planting in 1985. The sites in central Newfoundland include an abandoned pasture and two recently logged areas. The site in eastern Newfoundland is located on farmland in an area that is character ized by drumlins. Since a biophysical assessment of these sites is still underway specific details are not yet available but will be published at a later date. Suffice to note that the three sites in central Newfoundland were chosen because of their proximity to existing wood chip users, i.e., the Abitibi Pulp and Paper Mill at Grand Falls and the Gander Regional Hospital. The site in eastern Newfoundland has two potential users, i.e., fuelwood for the Salmonier Correctional Institute and forage for the Salmonier Wildlife Park.

Biogeographical Research

To date biogeographical research has concentrated on baseline studies on the ecology, distribution and utilization of willows. A review of world literature shows the biogeography of willows in Eurasia is well known, but has not been widely studied in North America except as a shelterbelt species on the prairies. The current emphasis of biogeographical research is to concentrate on the silvics of native and exotic willows which may have some potential in boreal agroforestry. Apart from the need to understand more fully the biology and ecology of willows, there is a particularly urgent requirement for studies on clone/site matching, development of biomass equations, optimum stand densities, control of insects, diseases and development of silvicultural techniques.

Biometeorological Research

The climate of Newfoundland is not easily divisible into homogenous units because of its insular nature, and also because it lies in the path of almost every major cyclone that tracks across the continent and up the eastern seaboard. The combination of unsettled weather associated with rontal systems and the complex topography of the Island means that comparatively small changes in elevation and aspect result in considerable differences in the gradients of atmospheric properties, most notably, wind. These differences are often reflected by a sharp contrast in biomass productivity. Research on the atmospheric parameters which control biomass productivity is of primary concern in the siting of energy plantations. However ,a major obstacle to microclimate studies, particularly the effects of wind on biomass production, is the technical and economic constraints which preclude effective and efficient measurement of climatic variables.

Robertson (1984b) used tamarack as a biological indicator to estimate the spatial and temporal variation of mean wind speed and direction in complex, forested terrain. The relationship between crown deformation and mean wind speed ($\bar{u}$) is expressed by the equation

$$\bar{u} = -5.96 + 10.0D - 1.7D^2 \quad (R^2 = 0.86)$$

D is the deformation ratio computed from

$$D = B + \frac{A}{45°}$$

$$\text{where } B = \frac{\text{mean branch extension leeward}}{\text{mean branch extension windward}}$$

A = Angle of trunk inclination

On reasonably level terrain the mean windspeed could also be estimated from the compression indice from the equation

$$\bar{u} = 34.4 - 43.1C + 15.8C^2 \quad (R^2 = 0.53)$$

$$\text{where } C = \frac{\text{Tree ring width leeward of pith}}{\text{Tree ring width windward of pith}}$$

Using these indices it was found that mean wind speeds in excess of 6 ms-l seriously retards tree growth and that siting of energy plantations should be avoided under these conditions. The study also showed that summer southwesterly winds are the main cause of tree deformation, therefore, in areas where mean wind speeds exceed 5 ms^{-1}, the orientation of plantations should be of prime consideration.

Energy balance studies to determine the efficiency of energy storage of selected willow clones under different climatic conditions is an important consideration. The energy balance is defined by the equation

$$Q^* = Q_H + \Delta Q_P + \Delta Q_S + Q_A$$

where Q^* = Net radiation flux density (Wm^{-2})

Q_H = Turbulent sensible heat flux density

Q_E = Turbulent latent heat flux density

ΔQ_P = Rate of biochemical heat storage

ΔQ_S = Rate of physical heat storage

Q_A = Horizontal energy transport in air per unit horizontal area.

Although our primary interest is the ΔQ_P term, i.e. theoretically the maximum amount of biomass a particular area can produce, the Q_A term is undoubtedly the most important in the Newfoundland context since wind is a major constraint to plant productivity. Currently, the methodology for studying the energy budget of plantations is being developed.

ACKNOWLEDGEMENTS

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COMPARATIVE PRODUCTIVITY OF SEEDED, NATURAL AND PLANTED REGENERATION FOLLOWING VARIOUS SITE TREATMENTS IN WHITE SPRUCE CLEARCUTS

R.G. McMinn

INTRODUCTION

Forest regeneration options are numerous. Stands may be restocked by natural regeneration, direct seeding or planting. The multiplicity of nursery stock types and site treatment methods increases the number of alternatives.

Regeneration strategy decisions depend on the interplay between two major factors - the productivity and the cost of regeneration options. This study indicates the relative productivity of a number of options.

The occurrence of seeded, natural and planted regeneration adjacent to each other in three clearcut sites 60 km east of Prince George, British Columbia, provided an opportunity to compare early white spruce (*Picea glauca* (Moench) Voss) growth rates following different methods of stand, establishment. Several site treatment alternatives could be compared in each site. All sites had dense competing vegetation. Plantations ranged in age from 8 to 13 years.

METHODS

The height and diameter at groundline of the 10 tallest trees representing the regeneration options present in each site were measured and stem volume calculated. Data were analyzed by the Student-Newman-Keuls multiple range test. The age of planted trees was obtained from plantation records. The age of natural regeneration was determined by counting the rings in stem discs cut at ground line. For purposes of comparison, heights and diameters of naturally regenerated trees were adjusted to remove differences from adjacent planted trees due to difference in age. Heights were reduced by the length of internodes added during the years that naturally regenerated trees exceeded the age of planted trees. Similarly, diameters were reduced by the width of extra rings. The age of natural regeneration may have been underestimated because the earliest rings were difficult to differentiate. Underestimation of age would overestimate the size of natural regeneration. The growth of stock in the two direct seeded plots may have been reduced by crowding. Even 13 years after seeding, more than 20 trees remained in each one square meter lot.

Sites had been prepared by scarifying, mixing or inverting, or had been left untreated. Scarifying with a bulldozer blade scalped off vegetation, surface organic matter and uppermost mineral soil to expose subsurface soil for planting or as a seedbed. In the mixing treatment, vegetation and surface organic matter were thoroughly mixed with the underlying mineral soil to form a new surface layer. Although this layer was enriched with organic matter, it was essentially mineral in consistency. The inverting treatment consisted of turning 25 cm^2 patches of soil upside down in the 15 cm deep

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hole left by digging out the patch. The original surface organic matter was thus placed upsidedown below the new surface layer of mineral soil which had originally been subsurface. Competing vegetation was adequately controlled by all treatments, at least for the first year.

RESULTS AND DISCUSSION

The data (Tables 1 - 4) show that for the period studied planted stock outproduced seeded or natural regeneration by three (Table 2) to several hundred fold (Table 4).

Treatments that retained the fertility of surface organic matter available to seedlings (mixing and inverting) produced significant gains in productivity compared to scarifying. Scarifying deeply enough to completely control competing vegetation by removing its roots deprives seedlings of the fertility of uppermost layers. Seedling productivity in lightly scarified areas where some surface material remained was somewhat better than that of adjacent seedlings where scarify-cation was deep (Table 1). Shallow scarification, however, generally provides inadequate control when competing vegetation is vigorous and dense (McMinn 1982a).

Retention of the fertility of surface organic matter by leaving the site untreated is not a viable option for seeding or natural regeneration (Dobbs 1972). Germinants rarely survive in undisturbed surface organic matter. Some grains were recorded with seedbeds formed by mixing rather than scarifying (Table 4).

Table 1. -Stem height, diameter and volume of white spruce natural regeneration and planted Styroplug 2[1] seedlings after 8 growing seasons following various site treatments in a clear-cut with a sandy soil (Site 1).

Regeneration method Site treatment	Height[2] cm	Diameter cm	Volume[3] cm^3
Natural regeneration			
Deep scarifying[4]	56a[5]	0.9a	13a
Light scarifying[6]	101b	1.5b	59b
Planting			
Deep scarifying	203c	3.2c	572c
Mixing[7]	241d	4.1d	1 118d

[1] Seedlings grown in containers with cavity volume of 2 in^3 (40 cm^3).
[2] Mean heights and diameters (at ground line) of 10 trees measured.
[3] Height times one-third cross sectional area at ground line.
[4] All surface organic matter and uppermost mineral soil removed.
5 Values in each column differ significantly (p-0.05).
[6] Some surface organic matter remaining.
[7] Mixed layer 15 cm deep produced by Madge Rotoclear.

The largest difference between seeded and planted stock occurred with large stock planted in untreated areas (Table 4). Standard stock (eg 2+0 bare root or Styroplug 2 seedlings) generally grows poorly when subject to competition from dense vegetation (McMinn 1982b). Retention of the fertility of surface organic matter by leaving sites untreated would seem most feasible when superior stock is outplanted.

The divergent growth trends shown in Figure 1 provide evidence that early differences in productivity *may* increase with time. If such trends continue, high early productivity might predict reduced time to merchantable size. With a sustained yield policy, shortening time between stand establishment and harvesting would mean larger annual allowable cut. While this may be unimportant when poor markets reduce current need below allowable cut, if demand rises in future, an increase in allowable cut would be desirable.

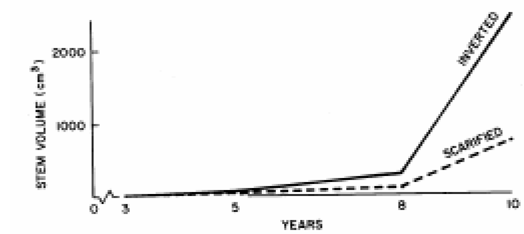

Figure 1. -- Stem volume for the first 10 growing seasons of Styroplug 2 white spruce seedlings in planting spots prepared by scarifying and inverting treatments (Site 2).

Table 2. -Stem height, diameter and volume of white spruce natural regeneration and planted Styroplug 2[1] seedlings after 10 growing seasons following various site treatments in a clear-cut with a silt loam soil (Site 2).

Regeneration method Site treatment	Height[2] cm	Diameter cm	Volume[3] cm^3
Natural regeneration			
Deep scarifying[4]	56a[5]	0.9a	13a
Light scarifying[6]	101b	1.5b	59b
Planting			
Deep scarifying	203c	3.2c	572c
Mixing[7]	241d	4.1d	1 118d

[1] Seedlings grown in containers with cavity volume of 2 in^3 (40 cm).
[2] Mean height and diameter (at ground line) of 10 trees measured.
[3] Height times one-third cross sectional area at ground line.
[4] All surface organic matter and uppermost mineral soil removed.
[5] Values in each column differ significantly.

Table 3. -Stem height, diameter and volume of white spruce natural regeneration and planted Styroplug 2[1] seedlings after 11 growing seasons following various site treatments in a clear-cut with a silt loam soil (Site 2).

Regeneration method Site treatment	Height[2] cm	Diameter cm	Volume[3] cm^3
Natural regeneration			
Scarifying[4]	189a[5]	2.5a	321a
Planting			
Scarifying[4]	293b	5.1b	2 067b
Mixing[6]	331c	6.5c	4 030c

1 Seedlings grown in containers with cavity
2 volume of 2 in (40 cm).
Mean heights and diameters (at ground line) of
3 10 trees measured.
Height times one-third cross sectional area at
4 ground line.
All surface organic matter and uppermost mineral soil removed.
5 Values in each column differ significantly.
6 Mixed layers 20 cm deep produced by Howard Rotovator driven by p.t.o. of farm tractor.

CONCLUSIONS

The data from this study indicate that:

1. planting results in much higher early productivity than either seeding or natural regeneration;
2. with standard stock, early productivity may be doubled or trebled by methods of site treatment that retain the fertility of surface organic matter available to seedlings (mixing and inverting), as compared to removal of surface organic matter by blade scarifying;
3. with superior stock, able to withstand the effects of competing vegetation, retention of surface organic matter by leaving the site untreated may give the highest productivity;
4. if the early increases in productivity indicated by this study were maintained, annual allowable cut would be increased.

Table 4. -Stem height, diameter and volume of white spruce seeded and natural regeneration and planted stock after 13 growing seasons following various site treatments in a clearcut with a silt loam soil (Site 3).

Regeneration method Stock/Site treatment	Height[1] cm	Diameter cm	Volume[2] cm^3
Seeded[3]			
Scarifying[4]	94a[5]	1.4a	54a
Mixing[6]	114b	1.7ab	90ab
Natural regeneration			
Mixing[6]	114b	1.9b	115b
Planting			
2+0[7] / Scarifying[4]	346c	6.1c	4 552c
2+0 / Mixing	473d	8.3d	9 082d
2+1[8] / Untreated	510 e	9.3e	12 106e
Styroplug 8[9] / Untreated	536 e	10.3f	15 702e

1 Mean heights and diameters (at ground line) of 10 trees measured.
2 Height times one-third cross sectional area at ground line.
3 In a one square meter plot.
4 All surface organic matter and uppermost mineral soil removed.
5 Values in each column followed by the same letter do not differ significantly (p = 0.05).
6 Mixed layer 7 cm deep produced by 10 HP garden rotovator.
7 Bare root seedlings.
8 Bare root transplants.
9 Seedlings grown in containers with cavity volume of 8 in (125 cm) for two growing seasons.

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ECONOMICS OF PRECOMMERCIAL THINNING IN JACK PINE

C. Rodney Smith, J. D. Johnson and L. F. Riley

ABSTRACT: The economics of pre commercial thinning in jack pine (Pinus banksiana Lamb.) for saw log production is analyzed with data produced to date from two precommercial thinning trials undertaken in northern Ontario in 1970. Overstocked conditions in the unthinned stands make diameter and density projections imprecise; however, preliminary indications are that neither of these two thinnings will provide attractive returns. Higher densities in the unthinned stands at rotation more than offset the economic contribution of the higher average diameters of the thinned stands. Further measurements are required to predict the, development of the unthinned stand more precisely. Optimum estimates of diameter and density development indicate that the stand thinned at age 9 years will provide a positive return to investors requiring a real rate of return of 4%. The stand thinned at age 9 years yields a higher return than the stand thinned at age 22 years because of the high treatment cost of the 22-year-old thinning.

INTRODUCTION

One of the potential solutions to Canada's decreasing timber supply is the practice of more intensive forest management to improve the quality and volume per hectare (Reed and Assoc. 1978). By redistributing growth to the remaining trees, precommercial thinning promotes the growth of larger and more valuable trees on shorter rotations (Fasick 1965). Intensive management practices such as pre commercial thinning must" however, be operationally practicable and economical, and must yield desirable biological results. Unfortunately, few thinned stands have been assessed at maturity, the only time when the impact of thinning can be fully determined (Riley 1973).

The purpose of this paper is to set out a range of criteria for evaluating the economics of thinning for saw log production in overly dense jack pine (Pinus banksiana Lamb.). Analyses are presented in case study form and are based primarily on results from operational trials conducted in 1969-1970 by the Great Lakes Forest Research Centre in northern Ontario. Results with regard to the efficiency and costs of various thinning tools and techniques used in the trials are described in Riley (1973). Ten-year growth response data are presented in Smith (1984). It is emphasized that results from the case study are interim in nature. Long-term results from this and other studies will facilitate the construction of more accurate economic models.

DESCRIPTION OF CASE STUDY TRIALS

Stands aged 9, 22 and 33 years (age classes I,

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II, and III, respectively) were treated. (Data from the age class III study have, for the most part, been excluded from the analyses.) All sites are typical for jack pine. Site and stand conditions before treatment are presented in tables 1 and 2 (Riley 1973).

All thinning work was carried out on a piecework basis. Trees were individually spaced. Operational data including the tools used and production and cost figures are provided in table 3 (Riley 1973).

Stand stocking and density of jack pine, and average height and diameter of selected codominant and dominant potential crop trees immediately after treatment and 10 years after treatment, are presented in table 4 (Smith 1984). Complete stand tables and, therefore, estimates of basal area and volume are not available at this time. An understorey of black spruce (Picea mariaIla [Mill.] B.S.P.) developed in the stands but jack pine remained clearly dominant after 10 years (Smith 1984).

GROWTH PROJECTIONS

Height and Diameter

The effect of thinning on height growth is insignificant, both minor increases and decreases having been reported (Wilson 1951, Cayford 1964, Steneker 1969, Benzie 1983, Smith 1984). On the other hand, diameter has been shown to increase as a result of thinning over a wide range of age classes (Wilson 1952, Cayford 1961, 1964, Benzie 1983).

In the Ontario case study, the projected incremental increase in average diameter of the selected crop trees in the thinned age class I and II stands is conservatively estimated to be marginal at approximately 0. 50 cm by age 90 years (Smith 1984). There is reason to believe that significantly higher gains from thinning may be possible.

In the first place, diameter growth in the unthinned stands may have been overestimated. Numerous authors state that overly dense stands of jack pine tend to stagnate (Gevorkiantz 1947, Roe and Stoeckeler 1950, Wilson 1952, Skilling 1957, Fowells 1965, Steneker 1969, Bella 1974, and Benzie 1977). Estimates of densities at which stagnation may occur are unclear or vary widely (e.g., from 5,000 [Benzie 1977] to 25,000 [Fowells 1965] sapling-size [5 to 12 cm DBH] stems per ha). The unthinned stands in the Ontario case study fall within this range (Smith 1984) and there is evidence of stagnation. In the age class III control stand (5,900 stems per ha at age 33 years), the periodic annual increment (PAl) in breast height diameter (DBH) between the ages of 28 and 43 years was one-third that of Plonski's (1974) normal, fully stocked stand (i.e., 0.1 cm versus 0.3 cm, respectively). Differences may in fact be even more pronounced, since Plonski's figures are based on stand averages while the case study values are from dominant and codominant crop trees only.

In the second place, more favorable responses may have been achieved if the stands had been thinned to lower densities (with wider spacings). It has been shown that, generally, the heavier the thinning the greater the response (Cayford 1961, 1964, Bella and DeFranceschi 1974b, Benzie 1983). In both the age class I and the age class II stands, spacing failed to meet the prescribed values (i.e., 1.6 m versus 1.8 m in the former and 2.2 m versus 2.4 m in the latter).

For the purposes of analysis, it is assumed that DBH projections in the thinned stands will be at least as good as shown in Smith (1984) (i.e., about 20 cm DBH at age 90 years in both the age class I and the age class II stands). The 0.5 cm DBH advantage of the thinned over the unthinned stands mentioned previously may be taken as a minimum. As a maximum, it may be reasonable to expect a difference of 3.0 cm. Therefore, average DBH in the unthinned stands at 90 years may be as high as 19.5 cm and as low as 17.0 cm.

Density

Density in the thinned stands at rotation may be approximated by using variable density growth and yield tables developed by Evert (1976) from permanent sample plots maintained by American Can of Canada Ltd. and Kimberley Clark of Canada Ltd. in north central Ontario. Yields are presented for natural stands which had variable numbers of trees at age 30 years. The height/age and, therefore, site relationships are very similar to those of Plonski (1974). Stand age, density and height are required to use Evert's model.

Projections were made from ages 30 and 35 years in the age class I and the age class II stands, respectively, to age 90 years. Densities at ages 30 and 35 years were determined from simple projections of the 10-year growth data. In the absence of complete stand information, Plonski's mean stand height for site class II was used. Densities at age 90 years were determined to be 1010 and 829 stems per ha for the age class I and the age class II thinned stands, respectively (table 5).

Evert's tables are based on a range of densities from 620 to 3700 stems per ha at age 30 years. These densities are considerably lower than the densities of the unthinned stands in the case study. For this reason, Evert's tables could not be used. At this point it is not possible to predict the extent to which mortality will affect density at rotation in the unthinned stands.

Volume

The critical question remains as to whether

Table 1. Site descriptions

Age class	District	Forest section[1/]	Site class[2/]	Moisture regime[3/]	Soil
I (9 yr)	Gogama	B7	2	1	medium sand
II (22 yr)	Chapleau	B7	2	2	fine sand

[1/] Rowe (1972)
[2/] Plonski (1960)
[3/] After Hills (1952)

Table 2. Stand descriptions (before treatment) [1/]

Age class	Stocking %	Density (trees/ha)	Avg. DBH (cm)	Avg. ht (m)	Stand origin
I (9 yr)	99[2/]	13,170	2.5	1.8	scarification and aerial seeding
II (22 yr)	96[3/]	10,428	5.1	5.8	wildfire

[1/] Values converted from Imperial to S.I. units.
[2/] Percentage of 4-m^2 quadrats with at least one tree.
[3/] Percentage of 6-m^2 quadrats with at least one tree.

Table 3. Operational data[1/]

Age class	Treatment	Treated area (ha)	Prescribed spacing (m)	Average spacing after treatment (m)	Labor (man-hours/ha)	Cost/ha[2/] (1970 dollars)
I (9 yr)	hand tools	5.0	1.8	1.6	18.93	45.42
	brush saws	11.6	1.8	1.6	9.71	39.33
II (22 yr)	hand tools	0.6	2.4	2.2	67.06	234.72
	chainsaw	2.0	2.4	2.2	35.58	177.91

[1/] Values converted from Imperial to S.I. units.
[2/] Including equipment, materials and supplies.

Table 4. Stocking, density, height and diameter response after 10 years

		Stocking (%)		Density (trees/ha)		Average ht (m)		Average DBH (cm)	
Age class	Treatment	After treatment	10 years	After treatment	10 years	After treatment	10 years	After treatment	10 years
I (9 yr)	thinned	80	76	3,906	3,412	1.8	6.7	2.5	8.4
	control	--	84	--	13,232	1.8	7.0	2.5	6.6
II (22 yr)	thinned	86	80	2,066	1,858	7.0	11.6	8.2	12.4
	control	--	98	--	8,303	5.8	11.0	8.1	10.1

Table 5. Projected densities of thinned Stands

	Age (yr)	Height (m)	Density >2.5 cm DBH (trees/ha)
Age class I	30	10.3	3100
	90	22.0	1010
Age class II	35	11.8	1201
	90	22.1	829

Average projected density (age 90)

$$= \frac{1010 + 829}{2} = 919.5 \text{ trees per ha}$$

increased diameter growth from thinnings will be able to compensate for the initial reduction in total number of stems. Estimates of total volume production are difficult. Cayford (1961, 1964) reports that 32- and 40-year results from thinnings in Saskatchewan and Manitoba at age 18 and 10 years, respectively, did not result in increased total volume production. However, Benzie (1983) reports that 30-year results from thinnings in the Lake States at age 5 years show greater total volume production in stands thinned from 1.2 to 2.4 m. Cayford (1961) reports that in the above-mentioned stand thinned at age 10 years_ a 6-ft (1.8-m) spacing increased saw log volume by 1200 bd ft per acre (7.0 m^3/ha). In the stand thinned at 18 years, saw log volumes were increased from 435 to 1337 bd ft per acre (2.5 and 7.8 m^3/ha) at age 50 years with the greatest increase arising from thinning to 5- and 6-ft (1.5- and 1.B-m) spacings (Cayford 1964). Bella and DeFranceschi (1974a) estimate that pre commercial thinning may as much as double board foot (sawtimber) production by final harvest and the increase may be about 3000 bd ft per acre (17.5 m^3/ha) on average sites and perhaps twice that amount on good sites. (As data are lacking, the latter is an estimate only.)

Therefore, on the basis of results from outside Ontario, it may be reasonable to expect an increase of at least 6.0 m^3/ha of board foot volume as a result of thinning. This could be as high as 17.5 m^3/ha and, very optimistically, as much as 35.0 m^3/ha.

Rotation Age

If we assume that average DBH is used to establish time of harvest, we can expect that increased growth in the thinned stands will result in a reduction of at least 10 years in rotation age (Smith 1984). It is difficult to predict whether an earlier harvest will be desirable with respect to merchantable volume. Bella and DeFranceschi (1974a) are optimistic in stating that if the criterion is a specified volume of merchantable yield, medium intensity pre commercial thinning may shorten rotation age by about 10 years.

ECONOMIC CONSIDERATIONS

Estimates of the value of the thinned stand must be compared with similar estimates for the control stand, in order to assess the effectiveness of the thinning treatment. Any incremental revenue or reduced costs that can be attributed to the treatment will provide a measure of the future economic worth of the treatment. Then, by accounting for initial treatment cost and the time value of money, an assessment of the overall economic worth of the treatment can be made. It is assumed that both the controls and the treated stands are being managed for saw logs.

Incremental Revenue

Lumber recovery estimates for jack pine tree lengths as measured by butt diameter were provided by a local sawmill. Recoverable sawn volumes were Lhen apportioned into lumber grades by butt diameter, with percentages developed for jack pine by Flann and Petro (1964) being used. With the best estimates for future diameters of the thinned and unthinned stands (20.0 cm and 18.75 cm, respectively), and on the assumption that final densities of the thinned stands are 920 stems per ha and final densities of the unthinned stands are approximately 1000 stems per ha, projected incremental board-foot-volume-per-hectare is comparable to volume increments mentioned above in Bella and DeFranceschi (1974a) and Cayford (1964).

Total merchantable volume was estimated from recovery ratios also established by Flann and Petro (1964). The difference between total merchantable volume and sawn volume was assumed to be sold as pulp chips by the lumber manufacturer. Butt diameters were converted to DBH according to a relationship established by Alemdag and Honer (1977).

Appropriate unit prices were assigned to the sawn volumes by grade and to the pulp chips in order to generate an estimate of average revenue per stem by DBH in 1984 dollars. Wholesale prices of jack pine lumber by grade. 1/were adjusted by a projection of the 1984 jack pine selling price index 2/ with historical data being used to moderate any cyclical or seasonal attributes inherent in current prices. The latest estimates of pulp chip selling prices 3/ were inflated to 1984 dollars by using the pulp and paper selling price index 2/. It is assumed that there will be no real changes in unit prices of

1/ Anon. 1984. Selling prices to wholesalers reported by manufacturers. Knots and Slivers. May 25, 1984. Hearst, Ontario.
2/Statistics Canada. Industry price indexes. Catalogue No. 62-011. Monthly. March, 1984.
3/Statistics Canada. Pulp and paper mills. Catalogue No. 36-204. Annual. 1982.

the various products produced.

Figure 1 illustrates estimated revenue per tree by DBH. The use of density (stems per hectare) and average breast height diameter predictions for the thinned and control stands permits estimates of revenue per ha to be generated.

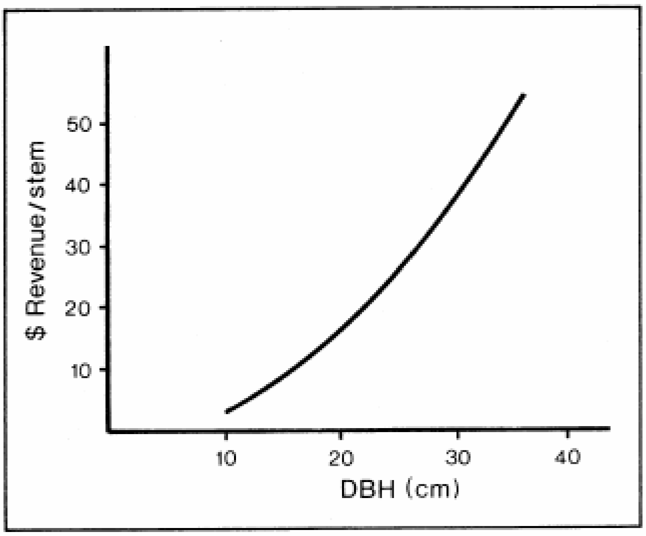


Figure 1. --Estimate of revenue per stem for jack pine in 1984 dollars.

It is assumed that no revenue is generated by the age class I or age class II thinning.

Incremental Harvesting Cost

It has been shown that unit harvesting costs vary inversely with diameter (Hannula 1971). Because the thinned stands are expected to yield stems with higher average diameters than the controls, the reduced harvesting costs should be considered a benefit directly attributable to the treatment at time of harvest.

The mechanization of woodlands operations has reduced the effect of stem diameter on unit harvesting costs. Previous studies in this area employed conventional cut and skid harvesting techniques and, therefore, likely overestimate the effect of log diameter on harvesting costs for mechanized systems. If we assume that the trend toward increased mechanization will continue, it would be appropriate to estimate the effect of stem diameter on logging costs under a fully mechanized system. It is assumed that diameter affects unit costs for only the felling, piling of stems and maneuvering in the stand. Methodology provided in a specific feller forwarder evaluation report by Legault (1976) was used to estimate cost per productive machine hour in 1984 dollars. Estimates of machine productivity as measured by individual tree volume in the Legault study and a volume diameter relationship established for jack pine by Payandeh (1982) were used to estimate machine productivity (i.e., harvesting time per tree) as measured by average breast height diameter. Figure 2 illustrates estimates of harvesting cost per stem and harvesting cost per unit volume by breast height diameter.

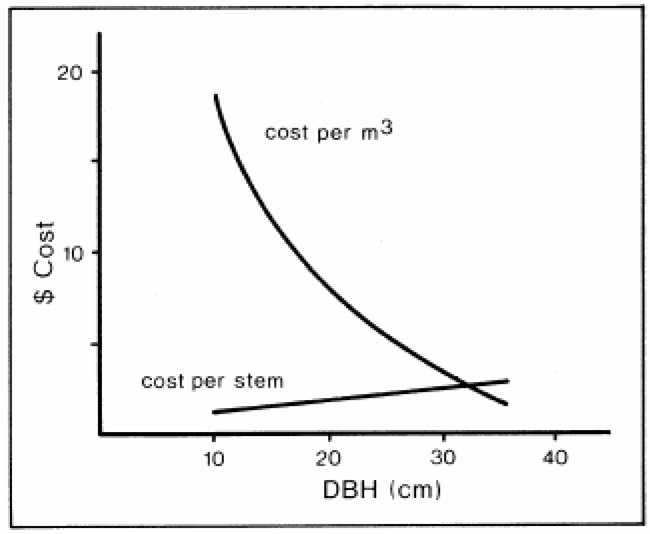


Figure 2. --Estimates of mechanical harvesting cost for jack pine in 1984 dollars. Cost to fell and load stems and to maneuver in stand only.

As with revenues, density and average diameter predictions can be used to estimate future harvesting costs for the thinned and control stands. It was assumed that real harvesting costs will not change throughout the life of the investment.

Other Production Costs

It is recognized that average stem diameter directly affects other unit production costs (i.e., roadside processing, transportation, milling); however, it is assumed for purposes of this analysis that in fully mechanized, efficient production systems, the present value of these effects would be negligible in view of the time periods involved and the limited magnitude of the diameter increment of the thinned stands over the unthinned stands.

Treatment Costs

It is useful to express treatment costs in 1984 dollars so that the analysis is relevant to forest managers today. It is assumed that the least expensive precommercial thinning treatments are employed (i.e., brushsaws in age class I, chain saws in age class II).

Treatment costs incurred in 1970 (see table 3) were inflated to 1984 dollars by using the Gross

National Expenditure Implicit Price Index 4/. In 1970 the age class I thinning cost $39.33 per ha ($124.00 per ha in 1984 dollars). Similarly, the age class II thinning cost $177.91 per ha in 1970 (approximately $560.00 in 1984 dollars).

Other Benefits

If the demand for jack pinesawlogs equals or exceeds supply when the thinned stand is ready for harvest, and if the thinned stands contain more board feet per ha than the unthinned stands, the incremental volume produced from the thinned stand will provide the economy with incremental value-added through the sawmilling industry. This potential benefit is not included in the analysis because of the high degree of uncertainty involved.

ECONOMIC ANALYSIS

Only the incremental future value of the thinned stands over the controls can be attributed to the treatments. Density and average diameter projections can be used to estimate the incremental future value (i.e., additional revenue and reduced harvesting costs) of the thinned stands over the controls. This incremental future value must then be discounted to the present by using an appropriate discount rate in order to account for the cost of the invested capital. Finally, the initial treatment cost must be accounted for. Two methods commonly used to make investment decisions are employed-internal rate of return and net present value.

Internal Rate of Return (IRR)

The internal rate of return (IRR) is the specific discount rate that makes the net present value of an investment equal to zero. The investor can then compare his required rate of return with the calculated IRR. If the investor's cost of capital is lower than the IRR, the project will have a positive net present value. If the investor's required rate of return is greater than the IRR, the investment should not be undertaken. The IRR method is particularly useful for ranking investment opportunities.

Projections of stand densities in the thinned stands are possible; however, future densities of the control stands are uncertain. Measurements to date suggest that both controls are still overstocked, and that natural thinning is progressing slowly. It is appropriate, therefore, to compare a range of possible control stand densities with a best estimate of density in the thinned stands under both the optimistic (i. e. , thinned stand average diameter of 20.0 cm and control stand average diameter of 17.0 cm), and conservative (i.e., thinned stand average diameter of 20.0cm and control stand average diameter of 19.5 cm) diameter projections. From the case study (see table 5), it is estimated that at age 90 years the thinned stands will have a density of 920 stems per ha.

Table 6 illustrates IRR achievable under various control stand densities at age 90 years for the age class I and the age class II treatments.

A number of observations can be made from table 6. First, the investment does not appear to be an overly attractive one. Even under the most optimistic conditions, the real IRR is only 4.5%. Only an investor with an extremely low required rate of return would consider such an investment. Row et ale (1981) suggest that a real rate of return of 4% is appropriate for long-term forestry investments by the USDA. Private investors require even higher returns.

Second, should the density of the controls remain high, then even under the most optimistic diameter projections, returns are low. This is due to the fact that if densities of the controls remain high, even though the harvesting conditions would be higher and the revenue per cubic metre less because of the lower average diameters, the volume would be so much higher than in the thinned stand that the net present value per ha would be higher. The higher revenue per ha in the 'controls more than offsets the increased harvesting costs.

Finally, in spite of the greater time period involved, the 9-year-old thinning results in higher IRR than the 22-year-old thinning. This is due to the high treatment cost associated with the 22-year-old thinning.

Net Present Value

The net present value method uses a specific discount rate to calculate the present value of the revenues and costs associated with an investment opportunity. The discount rate is considered the minimum rate of return required for a particular type of investment. A positive net present value indicates a positive return after risk and financing costs have been accounted for. A negative net present value would indicate that the investment opportunity should not be considered by the investor.

The major drawback associated with using net present value is the difficulty in choosing appropriate discount rates. Different investors often have differing minimum required rates of return on new projects. For this reason, it is useful to provide analysis for a range of real discount rates. Table 7 illustrates net present value estimates of both pre commercial thinning treatments over a range of control stand densities at age 90 years for the conservative and optimistic diameter projections with real discount rates of 4,5 and 6%.

4/Statistics Canada. National Income Expenditure Accounts. Catalogue 13-201. Quarterly. 1968 1982. 1983 and preliminary 1984 GNE Implicit Price Index obtained by request.

Table 6. Real internal rates of return (%) across various control stand densities at age 90.

(i) Age class I

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	2.62	1.28	-1.17	-2.59	-3.24	-3.68	-4.00
Optimistic	20.0	17.0	4.51	4.36	4.20	4.01	3.79	3.52	3.19

(ii) Age class II

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	0.87	0.07	-0.08	-0.83	-1.60	-2.11	-2.49
Optimistic	20.0	17.0	3.09	2.91	2.71	2.50	2.24	1.92	1.53

Two observations can be made from table 7. First, rational investors with real required rates of return of greater than 4% would not consider precommercial thinning in jack pine in either age class. An investor with a 4% required rate of return would accept only the 9 year-old thinning as a worthwhile investment and then only if he was certain that the most optimistic conditions would result.

Second, as illustrated in the IRR analysis, in all cases the 9-year-old thinning appears more economically attractive than the 22-year-old thinning.

Sensitivity Analysis

In view of the long time periods involved and the

Table 7. Net present value ($/hectare) estimates for various control stand densities at age 90.

(i) 4% real discount rate

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-81	-109	-137	-166	-193	-221	-248
Optimistic	20.0	17.0	60	41	21	1	- 19	- 39	- 58

Age class II (thinned at 22 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-489	-536	-582	-628	-674	-721	-767
Optimistic	20.0	17.0	-253	-286	-319	-352	-385	-418	-451

(cont'd)

Table 7. Net present value ($/hectare) estimates for various control stand densities at age 90 (concl.)

(ii) 5% real discount rate

Age class I (thinned at 9 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-105	-118	-130	-144	-156	-169	-181
Optimistic	20.0	17.0	- 38	- 48	- 57	- 66	- 75	- 75	- 94

Age class II (thinned at 22 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-523	-547	-571	-596	-620	-644	-668
Optimistic	20.0	17.0	-400	-417	-434	-452	-469	-486	-503

(iii) 6% real discount rate

Age class I (thinned at 9 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-113	-120	-126	-132	-138	-145	-151
Optimistic	20.0	17.0	- 85	- 89	- 93	- 98	-102	-106	-110

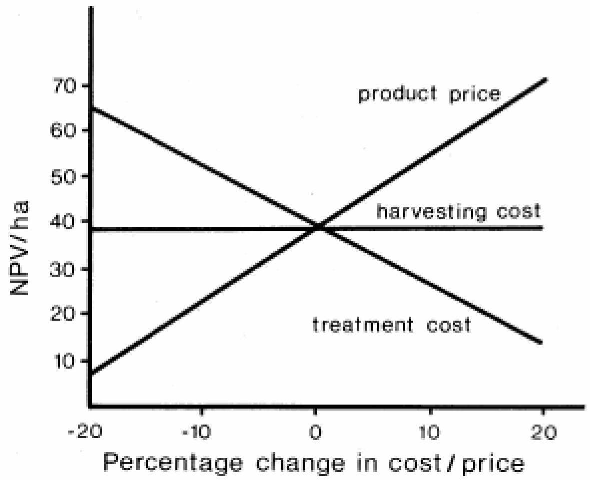
Age class II (thinned at 22 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-540	-533	-566	-578	-591	-604	-617
Optimistic	20.0	17.0	-476	-485	-494	-503	-512	-521	-530

number of assumptions made, it is necessary to explore the sensitivity of this investment opportunity to changes in costs and prices.

Age c lass I (9-year-old thinning)

Figure 3 illustrates the sensitivity of NPV at a 4% discount rate to changes in treatment cost, harvesting cost and revenue for the 9-year-old thinning. The optimistic projection of diameter increment is used and the control is assumed to thin itself naturally to 950 stems per ha at age 90 years. Price changes have the most pronounced effect on NPV. A 20% real decrease in prices prompts NPV to fall close to $0 per ha from $41.00 per ha. A 20% increase in treatment cost would cause NPV to fall to $16.00 per ha from $41.00 per ha. Real changes in harvesting costs have only a slight effect on NPV in the 9-year-old thinning.



Assumptions:

1) Average diameter of thinned stand is 20.0 cm at age 90,

2) Average diameter of control stand is 17.0 cm at age 90,

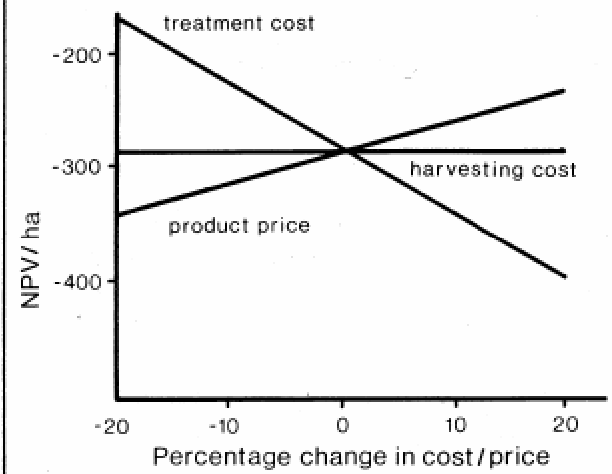
3) Density of thinned stand is 920 stems/ha at age 90,

4) Density of control stand is 950 stems/ha at age 90,

5) The control stand and the thinned stand are both harvested at age 90,

6) Real discount rate is 4%.

Figure 3. --Sensitivity of NPV in age class I treatment to changes in costs and prices.



Assumptions:

1) Average diameter of thinned stand is 20.0 cm at age 90,

2) Average diameter of control stand is 17.0 cm at age 90,

3) Density of thinned stand is 920 stems/ha at age 90,

4) Density of control stand is 950 stems/ha at age 90,

5) The control stand and the thinned stand are both harvested at age 90,

6) Real discount rate is 4%.

Figure 4. --Sensitivity of NPV in age class II treatment to changes in costs and prices.

Age class II (22-year-old thinning)

Figure 4 illustrates the sensitivity of NPV per ha in the age class II thinning to changes in costs and prices. (The most optimistic projection of the average diameter of the thinned stand over the control stand is assumed, and the control is assumed to have a density of 950 stems per ha at age 90.)

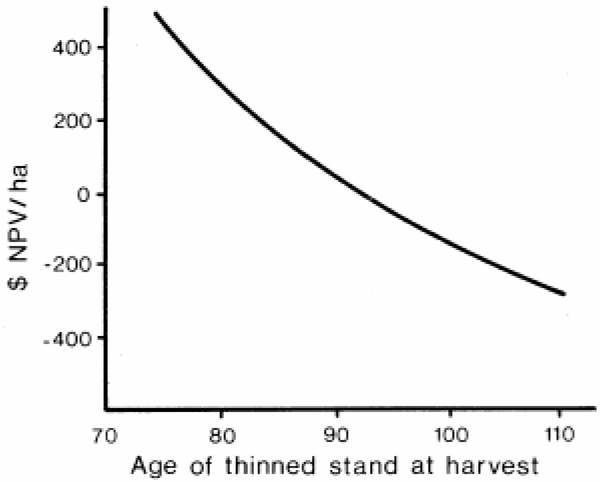
Unlike that of the age class I thinning, the NPV of the age class II thinning is most sensitive to initial treatment cost. In figure 4 it can be seen that if. treatment costs increased by 20%, then NPV would be reduced by $112.00 per ha. A 20% decrease in real prices would reduce NPV by $56.00 per ha. Again, real changes in harvesting costs have only a negligible effect on NPV per hectare.

If real treatment costs were halved to $280.00 from $560.00 per ha, then NPV per hectare would become positive for the age class II thinning, at a real discount rate of 4%. It is worth noting that a net revenue of $280.00 per ha produced at time of thinning (i.e. , approximately 10 m^3/ha of pulpwood) would have the same economic impact as reducing the treatment cost by 50%.

Sensitivity to rate of development of the thinned stands

Thus far it has been assumed that the controls and the thinned stands will be harvested at age 90 years. It is necessary, however, to explore the sensitivity of economic returns to changes in the rate of development of the thinned stands.

Figures 5 and 6 illustrate the effect of the timing of the final harvest (i.e., the rate of development of thinned stands) on NPV per ha for the age class I and age class II thinnings, respectively. It is assumed that at harvest the controls will have an average breast height diameter of 17.0 cm and a density of 950 stems per ha in comparison with 20.0 cm and 920 stems per ha for the thinned stands. A real discount rate of 4% is used.



Assumptions:

1) Average diameter of thinned stand at time of harvest is 20.0 cm,

2) Average diameter of control stand at time of harvest is 17.0 cm,

3) Density of thinned stand at time of harvest is 920 stems/ha,

4) Density of control stand at time of harvest is 950 stems/ha,

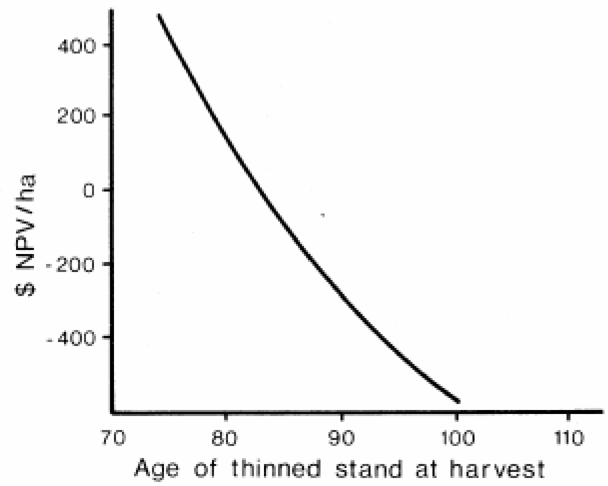
5) The control stand is harvested at age 90,

6) Real discount rate is 4%.

Figure 5. -- Sensitivity of NPV in age class I treatment to changes in rate of development.

In figure 5 it can be seen that a reduction in the time required until the age class I thinned stand reaches 20.0 cm has a dramatic effect on NPV per ha. If we assume optimistically that the thinned stand was harvested at age 80 years and the poorer quality control stand was harvested at age 90 years, the NPV of the precommercial thinning would increase from $41.00 per ha to $300.00 per ha.

The effect is even more dramatic in the age class II treatment. Figure 6 illustrates that a reduction in the age of harvest of the thinned stand from 90 to 80 years, just 10 years before the control is harvested, increases NPV from a loss of $286.00 to a profit of $147.00 per ha. Clearly a reduction in the investment period and the production of a superior stand makes the precommercial thinning treatment a far more promising investment opportunity.



Assumptions:

1) Average diameter of thinned stand at time of harvest is 20.0 cm,

2) Average diameter of control stand at time of harvest is 17.0 cm,

3) Density of thinned stand at time of harvest is 920 stems/ha,

4) Density of control stand at time of harvest is 950 stems/ha,

5) The control stand is harvested at age 90,

6) Real discount rate is 4%.

Figure 6. --Sensitivity of NPV in age class II treatment to changes in rate of development.

CONCLUSIONS

Average stem diameters responded favorably to the precommercial thinning treatment in both the age class I (thinned at 9 years of age) and the age class II (thinned at 2 years of age) thinnings. Data gathered from the case study to date, however, indicate that the magnitude of diameter increment in the thinned stands in comparison with that in the controls is not sufficient to provide economically attractive returns. Further measurements are required to predict the development of both the thinned and the control stands more accurately. Analysis indicates that the age class I treatment will outperform the age class II treatment. This is due primarily to the high cost of treatment in the age class II study. The present value of the age class I treatment is sensitive to changes in both product price and initial treatment cost. The present value of the age class II treatment is most sensitive to changes in initial treatment cost. Neither thinning is sensitive to changes in harvesting costs because of the predicted low diameters of both the controls and the thinned stands at the time of harvest. If subsequent measurements indicate that the controls are stagnating or that the thinned stands are outperforming the controls to such an extent that they will be ready for harvest before the controls, then the investment will become far more attractive.

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A SIMULATION MODEL FOR THE ECONOMIC EVALUATION OF FOREST REGENERATION SYSTEMS

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Abstract: This paper briefly discusses the main problems associated with evaluating long-term forestry investments involving risk and uncertainty. A computer model "FIDME" developed to evaluate such investments is then described. Input estimates for the model may be expressed by either point or subjective probability estimates. Simulated results will provide the probability that one investment might differ from others. Therefore, the forest manager will be able to choose, with a known degree of confidence, between investment alternatives. Three examples and model sensitivity are discussed.

INTRODUCTION

Forest renewal is the most important problem fencing forest managers in Canada. Because of the Canadian wood supply situation federal and provincial agencies and the forest industry are to invest increasingly large sums of money annually in forest renewal. Owing to the long-term nature of such investments, they are subject to risk and uncertainty.

In statistical decision theory, a distinction is made between risk and uncertainty. Risk situations are defined as those in which the probabilities of the outcomes are known or can be estimated. Uncertain situations are defined as those in which probabilities cannot be determined for the outcomes. No such distinction between risk and uncertainty will be made here. Generally, the greater the dispersion of the cash flow estimates, the greater the risk. What will the average price of a m^3 of black spruce pulpwood be in 50 years? Most managers would truthfully say "I don't know". However, investment decisions must be made today on the basis of uncertain future costs and returns. Even though the future stumpage price is unknown, it may be possible to specify a distribution of future prices. Such estimates are of course subjective. They are based on a knowledge of past trends augmented by intuitive feelings about the future.

There are several methods to adjust for risk in long-term investments. .The most common method is to use a risk adjusted discount rate defined as r = i+p, where r is the risk-free rate and p is a premium for risk. This approach is based on the premise that risky cash flows are worth less today than certain cash flows and must therefore be discounted at a higher rate. There are two problems associated with the use of the risk-adjusted discount rate. First, it assumes risk is compounding over time. Second, there is no real basis for choosing the appropriate adjustment factor.

An accepted method of adjusting for uncertainty is the use of certainty-equivalent coefficients. A certainty-equivalent coefficient transforms an

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uncertain cash flow into an equivalent certain amount. A certainty-equivalent coefficient for period t is defined as α_t, where $0 \leq \alpha < 1$ A certainty-equivalent coefficient of 1 imples that the cash flow is risk-free. A certainty equivalent coefficient of 0 implies the cash flow is so risky that it has no value. The main problem with this method is, of course, how to assign specific values to the coefficients.

Another way to cope with risk and uncertainty involves the use of subjective probability distributions. This method directly recognizes that the basic cause of risk is variability in the expected future cash flows. Subjective probability estimates may be used not only to account for risk and uncertainty, but they may also be used to quantify an expert's opinion augmented by intuitive feelings about the future outcomes. Several probability distribution functions such as Normal, Gamma, Beta and Weibull have been used for this purpose (cf. Schwitzer 1968, Payandeh and Tucker 1975, Payandeh and Field 1978).

Because of the long-term nature of the forest renewal investments and the risk and uncertainty associated with them, it is essential that they are chosen from the most promising alternatives possible. To evaluate and screen investment alternatives with relative ease and greater precision, forest managers need a technique that enables them to not only predict the rates of return but also indicates the likelihood of their being achieved. This paper briefly describes a computer simulation model developed for comparing the relative economic desirability of various forestry investments subject to risk and uncertainty--particularly those related to forestry renewal activities.

BRIEF DESCRIPTION OF THE MODEL

The model is named "FIDME", an acronym for "Forestry Investment Decisions Made Easy". It is an extension of the earlier model "REGEN" (Payandeh and Field 1978). FIDME is basically a very flexible "economic evaluator" or "cash flow analyzer" for comparing long-term forest renewal investment alternatives. Any set of forest regeneration systems and various silvicultural treatments and management actions associated with them may be compared as long as the differences between such regeneration systems can be expressed in terms of differences in costs, probability of success, stocking level, rotation age, expected yield, and future prires, etc. The model contains no assumptions. regarding the stand dynamics and growth as it deals with economic analysis only. However, the input estimates may implicitly reflect the overall assumptions made by the user regarding the interaction of economic, physical and biological factors affecting various regeneration systems.

The model is an easy-to-use simulation model, that will assist forest managers, policy makers and administrators in making rational economic decisions on various forest renewal investment alternatives. For example, it may be use to compare up to four forest renewal systems based on anyone of the four economic criteria of:2/ 1) cost effectiveness, 2) benefit-cost ratio, 3) present net worth and 4) internal rate of return (cf. Lundgren 1973, Payandeh 1977, and Foster and Brooks 1983).

Each forest renewal system or investment alternative may consist of one or more of the following types of costs and returns:

I. Initial costs:

   a) land value, i.e., purchase price or market value of land/unit area
   b) preparation costs, e.g., site preparation, access road construction, etc.
   c) establishment costs, e.g., cost of planting, cost of seeding, etc.

II. Annual costs , e.g. , property tax, road maintenance, forest protection and rent, etc.

III. Periodic costs, e.g., cost of fertilzation, thinning, spraying, etc.

IV. Final costs, e.g., harvesting and/or transportation costs (total cost of wood delivered to the mill).

V. Terminal cost, e.g. ,legal fees and/or other cost associated with the sale of the land, etc.

1/ The only assumption made in the model regarding the cost of stand establishment is that: an area or a site may be regenerated up to a maximum of three times per site preparation and that it might be site prepared up to a maximum of three times to produce a success ful regeneration.

2/ Definition of these criteria may be found in most forest management/economics texts. 1) Cost-effectiveness is based on future cost/ unit of volume (output). It does not require future price estimation and does not account for the difference in the quality of the products. A forest renewal with the lowest future cost/unit of volume would be the most economical one on this basis. 2) Benefit-cost ratio is the ratio of the sum of discounted returns to the sum of discounted costs. The alternative with the highest benefit-cost ratio would be the most economical one. 3) Present net worth is the difference between the sum of discounted returns and discounted costs. The alternative with the largest present net worth would be the most economical one. Benefit-cost ratio and present net worth are closely related and both require an assumed discount rate and estimation of future prices. 4) Internal rate of return is a discount rate at which the sum of discounted returns and costs are equal or the present net worth is zero. This criterion does not require an assumed discount rate, but it requires estimates of future prices.

The investment returns might be one or more of the following types:

I. Annual returns, e.g., users fees for hunting or fishing, etc.

II. Periodic returns, e.g., proceeds from commercial thinning, etc.

III. Final return, e.g., revenue from final harvest at rotation age.

IV. Terminal return, i.e., future market value of the land/unit area.

V. Final product price, future for price/unit the final products.

In the model up to four products, e.g., pulpwood, pole timber, saw timber and veneer, and four prices may be specified. The input for the model may be either in the form of point estimate (when the input estimate is known or may be determined free of error) or subjective or judgmental probability estimates (cf. Englehard and Anderson 1983, Yared 1983).

Like its predecessor "FIDME" uses mainly subjecttive or judgmental estimates provided by the forest manager based on his experience with a given forest renewal system. Such estimates are used in the model to generate appropriate probability distributions via the Weibull function. Each distribution so generated will represent the frequency distribution of a given cost, expected stocking level, future yield or product prices for any reforestation system that the forest manager wishes to specify.

The model is designed such that it simulates all forestry investments in question in a parallel manner. For example, in the case of comparing, say three regeneration systems, the area(s) or site(s) characterized by the input variables are reforested by the regeneration systems enough times to produce a desired number, e.g. , 300, of successful reforestations or "successes". All costs and returns associated with a successfully regenerated stand (including the cost of regeneration failures, if any) are properly analyzed, i.e., compounded or discounted depending on criteria used[3/] Finally a frequency distribution of the final results, expressed by any of the four economic criteria mentioned earlier, for each reforestation system is constructed, and from this the results can be obtained for a desired probability level.

Because various investment alternatives are simulated in a parallel manner to produce an equal number of "successes" and since the results are calculated on per unit output or area, the results of different operations are directly comparable. That is, all differences in costs (initial, annual, periodic and final costs), probability of success, stocking level, rotation age, expected returns (annual, periodic, final and terminal returns), and future product prices, etc. are accounted for.

FIDME is written in structured FORTRAN 77 and may be run interactively or in a batch mode. Input for the model can be entered from the terminal or may be read from an input file. The output similarly may be directed to the terminal or the line printer.

EXAMPLES OF MODEL APPLICATION

The application of the model is demonstrated here by describing three examples in some details. Although attempts were made to use current cost estimates where possible, the main objective of the examples is to show the model capability and flexibility and not to recommend one regeneration system over another one. The input estimates for the examples were mainly obtained from the recent literature (e.g., Anon. 1974, Mullin and Howard 1973, Waldron 1974, Olson et al. 1978, Bradley and Lothner 1982) and from several forest managers from the Ontario Ministry of Natural Resources 4/

In the first example the cost-effectiveness of pulpwood production from planting and seeding jack pine (*Pinus banksiana* Lamb.) are compared. This example may apply to a large area of clear cut on crown land in Ontario most suitable for growing jack pine. The main question facing the forest manager in this case, would be to seed or to plant the area. The forest manager knows from experience that the cost of planting such an area is much greater than that of seeding. On the other hand the chance of success in regeneration with planting is considerably better than seeding. He also knows that jack pine seeded stands

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3/ For example, present net worth is calculated as:

$$PNW = \frac{V_1(1+i)^1}{(1+r)^1} + \cdots + \frac{V_j(1+i)^j}{(1+r)^j} + \cdots + \frac{V_n(1+i)^n}{(1+r)^n} \quad (1)$$

where: PNW = present net worth $/unit area.
Vj = the cost or return in the jth year.
i = average inflation rate/year.
r = average interest rate/year.
n = rotation age.

Benefit-cost ratio is calculated from the above formula as the ratio of the sum of discounted returns over the discounted costs.

Internal rate of return is calculated by iterative solution of equation (1) above to find a value for r which equates PNW to zero.

For cost-effectiveness criteria the sum of future costs at rotation age are calculated from which future costs/unit volume is derived.

4/ Calvert, R. 1984. Ontario Ministry of Natural Resources, Timmins, Regional Office. Personal communication.

require at leas tone precommercial thinning at about 15 years of age. It is also assumed that the rotation age for seeded stands would be up to 10 years longer than planted stands or equivalently, the yield from seeded stands would be less than planted stands for the same rotation age.

Input estimates for the first example are summarized in Table 1. This example does not include input estimates for annual and liquidation costs and annual, periodic and terminal returns since such costs and returns do not usually apply to the crown land. In the case of planting jack pine bare-root stock are assumed to be planted at a rate of about 1900 trees/ha.

Table 1 provides subjective estimates for the cost of light mechanical site preparation required for planting jack pine as: a) low estimate = $110.00, b) high estimate $140.00, c) the probability that the cost of site preparation might be lower than the low estimate = 0.10, d) the probability that the cost of site preparation for planting jack pine might be lower than the high estimate = 0.95 and e) the minimum cost of light mechanical site preparation - $100/ha. Similarly, the five subjective estimates for the cost of heavy mechanical site preparation required for seeding jack pine were: $250.00, $320.00, 0.10,0.95 and $230.00/ha.

Table 1. Input estimates of Model "FIDME" for comparing the cost-effectiveness of planting and seeding jack pine

Input estimate	Regen. method	Point estimate	Subjective estimates: Low	High	Prob. low	Prob. high	Minimum
Site preparation 1/	plant.)	--	110	140	0.10	0.95	100
	seed.)	--	250	320	0.10	0.95	230
Establishment 1/	plant.)	--	250	350	0.05	0.95	225
	seed.)	--	30	60	0.10	0.90	20
Stocking standard	plant.)	--	0.45	0.65	--	--	--
	seed.)	--	0.45	0.65	--	--	--
Expected stocking	plant.)	--	0.40	0.95	0.10	0.90	0.35
	seed.)	--	0.20	0.95	0.10	0.80	0.00
Periodic cost 2/	plant.)	--	--	--	--	--	--
	seed.)	--	75	300	0.05	0.80	50
Product #1 yield m^3/ha	plant.)	--	200	300	0.10	0.95	150
	seed.)	--	150	250	0.10	0.95	120
Product #1 price $1/$m^3$ 3/	plant.)	--	1.5	2.00	0.10	0.90	1.00
	seed.)	--	1.5	2.00	0.10	0.90	1.00

Economic criteria cost-effectiveness
Rotation age 70 years
Interest rate 10%
Inflation rate 5%
No. of iteration 300
Random number generator starter (seed) 13345

1/ A maximum is required for the number of scarifications/site beyond which the site is considered abandoned due to repeated unsuccessful regeneration. Also a maximum is required for the number of regeneration operations/site preparation beyond which the area will not be rescarified. Such maximum for the above examples were 2 and 3 for both regeneration systems.

2/ For periodic costs and returns a start, an interval and an end year are required.

3/ The period for which future prices are estimated, e.g., 5, 10 or 20 years, is required beyond which future prices are projected based on the inflation rate.

Subjective estimates for the cost of planting jack pine bare-root stock were: a) low estimate of $250.00, b) high estimate of $350.00, c) the probability that cost of planting jack pine may be less than the low estimate = 0.05, d) the probability that planting jack pine may be less than the high estimate = 0.95 and the absolute minimum cost of planting jack pine bare-root stock = $225.00/ha. Likewise, the subjective estimates for the cost of seeding jack pine were: a) low estimate = $30.00, b) high estimate = $60.00, c) the probability that cost of seeding jack pine may be lower than the low estimate = 0.10, d) the probability that cost of seeding jack pine may be less than the high estimate = 0.90 and e) the absolute minimum cost of seeding jack pine = $20/ha. Stocking standards are specified as interval estimates and are the same for both regeneration systems. In the simulation process if a regeneration system results in stocking level less than .45, it would be considered a failure and the site (or area) would be replanted. When a regeneration method results in a stocking of .65 or better, it would be considered a successful regeneration.

Subjective estimates for the expected stocking levels for planting jack pine are given as: a) low estimate = 0.40, b) high estimate = 0.95, c) the probability of stocking being lower than the low estimate - 0.10, d) the probability that stocking may be lower than the high estimate = 0.90 and the absolute minimum stocking for plant ing jack pine = 0.35. The five subjective estimates for the expected stocking level for seeding jack pine are :a) low estimate = 0.20, b) high estimate = 0.95, c) the probability that stocking may be less than the low estimate = 0.10, d) the probability that stocking level may be less than the high estimate = 0.80 and e) the absolute minimum expected stocking level from seeding jack pine = 0.00.

Subjective estimate for the cost of precommercial thinning for seeding jack pine is given as periodic cost to occur at age 15 years as: a) low estimate = $75.00, b) high estimate = $300.00, c) the probability that cost of thinning may be lower than the low estimate = 0.05, d) the probability that the cost of thinning may be lower than the high estimate = 0.80 and e) the absolute minimum for the cost of thinning = $50.00/ha.

In the first two examples, it is assumed that the final yield would be harvested as a single product in the form of pulpwood. Subjective estimates for the final yield for planting jack pine were: a) low estimate = 200 m^3/ha, high estimate = 300 m^3/ha, c) the probability that the yield of pulpwood/ha for jack pine plantation might be less than the low estimate = 0.10, d) the probability that the yield/ha might be less than the high estimate = 0.95 and e) the absolute minimum yield of pulpwood = 150 m^3/ha. Similarly the estimates of yield/ha at rotation age for the seeded jack pine stand were: a) low estimate = 150 m^3/ha, b) high estimate = 250 m^3/ha, c) the probability that yield/ha from seeding jack pine may be less than the low estimate = 0.10, d) the probability that the yield estimate might be less than the high estimate = 0.95 and e) the absolute minimum yield of pulpwood from seeded jack pine stand = 120 m^3/ha. Future (i.e., ten years hence for the examples given here) pulpwood prices used were: a) low estimate = $1.50/m, b) high estimate - $2.00/$m^3$, c) the probability that pulpwood price might be less than the low estimate = 0.10, d) the probability that jack pine pulpwood price might be less than the high estimate = 0.90 and e) the absolute minimum for future pulpwood price = $1.00/$m^3$. Other input estimates for the first example are given at the bottom of Table 1.

In the second example three regeneration systems are compared on the basis of present net worth criteria. This example may also apply to large cutover areas of crown land in Ontario. It is assumed that three sites are involved here, the first one being most suitable for growing jack pine (e.g., sand flat site), the second area being most suitable for growing black spruce (e.g., peatland site), and the third area being most suitable for growing white spruce (e.g., an upland site). It is further assumed that bare-root stock will be planted in the case of jack pine and black spruce which require light mechanical site preparation and containerized tree seedlings will be used in the case of white spruce which requires heavy mechanical site preparation. The main differences in site productiveity between the three areas are reflected in the rotation ages used and estimates of final yield for the three regeneration systems being compared.

Input estimates for the second example are summarized in Table 2. It is noted that the input estimates for planting jack pine bare-root stock is identical to that of the first example. Subjective estimates for the cost of site preparation and planting are assumed to be the same for both planting jack pine and black spruce bare-root stock as given in Table 2. Estimates for the cost of site preparation for planting containerized white spruce tree seedlings are given: a) low estimate = $250 00, b) high estimate = $320.00, c) the probability that the cost of site preparation may be less than the low estimate = 0.10, d) the probability that the cost of site preparation may be less than the high estimate = 0.95 and c) the absolute minimum cost of site preparation = $230.00/ha. Similarly, the five subjective estimates for the cost of planting containerized white spruce tree seedlings were: $150.00, $230.00, 0.10, 0.95 and $130.00/ha.

Stocking standard for the three regeneration systems specified by interval estimates were the same as in the first example as: low = 0.45 and high = 0.65. The five subjective estimates for the expected stocking for the three regeneration systems were: 0.40, 0.95, 0.10, 0.90 and 0.35 for planting jack pine, 0.35, 0.90, 0.10, 0.95, and 0.30 for planting black spruce and 0.45, 0.95, 0.05, 0.95 and 0.40 for planting white spruce containerized seedlings, respectively. Subjective estimates for the final yield for the three regeneration systems were: 200 m^3, 300 m^3,

Table 2. Input estimates for Model "FIDME" for economic comparison of three regeneration systems of planting jack pine and black spruce bare-root stock and white spruce containerized seedlings on three different sites

Input estimate	Regen. method	Point estimate	Subjective estimates: Low	High	Prob. low	Prob. high	Minimum
Site preparation $/ha 1/	Pj BR)	--	110	140	0.10	0.95	100
	Sb BR)	--	110	140	0.10	0.95	100
	Sw Con)	--	250	320	0.10	0.95	230
Establishment $/ha 1/	Pj BR)	--	250	350	0.10	0.95	225
	Sb BR)	--	250	350	0.10	0.95	225
	Sw Con)	--	150	230	0.10	0.95	130
Stocking standard	Pj BR)	--	0.45	0.65	--	--	--
	Sb BR)	--	0.45	0.65	--	--	--
	Sw Con)	--	0.45	0.65	--	--	--
Expected stocking	Pj BR)	--	0.40	0.95	0.10	0.90	0.35
	Sb BR)	--	0.35	0.90	0.10	0.95	0.30
	Sw Con)	--	0.45	0.95	0.05	0.95	0.40
Product #1 yield m^3/ha	Pj BR)	--	200	300	0.10	0.95	150
	Sb BR)	--	180	230	0.10	0.95	150
	Sw Con)	--	280	350	0.10	0.90	250
Product #1 price $/$m^3$ 2/	Pj BR)	--	1.50	2.00	0.10	0.90	1.00
	Sb BR)	--	1.50	2.00	0.10	0.90	1.00
	Sw Con)	--	1.50	2.00	0.10	0.90	1.00
Rotation age years	Pj BR)	70	--	--	--	--	--
	Sb BR)	90	--	--	--	--	--
	Sw Con)	80	--	--	--	--	--
Interest rate		12%					
Inflation rate		5%					
No. of iteration		300					
Random No. seed		135					

1/ Same as in 1/ Table 1.

2/ Same as in 3/ Table 1.

0.10, 30.95 and 3150 m^3/ha for planting jack pine, 180 m, 230 m, 0.10, 0.95, and 150 m^3/ha for planting black spruce, and 280 m^3, 350 m^3, 0.10, 0 .90, and 250 m /ha for planting containerized white spruce seedlings. Future (i.e., ten years hence for these examples) pulpwood prices were the same for the three regeneration systems as given before (see Tables 1 and 2).

Input estimates for the third example are summarzed in Table 3. This example compares the relative economic desirability of three investment alternatives of growing timber for pulpwood and/ or saw log production with that of Christmas tree production on three different areas (sites). This example may apply to privately owned forest lands and is presented here mainly to demonstrate the flexibility of the model application. The objective of such an economic comparison might be to rank or priorize the areas for investment by the land owner based on the expected rate of return from each alternative investment.

The initial cost (i.e., the market value of the land $/ha) for the three sites for planting jack pine, black spruce and Scots pine *(Pinus sylvestris* L.) are assumed to be $100.00, $25.00 and $500.00/ha, respectively. Since the present value of land is either known or is subject to minor variability, point estimates were used in this case. The difference between the initial cost for the three sites presumably reflects the difference in value of the land due to differences in site quality, location, accessibility and other factors affecting the market value of forest lands. Subjective estimates for the cost of site preparation and regeneration establishment for both planting jack pine and black spruce are identical to the previous example. In the case of Scots pine plantation, however, it is assumed to require intensive site preparation similar to that of containerized planting as given in Table 2. The cost of planting for Scots pine is assumed to be the same as that of jack pine and black spruce (see Table 3). Stocking standard for all three regeneration systems are assumed to be the same as in the previous examples. The expected stocking for both planting jack pine and black spruce were also assumed to be the same as those given in the previous example. The five subjective estimates for the expected stocking for Scots pine were: a) low estimate = 0.80, b) high estimate 0.95, c) the probability that the expected stocking might be lower than the low estimate = 0.10, d) the probability that the expected stocking might be lower than the high estimate = 0.95, and e) the absolute minimum for expected stocking = 0.50.

The annual cost/ha, i.e., property tax, etc., were assumed to be $4.00, $1.00 and $20.00/ha/year for the three sites, respectively. In the case of jack pine plantation it was assumed that it will be thinned twice at the ages of 15 and 35 years, the latter being a commercial thinning. The subjective estimate for the cost of both thinnings were assumed to be the same as those given for the first example. No periodic costs were assumed in the case of planting black spruce as indicated in Table 3. The costs of tending the Scots pine plantation were expressed in the form of two periodic costs : one for herbicide spraying to reduce competing vegetation and the other for pruning and shaping individual trees. It was assumed that herbicide application will begin in the second year and will be repeated every other year until age eight years. Subjective estimates for the cost of spraying (Olson et al. 1979) were as: a) low estimate = $35.00, b) high estimate = $60.00, c) the probability that the cost of spraying will be less than the low estimate = 0.10, d) the probability that the cost of spraying will be less than the high estimate = 0.90 and e) the absolute minimum for the cost of spraying = $30.00/ha. It was also assumed that the pruning operation will begin at the first year and it will be carried on every year until year 9, one year before harvesting. Table 3 gives the five subjective estimates for the cost of pruning as: $120.00, $150.00,0.10, 0.90 and $100/ha.

The next input estimate given in Table 3 is the liquidation cost, e.g., commission and legal fees for the sale of the land for the Scots pine plantation site as $50.00/ha. It is assumed that the Christmas tree site will be sold following the second rotation, i.e., after 20 years, at $700.00/ha. Annual return, e.g., users fee for hunting, fishing, picnicking, etc., for the jack pine site is assumed to be $4.00/ha. It is assumed that the commercial thinning applied to the jack pine stand at the age of 35 will result in a periodic return of: a) low estimate =

Table 3. Input estimates for Model "FIDME" for economic comparison of three forestry investment alternatives of planting jack pine and black spruce bare-root stock for pulpwood and/or saw log production and planting Scots pine for Christmas tree production on three privately owned sites

Input estimate	Invest. method	Point estimate	Subjective estimates: Low	High	Prob. low	Prob. high	Minimum
Initial cost $/ha	Pj BR)	100	--	--	--	--	--
	Sb BR)	25	--	--	--	--	--
	Ps Ch)	500	--	--	--	--	--
Site preparation $/ha 1/	Pj BR)	--	110	140	0.10	0.95	100
	Sb BR)	--	110	140	0.10	0.95	100
	Ps Ch)	--	250	320	0.10	0.95	230
Establishment $/ha 1/	Pj BR)	--	250	350	0.05	0.95	225
	Sb BR)	--	250	350	0.05	0.95	225
	Ps Ch)	--	250	350	0.05	0.95	225
Stocking standard	Pj BR)	--	0.45	0.65	--	--	--
	Sb BR)	--	0.45	0.65	--	--	--
	Ps Ch)	--	0.45	0.65	--	--	--
Expected stocking	Pj BR)	--	0.40	0.95	0.10	0.90	0.35
	Sb BR)	--	0.35	0.90	0.10	0.95	0.30
	Ps Ch)	--	0.80	0.95	0.10	0.95	0.50
Annual cost $/ha	Pj BR)	4	--	--	--	--	--
	Sb BR)	1	--	--	--	--	--
	Ps Ch)	20	--	--	--	--	--
Periodic cost #1 $/ha 2/	Pj BR)	--	75	300	0.05	0.80	50
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	35	60	0.10	0.90	30
Periodic cost #2 $/ha 2/	Pj BR)	--	75	300	0.05	0.80	50
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	120	150	0.10	0.90	100
Liquidation cost $/ha	Pj BR)	--	--	--	--	--	--
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	50	--	--	--	--	--
Annual return $/ha 3/	Pj BR)	4	--	--	--	--	--
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	--	--	--	--	--
Periodic return $/ha 2/	Pj BR)	--	60	100	0.20	0.80	50
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	--	--	--	--	--
Terminal return $/ha	Pj BR)	--	--	--	--	--	--
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	700	--	--	--	--	--
Product #1 m^3/ha (trees/ha)	Pj BR)	--	150	200	0.10	0.95	100
	Sb BR)	--	180	230	0.10	0.95	150
	Ps Ch)	--	800	950	0.10	0.90	700
Product #1 price $/unit 4/	Pj BR)	--	1.50	2.00	0.10	0.90	1.00
	Sb BR)	--	1.50	2.00	0.10	0.90	1.00
	Ps Ch)	--	3	5	0.10	0.90	2.50
Product #2 m^3/ha	Pj BR)	--	75	100	0.10	0.95	50
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	--	--	--	--	--
Product #2 price $/unit 4/	Pj BR)	--	10.00	15.00	0.10	0.90	5.00
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	--	--	--	--	--
Rotation age (years)	Pj BR)	70	--	--	--	--	--
	Sb BR)	70	--	--	--	--	--
	Ps Ch)	10	(analysis carried out for two rotations)				

Interest rate	10%
Inflation rate	5%
No. of iteration	300
Random No. seed	1235

1/ Same as in 1/ Table 1.

2/ In the case of annual costs and returns, a start and an end year is required.

3/ Same as 2/ in Table 1.

4/ Same as 3/ in Table 1.

$60.00, b) high estimate = $100.00, c) the probability that the periodic return will be less than the low estimate = 0.20, d) the probability that the return from commercial thinning will be less than the high estimate = 0.80 and e) the absolute minimum from periodic return = $50.00/ha.

In the case of jack pine plantation, it is also assumed that the final yield will be in the form of two products of pulpwood and saw log. The five subjective estimates for pulpwood production were: 150, 200, 0.10, 0.95 and 100 m^3/ha and those for saw log production were: 75, 100, 0.10, 0 .95 and 50 m /ha. In the case of black spruce plantation, the final yield is assumed to be used as pulpwood only and the estimates were the same as in the previous example. The final product from the Scots pine planation is expressed as the number of Christmas trees/ha harvested as: a) low estimate = 800, b) high estimate = 950, c) the probability that the number of Christmas trees will be less than the low estimate = 0.10, d) the probability that the number of trees will be less than the high estimate = 0.90 and e) the absolute minimum estimate = 700 Christmas trees/ha. Future (i.e. , ten years hence for this example) pulpwood prices used for the jack pine and black spruce were the same as in the previous examples. The subjective estimates for the future price of Scots pine Christmas trees (on the stump) were: a) low estimate = $3.00, b) high estimate = $5.00, c) the probability that future price will be less than the low estimate = 0.10, d) the probability that the future price will be less than the high estimate = 0.90 and e) the absolute minimum = $2.5/tree. Finally, the five subjective estimates for future price of saw log jack pine were assumed to be: $.10.-00,.$15 .00, 0.10, 0.90 and $5.OO/$m^3$. Other input estimates for the third example are given at the bottom of Table 3.

RESULTS (OUTPUT) AND INTERPRETATION

As mentioned earlier the sole purpose of the examples used above and the results described here is to demonstrate the model application and its flexibility and not to recommend a specific regeneration system. Some of the assumptions made may only apply to hypothetical situations, nevertheless the examples should serve to demonstrate the model capabilities and applications.

Results- of the first example are summarized in Table 4. The first column of Tables 4-6 labelled "Probability of exceeding" applies to the remaining columns in these tables. The second row (or line of Table L} indicates, for example, that there is a 10% chance that the future cost per m^3 of pulpwood will exceed $84.04 for planting jack pine and $76.06 for seeding jack pine. Conversely, there is a 90% chance that the future cost per m^3 of pulpwood would be equal to or less than these figures for planting and seeding jack pine. Future cost difference between planting and seeding jack- pine is given in column 4 of there is a 10% chance that the future cost of a m^3 of pulpwood from a jack pine seeded stand will be less than that of a jack pine planation by $7.98. Line 3 of Table 4 indicates that there is a 20% chance that the future cost of pulpwood per m^3 will exceed $65.94 from jack pine plantations and $67 .99 from jack pine seeded stands. Conversely, Table 4 indicates that there is an 80% chance that the future cost per m^3 will be between $27 .50 and $65.94 for pulpwood from jack pine plantation and between $29.32 and $67.99 for pulpwood from seeded jack pine stands. Column 4 of table 4 also indicates that there is an 80% chance that future cost per m3 of pulpwood from planting jack pine will be less than that from seeded stands by about $1.82 or more.

As mentioned earlier, the first example should demonstrate the application of the model in fairly simple situations where two or more regeneration systems. are to be compared for a given area (or site) and for the same rotation age. In the above example, the main differences between seeding and planting jack pine were expressed in terms of differences in the cost of site preparation, the cost of stand establishment, expected stocking, thinning requirements and the difference in the final yield. Based on the input estimates used for this example, it may be stated that there' is only less than a 20% chance that seeding jack pine may be a more cost-effective regeneration system than planting jack pine. On the other hand, there is more than 80% chance that, planting jack pine would be a more cost-effective regeneration method than seeding jack pine.

Table 4. Output of simulator "FIDME" for comparing the cost-effectiveness of pulpwood production from planting and seeding jack pine for a rotation age of 70 years, an interest rate of 10% and an inflation rate of 5%

	Future cost $/$m^3$		Future cost difference $/$m^3$
Probability of exceeding	Planting jack pine	Seeding jack pine	Planting - seeding jack pine jack pine
0.00	236.47	173.39	63.08
0.10	84.04	76.06	7.98
0.20	65.94	67.99	-2.05
0.30	55.17	63.53	-8.36
0.40	49.26	60.38	-11.12
0.50	45.75	56.98	-11.23
0.60	43.67	53.17	-9.50
0.70	41.07	49.86	-8.79
0.80	38.57	46.60	-8.03
0.90	35.92	42.82	-6.91
1.00	27.50	29.32	-1.82

Table 5 summarizes the results of example 2 in which three regeneration systems of planting jack pine and black spruce bare-root stock and planting white spruce containerized tree seedlings were compared on the basis of present net worth. As indicated' in Table 2 the main differences between the three regeneration systems were expressed in terms of the cost of site preparation, the cost of stand establishment, expected stocking level, final yield and rotation ages. Differences in site productivity of the three areas are expressed mainly in terms of the final yield and rotation age. The results of this example may be used to rank the three areas for regeneration or priorize the three investment alternatives.

Table 5 compares the three regeneration systems on the basis of present net worth. Line 2 of Table 5, for example, indicates that there is a 10% chance that present net worth/ha might exceed $444.29 for planting jack pine, $270.48 for planting black spruce and $473.65 for planting white spruce containerized seedlings, respectively. This table also indicates that there is a 50% chance that present net worth/ha will be between $248.45 and $727 .19 for planting jack pine bare-root stock, and between $118.47 and $477.83 for planting black spruce bare-root stock and between $318.40 and $664.64 for planting white spruce containerized tree seedlings, respectively. It should be noted that where present net worth is positive, it means that the investment is more attractive than the alternative rate of return by that amount/unit area. when present net worth is negative, it means that the investment is less profitable than the alternative rate of return by that amount/unit area. For the above example results indicate that there is less than 20%,30% and 10% chance, respectively, that these investments might be less profitable than the alternative rate of return. Based on the input estimates used and assumptions made for the second example, it may be concluded that of the three regeneration systems compared planting white spruce ,will be the most profitable investment followed by planting jack pine and black spruce.

Results of the third and final example are summarized in Table 6. This table compares the three investment alternatives of planting jack pine for pulpwood and saw log production, planting black spruce for pulpwood production an planting Scots pine for Christmas tree production on the basis of internal rate of return. The main differences between the three forestry investments have been expressed not only in the costs of site preparation, plantation establishment, expected stocking, final yield and rotation age, they have also been expressed in terms of initial cost, annual, periodic and liquidation costs; and annual, periodic and terminal returns. Other differences have been expressed in terms of the number and types of products, e.g., pulpwood versus pulpwood and saw log and Christmas tree production. Also differences have been expressed in terms of future price of different products from each investment. The results of the model application should provide., a basis for ranking of the above three investments for the hypothetical forest landowner.

Table 6 provides the expected rate of return from the three ivnestments at 10% probability interyale Line 2 of this table indicates, for example, that there is a 10% chance that the rate of return from planting jack pine would be between 12% to 13% and that from planting black spruce would be about 11% and that from planting Scots pine for Christmas tree production would be between 20% to 22% . Conversely, it indicates that there is a 90% chance that the internal rate of return from planting jack pine would be between 11% to 12% and that from planting black spruce would be between 8% to 11% and that from planting Scots pine would be between 17% to 19%, respectively. This table also indicates that the internal rate of return for planting Scots pine is 6% to 9% higher than that for growing jack pine and is 9% to 11% higher than that for planting black spruce at most probability levels. Therefore the task of ranking the three investment alternatives become fairly simple. Under the assumptions made and based on the input estimates used for this example, planting Scots pine for Christmas tree production would be the most attractive investment followed by planting jack pine for pulpwood and saw log production and planting black spruce for pulpwood production.

MODEL SENSITIVITY

A large number of trial runs were conducted to examine the model sensitivity with regard to changes in various input estimates. The results

Table 5. Output of model .'FIDME" for economic comparison of three regeneration systems of: planting jack pine and black spruce bare-root stock and planting of white spruce containerized tree seedlings based on present net worth criteria and an interest rate of 12% and inflation rate of 5%

	Present net worth $/ha		
Probability of exceeding	Planting jack pine	Planting black spruce	Planting white spruce
0.00	727.19	477.83	664.64
0.10	444.29	270.48	473.65
0.20	377.52	231.25	426.37
0.30	330.28	205.53	388.67
0.40	289.47	152.89	358.54
0.50	248.45	118.47	318.40
0.60	217.96	83.42	282.21
0.70	167.19	25.00	250.79
0.80	109.79	-70.36	207.62
0.90	-11.94	-211.33	164.10
1.00	-1041.37	-935.62	-47.83

Table 6. Output of model "FIDME" for example 3 in comparing the relative economic desirability of three forestry investments, namely, planting jack pine for pulpwood and lumber production, planting black spruce for pulpwood production and planting Scots pine for Christmas tree production on the basis of internal rate of return criteria

	Internal rate of return		
Probability of exceeding	Planting jack pine	Planting black spruce	Planting Scots pine
0.00	0.13	0.11	0.22
0.10	0.12	0.11	0.20
0.20	0.12	0.11	0.20
0.30	0.12	0.10	0.20
0.40	0.12	0.10	0.19
0.50	0.12	0.10	0.19
0.60	0.12	0.10	0.19
0.70	0.12	0.10	0.18
0.80	0.12	0.10	0.18
0.90	0.12	0.09	0.18
1.00	0.11	0.08	0.17

of these trial runs may be summarized as follows:

1) The model is very sensitive to estimates of expected stocking levels as compared to the stocking standards for all criteria. For example, if stocking standards are reduced by 10%, say from 65% to 55%, for all regeneration systems, the relative performance of the regeneration system with the lowest expected stocking level shows the most improvement and that with the highest expected stocking level results in the least improvement.

2) The model is quite sensitive to estimates of the final yield for all criteria and it is also sensitive to the estimates of future prices, except in the case of the cost-effectiveness criterion. That is, if the estimates of the final yield or product prices for all investment are changed by a constant amount, the regeneration system with the lowest yield or product price will be most affected.

3) The model is also quite sensitive to initial cost, i.e., land value, cost of site preparation and stand establishment, for all economic criteria. The timing and relative magnitude of these costs have considerable effect on the relative comparison of investments under consider ation. For example, if the initial costs for all regeneration systems being compared are doubled ,without affecting the final return and product prices, the regeneration system with the lowest initial cost will be most affected. However, if raising the initial cost by a given amount increases the expected stocking levels or reduces the rotation ages proportionately, the relative economic performance of the regeneration system with the lowest initial cost, or the lowest expected stocking level and/or the longest rotation age will improve the most.

4) The model can be fairly sensitive to periodic costs ,and return but this sensitivity is dependent on their relative magnitude and frequency of occurrence. If periodic costs for fertilization or thinning results in the reduction of ,rotation age and/or increases the final yield for a regeneration system, it might become' the factor most affecting the relative economic performance of such a regeneration system.

5) The model is somewhat insensitive to the estimates of annual costs and returns, mainly because of their relative magnitudes as compared to other costs and returns. Annual costs and returns do not usually influence the final yield and product prices.

6) Finally, the model is least sensitive to the estimates of terminal costs and returns--mainly because of their relative magnitude and timing.

SUMMARY

The model described above contains significant improvements and modifications over its predecessor "REGEN". It allows comparison of any kind of long term forestry investments consisting of a few to many types of costs and returns. It is mainly an interactive model which allows the use of either point or subjective estimates for nearly all inputs required. If properly used, the model should provide a valuable aid to forest managers in making rational economic decisions on various silvicultural investments—particularly those related to the forest renewal. With the aid of this model, the forest manager may choose a regeneration system with the best chance of being the most economical regeneration system or, alternatively, he may choose the regeneration system that has the best chance of producing wood at the lowest future cost/unit volume.

Application of subjective probability estimates in this model serves a three prong objective: 1) It serves as a built-in mechanism to adjust for the risk and uncertainty associated with the long-term investments under consideration, 2) It provides a simple method of utilizing limited data augmented by personal experience or feelings about future outcomes of given set of conditions, and 3) It allows incorporation of variability and thus associated probability with the results. It is hoped that forest managers will take full advantage of this model in choosing the most appropriate regeneration systems at this critical time.

The model is written in structured FORTRAN 77. A tape copy of the program listing and input examples may be obtained from the author.

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SIXTH INTERNATIONAL WORKSHOP ON FOREST REGENERATION

AT HIGH LATITUDES

Minutes of the Business Meeting
Edmundston, New Brunswick, Canada August 10, 1984

The meeting opened with a discussion concerning the 1985 workshop. Owe Martinson briefed us about the proposed agenda for the workshop. It will include 3 days of travel to northern and western Sweden. An additional day will be devoted to the presentation of papers. The meeting will take place June 16-22. Its theme will be, "Regenerating Forests Close to Timberline".

Proposals for the 1986 meeting were also discussed. It was decided that this meeting will be held at Ft. St. John, British Columbia, Canada. The invitation to come to Canada was offered by Bob McMinn of the Pacific Forest Research Centre of the Canadian Forestry Service. Sven-Eric Appelroth proposed that the meeting in 1987 be held in Fin land and Russia. His proposal was accepted and the group authorized him to begin arrangements.

The next item on the agenda dealt with our relationship with IUFRO. There was general agreement that our workshop group needed a more formal structure. It was decided that we should try to have a separate working party within Division I of IUFRO. The following motion was passed unanimously:

> The chairman of this group is authorized to initiate discussion with IUFRO officials concerning the possibility of this group becoming an official research working unit of IUFRO.

Jim Cayford agreed to be the contact person with IUFRO at their September meeting. He will advise Dick Herman of IUFRO before that meeting of the group's request. He will act on behalf of the chairman. Sven-Eric Appelroth noted that this will increase the chances of having Soviet participation.

Those attending the meeting agreed to have Dr. Andrew Gordon's paper on black spruce published, if submitted, as part of the 1984 proceedings. Dr. Gordon had to cancel his plans to attend the workshop because of his dissertation defense.
After much discussion, it was agreed, if possible, that the name of our group should be the Northern Forest Regeneration Working Group. Several alternatives, including boreal, high latitude and taiga, were discussed. The working group's goal would be to: “promote the exchange of experience and research results on forest regeneration practices in the northern forest”.

Edmond C. Packee of the Agricultural and Forestry Experiment Station of the University of Alaska, U.S.A. was appointed to serve as chairperson.

Respectfully submitted,

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THEME AND LOCATION FOR THE 1985 WORKSHOP

Owe Martinsson

This workshop is dealing with problems of forest regeneration on northern latitudes and the southern boundary of interest has been set to the 55:th parallel. The influence from the latitude on the forest vegetation is, however, not the same in one part of the world compared to another.

In central and eastern Canada the 55:th parallel runs through a country with severe climatical conditions for forest production and on the other side of the globe the 55:th parallel doesn't even touch the southern part of Scandinavia. Still there are productive forests in northern Norway north of the 70:th parallel. Sweden has well growing beech forests on latitude N 570, oak grows as a commercial species on latitude N 60° and on lower altitudes there is a commercial forestry of conifers north of the artic circle.

The warm current from the gulf of Mexico makes the winters in Scandinavia relatively mild and short and the large continent in the east has a continental influence on the summer climate. Besides the northern latitudes of Scandinavia make this area unique in the world in the combination of an almost continous day light in the growing season and a relatively warm climate.

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There are, however, other limitations of forest production which only to some extent are associated with the latitude.

According to the Swedish Act of Forestry a boundary for special problems of regeneration has been established in the north deviding the country in two parts (Fig 1). The boundary is mainly based upon altitude and excludes 3.8 mill hectares of forest land from commercial forestry due to a too big risk for failure of forest regeneration. Most of these forests are containing high quality timber and are today economically attractive.

The Swedish Forest Service and the Swedish Faculty of Forestry have to an ever increasing extent been involved in the task of forest regeneration under these extraordinary conditions. There are several experiments of site preparation, planting and direct seeding close to or above the timber line. Several provenance trials with native and/or introduced tree species were established more than 30 years ago.

In lower elevation areas on the same latitude are detailed descriptions of forest management, seed ing, planting, site preparation, controlled burning since 1908 the result of which can be studied today.

In a world of limited resources the problems of regenerating forests not only at northern latitudes but also in areas of high altitude should be of general interest also in other countries of the north.

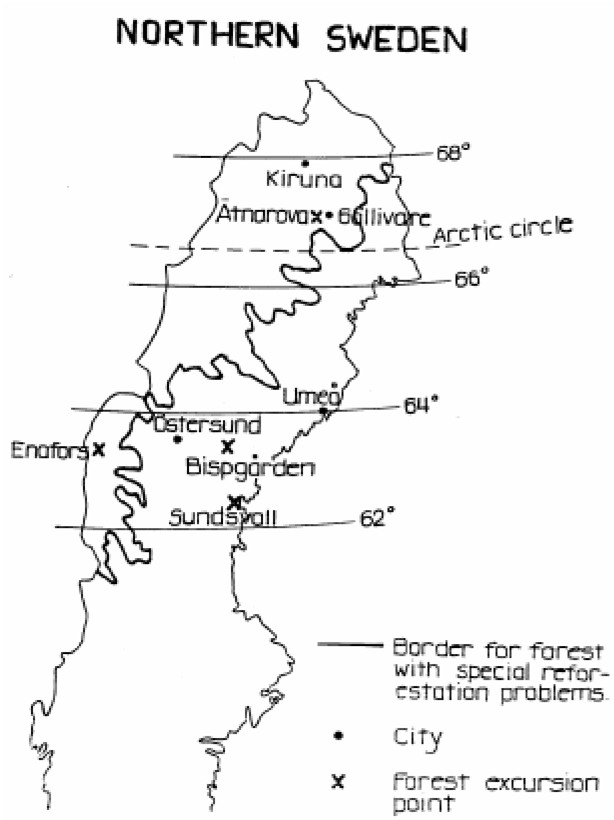

Figure 1. Areas excluded from commercial forestry due to reforestation problems.

Therefore I will suggest that the 1985 meeting of this workshop will take place in northern Sweden under the theme "Regeneration of forests close to the timber line".

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SIXTH INTERNATIONAL WORKSHOP ON FOREST REGENERATION AT HIGH LATITUDES

August 10-11, 1984

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The proceedings contains nine papers presented at a workshop on regeneration at high latitudes. The papers reflect work being done in Canada and Scandinavia.

Keywords: Yield, boreal forests, latitudes (-site, regeneration (stand).

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