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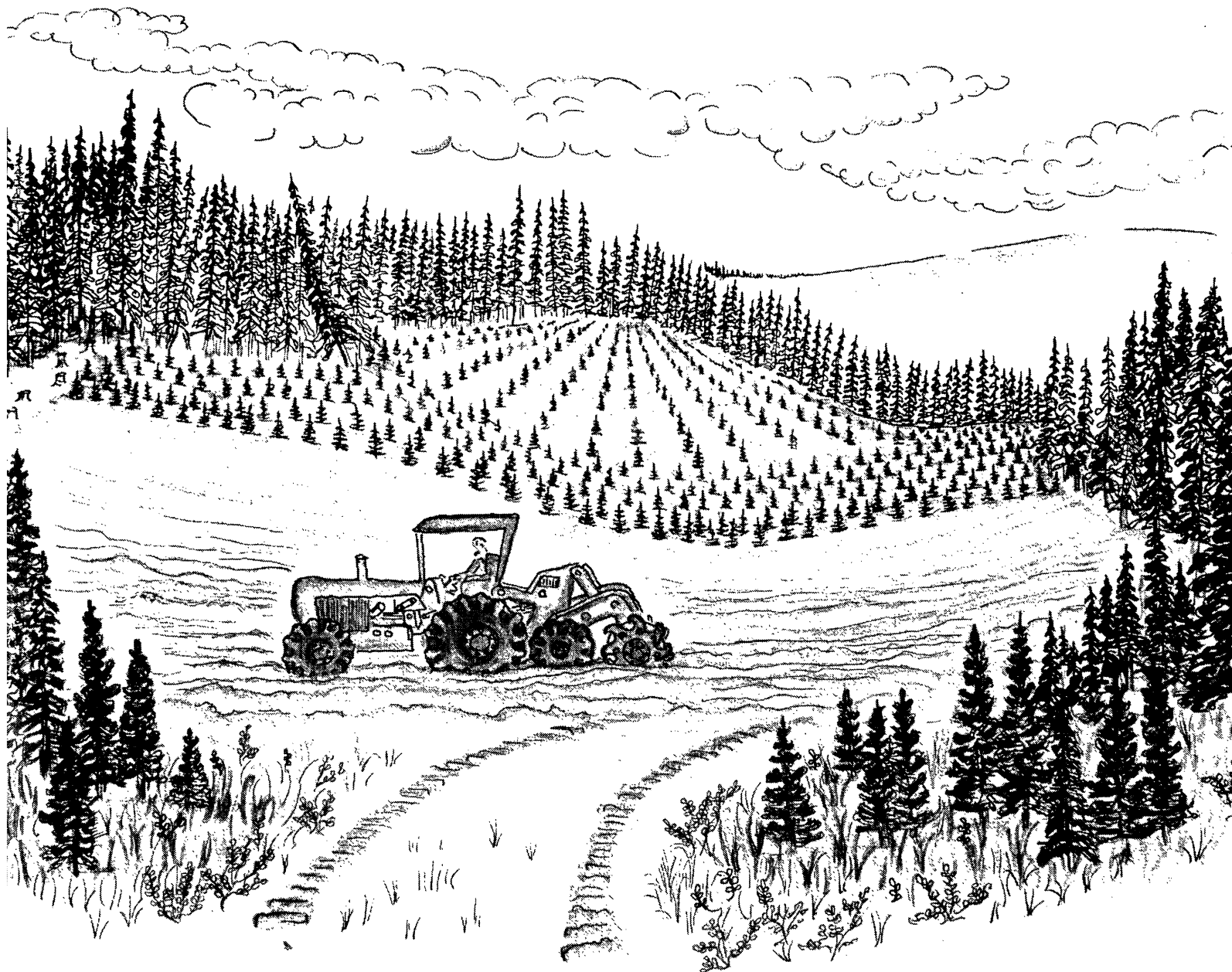
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Forest Regeneration at High Latitudes

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FOREST REGENERATION AT **HIGH** LATITUDES

Edited by
Mayo Murray and Robert M. VanVeldhuizen

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INTRODUCTION

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Early in 1979 we surveyed forest managers and researchers in a number of northern countries to identify topics in forest management of circumpolar interest. Responses most frequently centered on problems of forest regeneration and related harvesting practices. As a result, an international workshop was held in Fairbanks, Alaska, on 13-15 November 1979, to obtain a perspective of forest regeneration at high latitudes.

Through support from the Forest Service, U.S. Department of Agriculture, and the Bureau of Land Management, U.S. Department of the Interior, the School of Agriculture and Land Resources Management, University of Alaska, brought together at the workshop foresters from Canada,

Norway, Sweden, Finland and Alaska. Papers included in this report were presented at the workshop. Techniques for forest regeneration described in other northern countries may have applications in Alaska as demands increase for forest products and forest biomass as an energy source.

Subsequent workshops are planned in collaboration with the International Union of Forestry Research Organization to assess forest management techniques for the regeneration of white spruce in Alaska and the Yukon Territory. In the meantime, sincere appreciation is expressed to the authors of papers in this interim report of the working group that assembled in Fairbanks, Alaska, in November 1979.

DEVELOPING A PROGRAM FOR RESEARCH AND APPLIED MANAGEMENT
RELATED TO FOREST REGENERATION

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FOREST REGENERATION AND LEVELS OF
MANAGEMENT

Forest regeneration includes a wide field of biological and technological aspects. The area of forest land in northern latitudes is rather limited in relation to the forest areas of the whole world, and the number of species especially, are small. However, northern latitudes involve increasing biological problems due to the forest growing so close to the alpine and polar tree limits.

There is reason to discuss whether or not all aspects ought to be considered in a research program on forest regeneration. First of all, should all areas on the northern latitude be involved? Even north of the 60th parallel the conditions for the growing forest vary rather considerably and quite a few tree species are involved. I have the feeling that a research program outlined for limited areas and selected species would be most fruitful and easier to carry out. Also for economical reasons it would not be possible to develop a research program covering all the different conditions and species. Consequently, as a starting point at least, I think we ought to discuss and decide which regions and species should be involved in a cooperative program of research and applied management.

If separate regions are chosen, the program should then contain selected items and problems most likely to be of paramount importance for the future forestry of these regions, up to the turn of the century. As applied management should be involved in the program, the research part of it should, as far as possible, cover the level of intensity of forest management to be expected in the future.,

In general terms, three levels of future forestry can be mentioned with different consequences for applied research.

1. Harvesting merchantable trees and stands without concern for further development or yield. This is the low intensity level where the areas are left for a long period until nature has provided for merchantable trees again.
2. Harvesting merchantable trees in a way that secures a reasonable natural regeneration of valuable species, or enables remaining smaller trees to develop into merchantable dimensions. Medium intensity level.

3. Artificial regeneration (planting or sowing) immediately or soon after the harvesting cut, securing a good regeneration of the most important species. This is the high intensity level with no time wasted and the whole area producing good timber.

Management on the lowest level needs little or no research. Management on the medium level with natural regeneration depends greatly on climate, soil and species.

Climate of northern latitudes, especially summer temperature and length of growing season, is a limiting factor for flowering and ripening of seed. Low summer temperature also causes a low rate of humus decomposition, resulting in a thick layer of raw humus which is a poor bed for germinating seeds.

Besides climate, humus decomposition is influenced by soil conditions, especially the structure and moisture content. Small seedlings of conifers will receive strong competition from ground vegetation, varying with species and vigor of the plants. Scarification improves the seed bed and lessens the competition considerably.

By means of scarification, management based on natural regeneration may reach a fairly high level. The same is the case without scarification, for instance for pine on dry sandy soils with thin humus layers, where the natural regeneration will be abundant.

A condition for using natural regeneration is that one or more suitable species are present in the area. When introducing new species or provenances, artificial regeneration is required.

Within this complex of natural regeneration, there are plenty of questions suitable for applied research.

Management on the high level of intensity with artificial regeneration has few restrictions, this being the main reason why nearly all areas of medium and good spruce sites are artificially regenerated in Scandinavia as well as in northern Europe.

However, the cost of regeneration may be a limiting factor, especially in remote areas and in steep terrain where income from harvesting is greatly reduced by high costs for

cutting and transport. On the other hand, management planning is simpler, and advanced harvesting methods and machines can be used without such restrictions as size of cutting areas, leaving of seed trees or preventing damage on regeneration.

On some sites, where broad-leaved trees are very vigorous, a plantation of conifers has to be followed by tending, reducing the broad-leaved competition. This can be done by hand, machines or chemicals. Also management based on natural regeneration with scarification may need to fight the broad-leaved competition.

In such highly intensive management there are a multitude of questions calling for research.

It is not my task at present to draw any conclusions regarding regions or levels for a cooperative program for research and applied management. But the ideas presented here might be of interest when discussing and deciding upon which problems should go into a program. Such a program for research and applied management has, besides the intensity level, to a very great extent, to be based on the existing conditions for instance terrain, site, species, climate, etc.

FOREST REGENERATION IN NORWAY

The second part of this paper will give some information on forest regeneration as practiced in Norway where, in fact, all three intensity levels are used.

The mountain forests are managed according to intensity level 1 or something between 1 and 2. At least, in the upper belt of approximately 200 m adjacent to the timber line, artificial regeneration is seldom used. In addition to low density and lack of regeneration, the mountain forests are slow growing and not usually managed intensively. Cuttings are mostly made to salvage mature and dying trees.

Below this upper two hundred meter belt, the forests in Norway are usually managed. Of these forests about one third of the area is Scotch pine (*Pinus sylvestris* L.). In Norway the best pine sites are along the rivers on dry, sandy soils. The thin humus layer and sparse ground vegetation, mostly lichen, offer good conditions for natural regeneration of pine. There are also areas at high elevation with a site class most suitable for carrying pine where there are very few pine trees left. Such areas will be planted with pine although in Norway pine planting is less than 10% of the planting program. In Sweden and Finland however, planting pine is very common.

The main coniferous species of Norway is Norway spruce (*Picea abies* [L.] Karst.) which amounts to two thirds of all the forests of Norway. In addition, a large afforesta-

tion scheme for the coastal districts of Western Norway has been underway for the last thirty years. Native trees in this area are Scotch pine and some broad-leaved trees. For the afforestation up to 80% of Norway spruce is used, and Sitka spruce (*Picea sitchensis* [Bong.] Carr) is used in the outer, windy areas.

Generally, planting is the preferred method to establish spruce regeneration in Norway, except for the upper 200 m belt as mentioned. This means intensity levels 3 or in some smaller forests where natural conditions are very favorable, something between level 2 and 3.

There are several reasons for using planting:

1. The natural regeneration of Norway spruce very often comes slowly and scattered due to periodic seed-years and unfavorable germinating conditions in the raw humus layer. In addition, natural regeneration is often over-grown by broad-leaved trees, mostly birch.
2. When raising natural regeneration under shelter trees it is difficult to avoid damage to this regeneration when harvesting the shelter trees. This problem has been more pronounced due to the horse being substituted by increasingly bigger and heavier tractors causing much damage to the young regeneration.
3. Planning management is easier when planting is used to establish the new stand. Regeneration cutting can then be planned and carried out independent of seed years and germination conditions.

Another advantage is that the best provenances can be used to secure the most valuable yield in the future. In areas where it is preferable to change species, planting is the only solution, for instance Sitka spruce or lodgepole pine (*Pinus contorta* Dougl. ex Loud).

When planting, the most suitable density can be selected. This usually means adequate density to secure a good proportion of high quality sawlogs, but still open enough to limit the number of thinnings to two or three.

The type of seedlings has gradually been changed during the last three or four years. Two-year-old rooted seedlings are at present more commonly used than the four-year-old bare-root seedlings. These young, rooted seedlings are slightly cheaper to produce in nurseries, and they are much quicker and cheaper to plant in the field. Another advantage is that the planting season can be prolonged. However, as the young, rooted seedlings are smaller, scarification before planting is highly recommended and more necessary than when planting bigger four-year-old seedlings. However, I expect the gentlemen from Sweden and Finland to deal more closely with these problems.

THE IMPORTANCE OF RAW HUMUS ACCUMULATION IN BOREAL FOREST MANAGEMENT

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INTRODUCTION

Boreal forests are associated with accumulations of partially decomposed organic matter on the soil surface referred to as raw or mor humus.

Besides representing an important store of nutrients whose availability is largely controlled by microbial activity, this layer has thermal insulating properties and often has undesirable seedbed properties (Kraus, Weetman and Arp, 1978). Attempts in North America to develop biologically meaningful classifications of the humus layer have not been very successful. Classifications based on physical properties and appearance do not reflect the very complex biological properties of the layer. Chemical degradation into humic fractions have also been difficult to interpret.

The use of designated forest site types have been more meaningful, using lesser vegetation to characterize a biological condition, which will respond to change in a consistent pattern. Each designated type has associated with it a humus layer of characteristic properties such as depth, texture, cation interchange capacity, N content, etc. Such classifications are now widely used in Canada to characterize the biotic or changing component of the site, as opposed to the physiographic or constant component of site expressed in landform and soil classifications (Linteau 1955, Lafond 1969). Some of the better known types, which cover very large areas of the boreal forest are the Black Spruce-Feather Moss Type; the Jack Pine-Lichen-Bearberry Type; and the Black Spruce Labrador Tea Type (Kabzems et al. 1976).

For each of these types there are characteristic patterns of succession following disturbance and recommended silvicultural practices. These patterns and practices are largely dependent on the properties of the humus layers of each site type. This paper will review some of these properties and point out some of the implications for silviculture practice.

NUTRIENT CONTENT AND AVAILABILITY

Rowell (1935) pointed out long ago that differences in mull and mor are not associated with different rates of organic matter decomposition, but as different types of decomposition. The accumulation of leaves, branches and

roots represents, for many drier and shallow sites, the bulk of the macronutrient supply on the site. The richest boreal sites are associated with herbaceous vegetation, poorer sites with feather mosses, and ericaceous vegetation, and the poorest with lichens, if dry, and sphagnum, if wet. The presence of raw humus in itself has been suggested as characteristic of a very strong biological competition for nitrogen, associated with: high C/N ratios; a blockage of the N cycle; decomposition primarily accomplished by fungi; low concentrations of $\text{NH}_4\text{-N}$; little nitrification and large organic-N reserves. Except on some of the richest herbaceous sites, or those with seepage water, most forest ecosystems can be expected to be responsive to N fertilizer additions once the biological competition for N is expressed by closed crown canopies. Due to large P and K reserves in the humus layer, these elements are unlikely to be limiting; particularly on minerologically rich tills.

Following cutting or fire there is a period of much greater nutrient availability, which has been referred to as the "assart effect" by Rommell and Tamm (Tamm and Pettersson 1969). The magnitude and length of the assart effect are of great practical importance. They are associated with both the increased temperature and moisture which favors humus decomposition and the sudden lack of nutrient uptake and sudden availability for decomposition of large quantities of fine roots. While everybody recognizes this effect, little information is available on the rate and quantities of increased nutrient availability. In practical terms it is important to "capture" this nutrient availability in the desirable tree or shrub species.

It seems likely that in boreal forests lack of "nutrient sinks" would lend to spectacular $\text{NO}_3\text{-N}$ losses noted in the bromocil treated watershed of Hubbard Brook, N.H., since presumably nitrification rates in mors is lower than the more moder type humus layers in New Hampshire. Of more concern on poorer sites with a natural component of *Ledum*, *Kalmia* and *Vaccinium* species, is to avoid "heathland degeneration"—the complete capture of the site by ericaceous species. Under these conditions, Damman (1971) has shown that a new type of humus layer, dominated by ericaceous roots develops, which represents a great immobilization of nutrients and is a stable climax type. Extensive areas of Newfoundland, Quebec and parts of Europe have developed heaths, particularly following repeated fires or grazing, which destroys forest regeneration.

In many older boreal forests there are often appreciable quantities of black spruce (*Picea mariana* [Mill.] B.S.P.) advance growth. Following mechanical harvesting, particularly on ericaceous type sites, the future productivity of patchy advance growth, in competition with *Kalmia* and *Ledum*, may be in question. On the poorest sites, particularly in jack pine (*Pinus banksiana* Lamb.), it could be considered as being "off-site" and should be removed. We should know more about the assart effect and advance growth potential.

Recognition of the assart effect is important in securing the reproduction. Prompt planting is required, following fires and cutting. For a nutrient demanding species such as white spruce (*Picea glauca* [Moench] Voss), this is particularly important if extended periods of "check" are to be avoided. For black spruce, prompt capture of the site by planted stock, which partially emulates the prompt natural regeneration following fire, can produce spectacular growth rates associated with high levels of available nitrogen particularly if other hardwood competition is removed by herbicides. Opportunistic species such as aspen (*Populus tremuloides* Michx.) exploit this natural condition, act as "scar tissue" in healing massive disturbances, and by rapid re-establishment of litterfall, play an important role in humus and nutrient conservation on dry and shallow sites.

Full tree logging, which removes large quantities of nutrients in foliage and removes potentially decomposable organic matter, thus has a double influence of reducing the length and magnitude of the assart effect and may also reduce the priming effect on decomposition of the slash. Our recent attempts (Weetman, Clemmer and Algar, 1979) to determine the magnitude of the direct export and to simulate with a humus process model, the effects of full tree logging, suggest the combined effects may be serious and involve N, P and Ca.

There are also some concerns about acid rain and heavy metal pollution problems which have been prevalent in Europe and around Sudbury, Ontario. European ecosystem studies of the SWECON project in Sweden, SOLLING project in Germany and the Spruce Ecosystem Study in Czechoslovakia are multidisciplinary projects designed to analyze these problems. We have no equivalent studies in the boreal forests of Canada.

SEEDBED AND THERMAL PROPERTIES

The literature on boreal forests is replete with references to the desirable properties of mineral soil and rotten wood, as opposed to raw humus, as seedbeds for spruce and pine, due primarily to problems of dessication. Of great concern here is the parallelism of the effects of forest fires and the effects of modern mechanized logging in creating suitable seedbeds on raw humus. The differences are dramatic and serious. Logging generally does not expose a sufficient amount, nature and distribution of mineral soil to adequately provide for appropriate seedbeds for conifers. Furthermore, except in some jack and lodgepole pine (*Pinus contorta* Doug. ex. Loud) stands, serotinous seed supplies are not available. Lack of utiliza-

tion of aspen and birch (*Betula* spp.), leads to hardwood invasion and forest cover type switches occur. A study we conducted between 1966 and 1976 on 36 case history areas across Eastern Canada, in which we examined stands before, immediately after, and 5 and 10 years after logging, suggests (based on computer simulation of projected yields) a rather pessimistic picture (Frisque, Weetman and Clemmer, 1978).

Of concern are the vast areas logged each year. Of the approximately one million hectares (2.5 million acres) logged in Canada, about 600,000 ha (1.5 million acres) are in boreal forests. The lack of regeneration on these areas is of national concern and alarm for Canada. Besides the lack of money and nursery stock to plant areas, it is often biologically and physically infeasible to plant remote and rough areas on which it is difficult to physically prepare the site by heavy equipment in preparation for hand planting. The problem is confounded by low stumpage rates on Crown lands (which represent 95% of Canada's forests), public apathy and lack of labor. More amenable to solution, but still lacking much attention, are the technical problems of scarification to produce good seedbeds in thick humus. There has been a proliferation of locally developed and imported types of dragged and pushed equipment either designed to mix the humus and mineral soil or to push the humus aside.

Of concern here are the requirements to maximize heat penetration on humus insulated cold soils in boreal forests, where low temperatures limit both root growth and nitrogen availability, and to avoid excessive mineral soil exposure associated with flooding, frost heaving and lack of nutrients. Our approaches are largely empirical, based largely on availability of equipment. It ought to be possible to provide for a happy combination of seedbed properties and assart effects more often than we do. Perhaps more important is that, when we achieve a biologically desirable effect, we often cannot explain it.

Finally, we are now involved in pre-commercial 'thinning programs to space young stands with the aim of reduction of rotation ages, improved control of species composition and tree size. Scandinavian studies have shown organic matter decomposition to be closely temperature regulated and have shown positive effects of such treatments in greatly increasing absolute volume growth as compared to very dense untreated stands. The effects being largely attributed to greater forest floor snow depth, less forest penetration and, thus, improved humus thermal regimes and decomposition rates. Under biologically N stressed conditions, the application of both precommercial thinning and nitrogen fertilization may have synergistic effects. We need more factorial thinning and fertilizer trials in boreal forests to test these effects.

SUMMARY

Boreal forests are associated with raw humus conditions. An understanding of the physical properties, seedbed characteristics and nutrient storage and availability characteristics of this layer are essential to an understanding of both

the natural stand dynamics and the management problems of boreal forests. This knowledge is best assembled and applied within a forest site type classification which recognizes the biologically discrete associated tree, plant, soil and humus conditions. Our understanding of humus processes is often largely imported and is very incomplete. We need not only improve forest site classification, but much better analysis of organic matter decomposition processes and associated nutrient availability. Our work in this area is presently limited by available techniques and thinking which are more appropriate for the agronomic job of growing annual crops in mineral soils, rather than perennial forest crops, with closed nutrient cycles, on cold northern soils dominated by raw humus.

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NUTRIENT CYCLING IN INTERIOR ALASKA FLOOD PLAINS AND ITS RELATIONSHIP TO REGENERATION AND SUBSEQUENT FOREST DEVELOPMENT

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INTRODUCTION

The river flood plains of interior Alaska are the sites of our most productive forests. During the early development of interior Alaska these flood plain forests were heavily utilized for logs and lumber for construction and for fuel for powering river steamboats and heating homes. In the future, relatively fast growing balsam poplar (*Populus balsamifera* L.) and white spruce (*Picea glauca* [Moench.] Voss) forests will undoubtedly receive considerable utilization by the forest industry. These sites may also provide interior Alaska's best potential for future short rotation energy forests (plantations).

In order to best manage these forests it is essential that we have a thorough understanding of the ecological controls that are acting on these ecosystems throughout the entire successional sequence. The river flood plains also offer a unique opportunity to examine the course of forest ecosystem development and to gain insight into mechanisms which control this development. The various stages in primary succession reflect physical, chemical and biological controls of ecosystem structure and function. The interaction, or feedback relations, among the controls and ecosystem processes are displayed in occurrence of the respective vegetation types, their growth rates and longevity. Each successional stage has a species combination which is in harmony with site quality.

Understanding the interplay of controls over successional change is an important step to developing sound forest management strategies. For example, short circuiting succession by planting a late successional species, such as white spruce, on an early successional surface may result in markedly reduced growth rates because of nitrogen limitation. Unless substantial amounts of fertilizer can be applied it is necessary to take advantage of early successional alder and its site ameliorating additions of nitrogen to insure successful growth of spruce.

Another important feature of flood plains is the fact that many site factors which control ecosystem development are relatively constant. This condition enables a clearer picture to be obtained of the changes in system structure and function during the course of succession. For

example, topography essentially is flat so that initially, runoff, drainage, etc. would be approximately the same at all sites. Level topography also results in relatively uniform initial microclimatic conditions. Soil parent material may also be quite uniform in chemical composition because of river mixing. As a result of these conditions the physical, chemical and biological controls of forest ecosystem development are more clearly defined and easily understood on river flood plains than in upland areas.

The Tanana River flood plain near Fairbanks offers an ideal opportunity to examine this primary succession in interior Alaska. The Tanana River is an actively meandering river fed primarily from glaciers in the Alaska Range and from unglaciated watersheds in the Tanana-Yukon uplands. Flood periods tend to occur during the spring snowmelt and breakup and during mid- to late-summer when rain or warm air interacts to quickly bring mountain streams to flood capacity. The spring flood can be short termed, caused by brief damming of the water by ice jams or it can be of a longer duration when exceptionally heavy snowpacks are melted by warm spring weather.

The area of this study lies within and adjacent to the Bonanza Creek Experimental Forest about 40-48 km (25-30 miles) southwest of Fairbanks. Here, on a number of islands and terraces adjacent to the river, all stages of forest succession can conveniently be observed. Over the past 15 years we have established a number of permanent plots in stands of most stages of succession where we have been recording vegetation changes, soils, and ecosystem processes, especially those related to nutrient cycling and biomass production. The data in figures and the following discussion are the result of these long term observations and is our preliminary attempt to synthesize this material in a discussion of flood plain succession. Some information from these studies has previously been published (Ganns, 1977; Van Cleve, 1973; Van Cleve and Viereck, 1972; Gill, 1971; Van Cleve et al., 1971; Viereck, 1970; Zasada and Gregory, 1969). The objective of this paper is to examine some controls of flood plain succession within the framework of nutrient cycling and system productivity and to examine how changes in the controls relate to regeneration and subsequent forest development.

EARLY SUCCESSIONAL STAGES ON THE TANANA RIVER

We define early successional stages as those which exist from the initial bare surface stage (I) through the open shrub stage (VI). These stages generally reflect dominance of physical-chemical control of successional processes with Stage III representing a transition stage.

Certain forms of physical control of ecosystem state and function generally are superimposed over the entire successional sequence. For example, terrace elevation above river stage reflects terrace age and determines frequency of flooding. However, the meandering nature of the river ultimately controls the fate of each terrace regardless of age. Thus older terraces at higher elevation may gradually be eroded along one reach with sediment deposited along another section of river channel initiating a new, low-level terrace. The higher elevation of old terraces and the advanced stage of forest development indicate these stages of succession are being influenced by alluvial erosion and deposition to a relatively small degree compared to lower elevation, younger terraces.

Until sufficient alluvium has accumulated to raise river terraces above the zone of frequent intra-year flooding, physical and chemical control (Stage I, Figure 1) dominate ecosystem structure and function. These mineral soil surfaces may appear to be ideal locations for seed germination and establishment. However, frequent inundation, sediment deposition and erosion makes them highly unstable zones for plant establishment.

During periods of dispersal abundant seed of herbs, shrubs and trees are deposited and germinate on these sites, 8

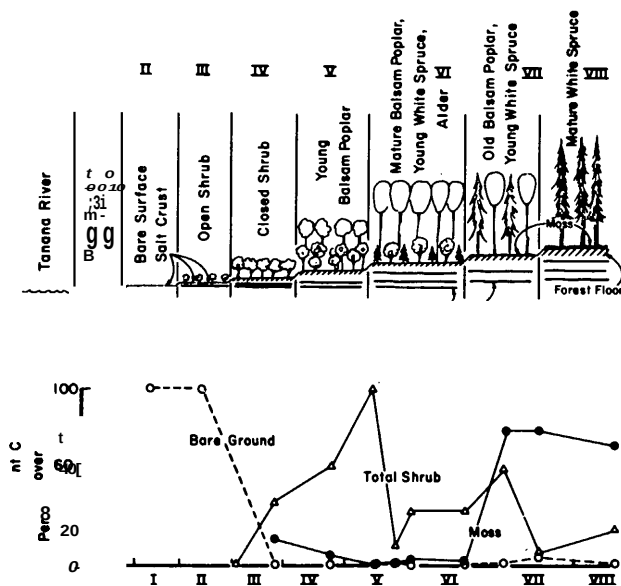


Figure 1—Estimates of percent cover for bare ground, total shrubs and moss on Tanana River successional sequence.

but the shallow rooted seedlings will be washed away or completely buried during the next stage of high water. Nutrient cycling in this environment is largely controlled by saturated flow of soil moisture and leaching of nutrients with elemental concentrations similar to those encountered in river water.

A combination of physical and chemical control exists in the next stage (Stage II) which is characterized by the formation of a salt crust on the bare surface. At this elevation above the river less frequent intra-season flooding occurs. Flooding generally is restricted to spring break-up and during mid- to late-summer high water. Physical removal or burial of shallow rooted seedlings still might occur. Ground-water rises to the surface by capillary action and as a result of surface evaporation deposits substantial concentrations of salts, especially CaSO_4 , or gypsum, and various chloride and carbonate bearing salts. The salt accumulation in the surface few centimeters of soil results in conductivities of nearly 12 mmhos/cm² in saturation extracts and SO_4 concentrations of 10 to 15,000 ppm of soil. The salts form a crust several millimeters thick largely composed of gypsum crystals mixed with soil particles. This high salt concentration may control germination and establishment of quaking aspen (*Populus tremuloides* Michx.) on the Tanana River flood plain. This important upland forest type is not encountered in the primary successional sequence on the flood plain although an abundant seed source is available in the adjacent uplands. Laboratory observation of germination success on samples of the salt crust indicate that aspen seed germination may be reduced by as much as 80% on crusts collected from terraces representative of the bare surface-salt crust and open shrub stages (Stages II and III, Figure 2). Balsam poplar (*Populus balsamifera* L.), the most important hardwood species on the flood plain sites, also show reduction in germination success in response to high salt concentrations, but to a smaller degree than aspen. Whether the effect is one of moisture stress, toxic salt concentrations or both is yet to be determined. Aspen seedlings germinated on salt crusts show substantially reduced rate of growth and smaller cotyledons and hypocotyls. This condition may result in reduced ability of seedlings to obtain sufficient

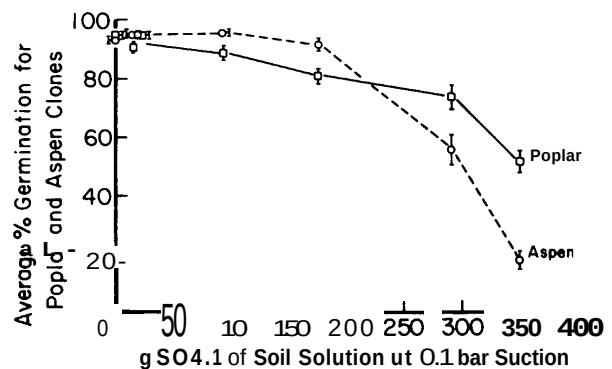


Figure 2—Average germination percentage for clones of balsam poplar and quaking aspen in relation to SO_4 concentration in soil solution.

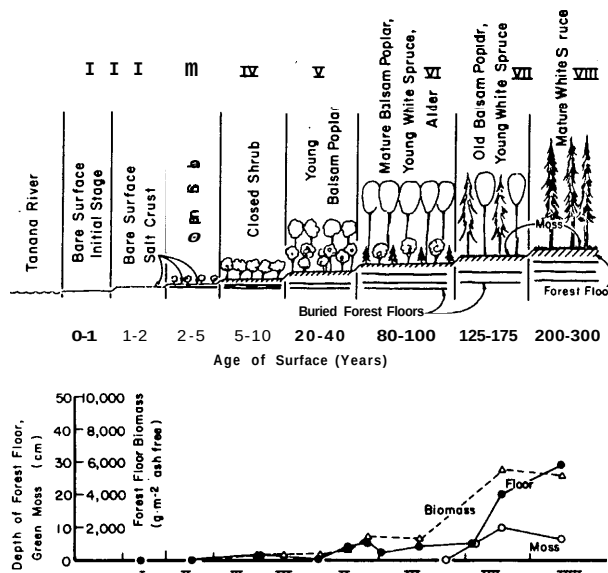


Figure 3—Forest floor and green moss depth and forest floor biomass on Tanana River successional sequence.

water to prevent desiccation. Through Stage II, physical-chemical controls associated with alkalai soil formation dominate nutrient cycling.

Continued sediment deposition raises terrace surfaces to levels at which greater success obtains in seedling establishment and an open shrub stage of willow and alder

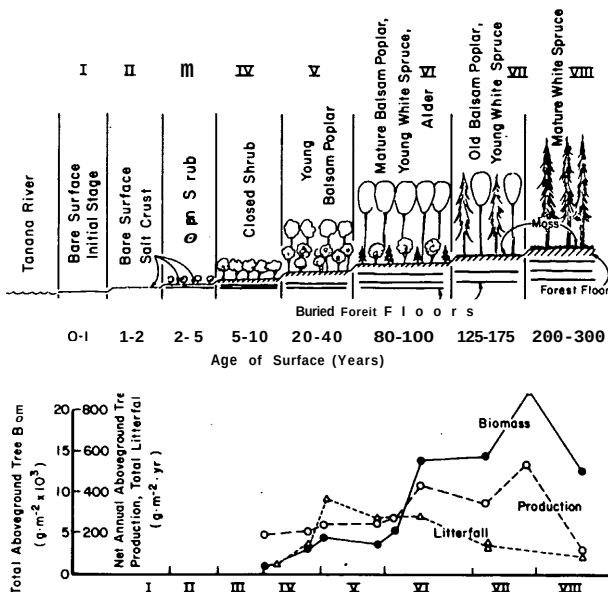


Figure 4—Forest productivity indices on Tanana River successional sequence.

results (Stage III, Figure 1). In addition, the continually changing river course results in quiescent periods during which newly established seedlings are not washed out by river erosion. Capillary rise of ground water continues. The visible manifestation of this phenomenon in the form of evaporate accumulation also occurs until terrace surfaces are higher than a meter above river stage. Even at this point high river stage may result in surface evaporation of ground water. However, leaching by snowmelt and rain water results in generally lower salt concentrations than encountered in late Stage II.

Stage III represents a transition between declining physical control and the rise of biological control of succession and nutrient cycling. Once well established, willows and alder act to slow river flow, stabilize terrace surfaces and provide biological control. By the end of this period, which ranges from 2 to 5 years, the impact of biological activity clearly is evident on ecosystem structure and function. Willow and alder (primarily *Alnus tenuifolia* Nutt. and a number of *Salix* spp. but with *S. alaxensis* [Anduss.] Cov. being the most abundant) shrub cover may reach nearly 40% and exposed mineral soil nearly disappears because of the development of a forest floor (Figures 1 and 3). Depth of forest floor ranges from 0 to 2 cm (0 to .8 in) and its weight approaches several hundred grams per square meter (Figure 3). Annual litterfall also approaches this magnitude (Figure 4). Accumulated above-ground live biomass is approximately 1 kg/m² (.21 lbs/ft²) and annual net production aboveground is approximately 200 g/m² (.04 lbs/ft²) (Figure 4). The increasing influence of biological control is also evident in the increase of amounts of soil nitrogen over earlier, non-vegetated stages (I and II). Soil nitrogen reserves may increase up to 4 times over that encountered in earlier stages (Figures 5, 6 and 7). This phenome-

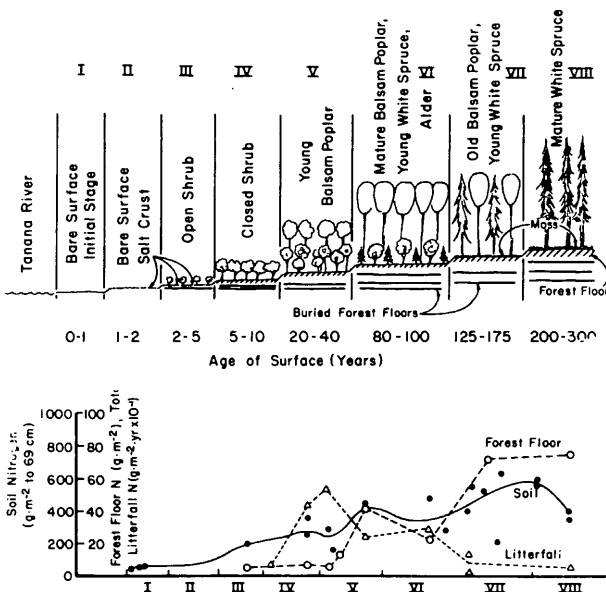


Figure 5—Indices of ecosystem nitrogen dynamics on Tanana River successional sequence.

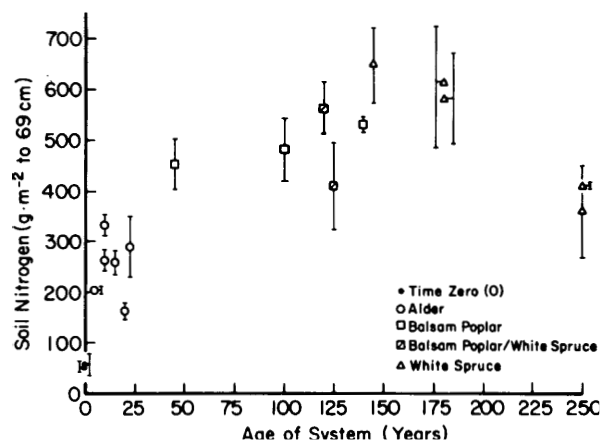


Figure 6—Trend of soil nitrogen reserves with time on the Tanana River floodplain.

non reflects the action of one of the most important site amelioration processes on the flood plain, symbiotic nitrogen fixation associated with *Alnus*. The presence of plant cover insures recycling of N through accumulation of this nutrient element in plant biomass and return to the soil in litterfall and root death. In the open shrub stage, annual return of N in litterfall is high (5 to 6 g/m²) (.0010-.0012 lbs/ft²) even though it may amount to less than 25% of the nitrogen stored in the forest floor. Another important control on nutrient cycling which appears at this time is the cation exchange capacity resident in the forest floor. Across a range of vegetation types from young to mature in upland and flood plain locations, for each gram increase in forest floor biomass the cation retaining power of the forest floor increases by 1.6 times (Figure 8).

The development of plant cover and the forest floor layer results in a decline in the importance of capillarity as a control of nutrient cycling and the virtual cessation of surface evaporation. Plants begin transpiring soil water, largely reducing the importance of capillarity in vertical transport of soil solution. The forest floor provides an effective barrier against evaporation at the mineral soil surface. Acidic leachates from the forest floor help to reduce surface soil pH and promote leaching of salts from the surface soil layers. However, it appears that time intervals of up to 300 years may be necessary before the concentration of sulfate and other minerals declines to lower, more stable levels (Figure 7). From the open shrub stage on, nutrients are concentrated in biological tissue largely through expenditures of energy fixed by photosynthesis and released for recycling by energy expended in microbial respiration.

MID-SUCCESSIONAL STAGES ON THE TANANA RIVER

We define midsuccession to extend from the closed shrub stage (IV) through the mature balsam poplar stage (IV), a period of approximately 75 to 90 years. This period is characterized by a rapid increase in shrub cover and net

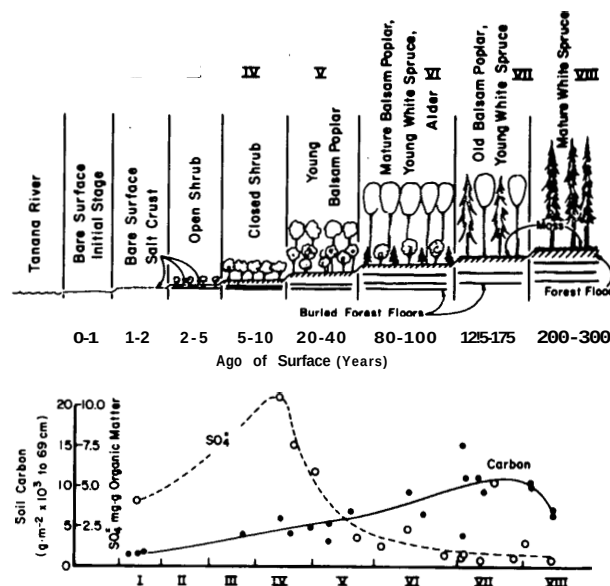


Figure 7—Change in soil carbon and sulfate content with time on the Tanana River floodplain.

productivity of balsam poplar (Figures 1 and 4). Tree basal areas may reach 35 m²/ha (153 ft²/acre), or 75% of the maximum basal area reached during the mature stages (Figure 9). Net annual production of balsam poplar, standing crop tree biomass and tree basal area appear to reach a peak for this vegetation type in mature balsam poplar stands (Stage VI). As the balsam poplar canopy closes the shrub layer changes drastically. A number of pioneer willows are intolerant of the shade and disappear completely. *Salix alaxensis* and *Alnus tenuifolia* persist but begin to decline in vigor and abundance. Other more shade tolerant

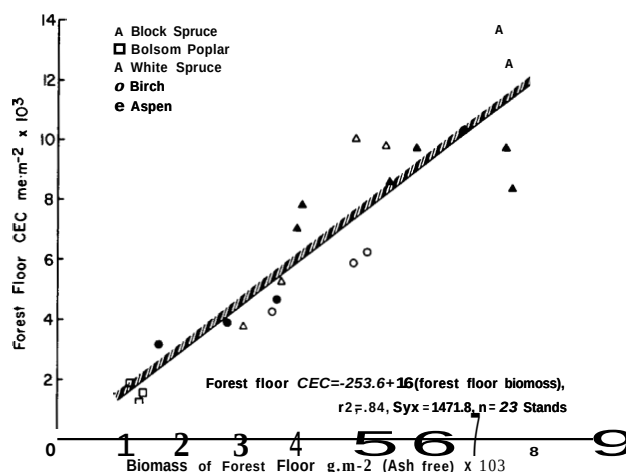


Figure 8—Cation exchange capacity in relation to biomass of the forest floor for interior Alaska forest types.

shrubs such as rose (*Rosa acicularis* Lindl.) and highbush cranberry (*Viburnum edule* [Michx.] Raf.) become common but do not have a high cover percentage. By the end of the young balsam poplar stage, shrub cover has markedly declined from near 100% to about 10% because of over-story shading. However, later in the balsam poplar stage during the period from about 80 to 100 years, the crown canopy has opened and shrub cover has increased to nearly 30%. The forest floor in mature balsam poplar stands attains about 1/6 of the total depth and biomass encountered on higher terraces supporting mature white spruce at 300 years (Figure 3). Standing crop of tree biomass may reach 15 kg/m² (3 lbs/ft²) and net annual above ground production 440 g/m² (.09 lbs/ft²), or 80% of that encountered in mature white spruce (Figure 4). Litterfall declines from a peak of 350 g/m² (.07 lbs/ft²) early in Stage V to 250 g/m² (.05 lbs/ft²) in Stage VI (Figure 4). This decrease in litterfall probably reflects the effect of higher stand density (1500-2000 stems/ha [600-800 stems/acre]) and intense competition for resources in the young balsam poplar stands (Stage V). Nearly 20% of the litterfall at the peak of deposition is woody plant debris, reflecting the intense natural thinning experienced by these young stands during this period compared with 10 to 14% of woody litter in the mature balsam poplar stage.

During this period mineral soil nitrogen reserves increase from about 300 g/m² (.06 lbs/ft²) to 500 g/m² (.10 lbs/ft²), near the average maximum encountered on the flood plain (Figures 4 and 5). This reflects the continued impact of biological nitrogen fixation associated with alder. However, in the mature balsam poplar stage the forest floor contains only about 50 g N/m² (.01 lbs N/ft²). As a result of the decline in litterfall, annual return of N to the forest floor has decreased from a peak of nearly 6 g/m² (.0012 lbs/ft²) to 3 g/m² (.0006 lbs/ft²). Toward the end of the mature balsam poplar stage (VI) soil carbon content increases to between 9 and 10 kg/m² (1.8 and 2.1 lbs/ft²), while profile SO₄ concentration declines to approximately 1 mg/g organic matter (.001 oz/oz) (Figure 7).

Physical and chemical controls still play a declining but important role in productivity and nutrient cycling through mid-succession. For example, capillarity may supply ground water to the tree rooting zone so that vegetation has adequate supplies of water throughout the growing season even during droughty periods. In addition, even though the soil solution appears to be low in such important nutrients as nitrogen and phosphorus, slow movement of soil solution through the rooting zone, along the gradient of the river may result in continual replacement of these reserves and satisfy plant nutritional demands. Leaching of surface soil layers by more acidic solutions moving through the forest floor results in the decline of soil pH from 7 or above to slightly acid range. This undoubtedly improves the availability to plants of phosphorus, which, under neutral to alkaline soil reactions and in the presence of abundant calcium, would largely be insoluble.

Flooding and sedimentation, now occurring at less frequent intervals, continue to increase terrace elevations. Buried forest floors, which are incorporated into the soil by periodic sediment deposition, are zones of low density,

high water retaining capacity and high nutrient concentration. This environment favors abundant microbial activity and organic matter mineralization. Plant roots are markedly concentrated in these buried organic layers.

Up to this point in succession, the plant species which have been most successful in establishing themselves are broad-leaved, deciduous species' (willows, alder, balsam poplar). Most of these species easily regenerate either by seed or by stump or root sprouting. They are also generally shade intolerant and have astonishingly rapid growth rates during early stages of stand development. These growth strategies appear to insure their quick establishment during stages of succession when ground surfaces are least stable and subjected either to erosion or periodic sedimentation.

Only after terrace elevation has reached the point where sediment deposition has declined to a relatively infrequent occurrence or the river course has markedly shifted to result in a quiescent period with regard to sedimentation, can white spruce become successfully established. White spruce requires a mineral soil seedbed (Zasada and Gregory, 1969) for germination and establishment. However, with perennial foliage it does not appear able to survive repeated within year, or yearly sediment deposition on needle surfaces. Seedling top growth rates are not rapid enough to elevate foliage to a level at which needles would be free of siltation. In addition, root growth rates may also be slow. In combination with lack of sprouting capability, these factors may further limit the ability of spruce seedlings to withstand erosion, overcome potential oxygen limitation to root systems following sediment deposition, or seek adequate water supply. Periods of drought and/or low water and deficient moisture supply by capillarity may also decrease seedling survival.

By the time of poplar stand maturity, the physical site conditions have been favorable for a sufficient time interval for spruce to become well established in the understory (Stage VI). During the late intermediate and early mature successional stages white spruce becomes a dominant species. Through the intermediate stages of succession tree growth and nutrient cycling have been dominated by relatively energy- and nutrient-costly growth strategies. For example, one gram of nitrogen (.03 oz) must be taken up by balsam poplar in the production of 50 grams (1.6 oz) of new foliage. However, 100 grams (3.2 oz) of white spruce foliage are produced per gram of nitrogen (.03 oz) taken up. One gram (.03 oz) of balsam poplar foliage supports the production of one gram (.03 oz) of branch and trunk wood. In white spruce one gram (.03 oz) of current foliage supports the production of two grams (.06 oz) of branch and trunk wood. Poplar must replace its entire complement of leaves each year, an energy costly strategy. On the other hand white spruce may replace only 10 to 12 percent of its foliage with new material each year and leaf longevity may extend to 7 years or more.

In summary, transition from mid- to late-successional forest stages is marked by the change from shorter term, rapid growth, energy and nutrient extravagant ecosystems to longer term, sustained growth in forests that appear to be energy and nutrient conservative in their growth pro-

cesses. The transition is also marked by the appearance of moss as a dominant component of the ground surface vegetation layer. These non-vascular plants are effective competitors with vascular plants, including trees, for mineral nutrient reserves.

MATURE SUCCESSIONAL STAGES ON THE TANANA RIVER

We define mature successional stages to be those which have the dominant tree basal area composed of white spruce. The young white spruce-old balsam poplar stage (VII) continues to have old balsam poplar as an overstory component but these individuals comprise less than 10 m²/ha (44 ft²/acre) basal area compared with the near 50 m²/ha (218 ft²/acre) basal area contributed by white spruce (Figure 9). Late mature stages (Stage VIII) have little or no balsam poplar remaining and white spruce basal area ranging between 40 and 50 m²/ha (174 and 218 ft²/acre). During the mature successional stages, shrub cover declines from a peak of about 50% in Stage VII to between 10 and 20% in Stage VIII (Figure 1) although there is a slight increase with age as the mature spruce stands become more open. One of the most dramatic changes to take place in the white spruce stages is the development of the moss mat. As the spruce canopy closes the feathermoss, *Hylocomium splendens* (Hedw.) BSG and *Pleurozium schreberi* (Brid.) Mitt., become dominant on the forest floor and the moss cover reaches nearly 80%. Bare ground surface again appears (up to 5%) as mature poplar and spruce fall and heaving of root systems exposes mineral soil. Some spruce seedling regeneration may arise on soil mounds.

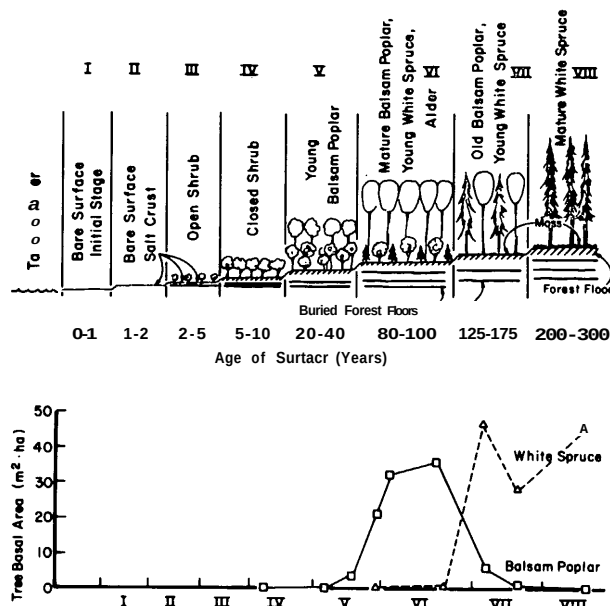


Figure 9—Tree basal area on the Tanana River successional sequence.

Depth of forest floor (25 to 30 cm [10 to 12 in]) and forest floor biomass (5000 g/m² [1.02 lbs/ft²]) reach maximum values in mature white spruce stands (Figure 3). Depth of living moss tissue may add an additional 10 cm (4 in) to total forest floor thickness, providing an effective insulating mat and maintaining cool soil temperatures compared with earlier stages of succession.

Accumulated aboveground tree biomass in the white spruce may reach 22 kg/m² (4.5 lbs/ft²) at approximately 180 years (Stage VII) but this total probably declines to a lower level in over-mature forests. The peak of net annual production, 500 g/m² (.10 lbs/ft²) is attained by 200 years and again probably declines when the stand reaches over-maturity. Total annual litterfall declines from approximately 180 g/m² (.04 lbs/ft²) to less than 100 g/m² (.02 lbs/ft²) from early to late mature white spruce stages.

Soil nitrogen continues to increase from the levels of the balsam poplar stages (V and VI) and reaches an average maximum of nearly 600 g/m² (.12 lbs/ft²) early in the mature stage and declines to slightly less than 400 g/m² (.08 lbs/ft²) in late mature stages (Figures 5 and 6). We feel this change in soil nitrogen reserves is caused by continued removal by plant growth and accumulation in standing live and dead biomass and in the forest floor. Verification of this trend awaits estimation of productivity and nutrient relations in very old white spruce forests. Forest floor nitrogen content remains constant at the peak value of approximately 80 g/m² (.02 lbs/ft²). Nitrogen return to the forest floor in litterfall approaches a lower value of about .7 g/m²/yr. (.00014 lbs/ft²/yr.). The turnover time for N in the forest floor at this stage is slow, approximately 125 years.

Along with soil nitrogen, carbon content reaches a maximum level of nearly 10 kg/m² (2.1 lbs/ft²) in Stage VII but decreases in Stage VIII to about 7 kg/m² (1.4 lbs/ft²) (Figure 7). At the present time it is difficult to attribute the control of decline and amounts of carbon and nitrogen to shifts in biological processes or variability in conditions on the river terrace. As might be expected, sulfate reaches the lowest concentration levels of the successional sequence, .6 mg/g of organic matter (.0006 oz/oz). Surface mineral soil horizon pH approaches 5, reflecting continued leaching of Ca, Mg, K. In addition, the forest floor has developed to nearly the maximum degree its retaining capacity for cations (Figure 8). Forest floor biomass of 5 kg/m² (1 lb/ft²) will have a cation exchange capacity of 7 to 8 eq/m² (.65 to .74 eq/ft²). This capacity is nearly 80 times greater than the total equivalents of cations (.09 eq/m² [.008 eq/ft²] Ca + K + Mg) returned in litterfall in one year on a mature stage forest site.

At this point in succession, capillarity and sedimentation are no longer functioning as controls of primary production and nutrient cycling. Mature stage terrace levels are sufficiently high above the river level that near catastrophic flooding is required for substantial sedimentation to occur. Leaching of surface soil layers depends on downward movement of snowmelt water and precipitation through the acidic forest floor.

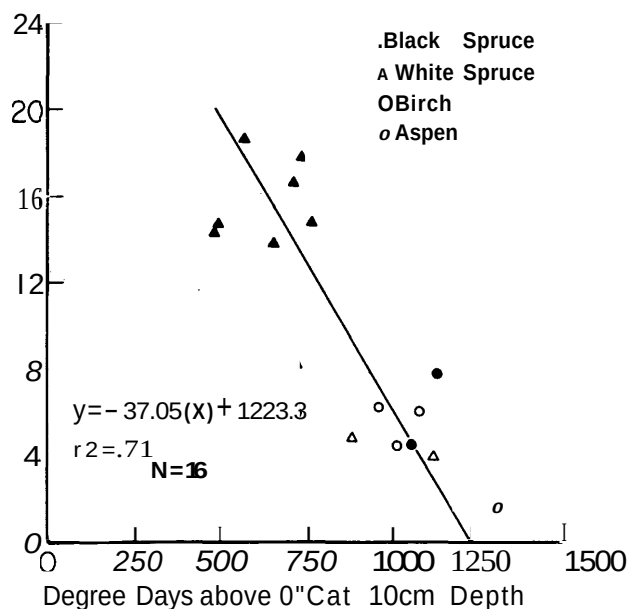


Figure 10—Forest floor depth-temperature relationship for interior Alaskan forest types.

Some wind deposition of sediment occurs in all stages of succession when silt particles are picked up from the mineral surfaces of Stages I and II. Amounts of nutritionally important elements deposited by this mechanism are not known at this time but patterns of loess movement on the floodplain appear to be highly variable. Given the requirement of bare mineral soil seedbeds, regeneration of succeeding forests depends on seedling establishment on windthrow mounds. However, the occurrence of this phenomenon is generally only sporadic. In any case, wind deposi-

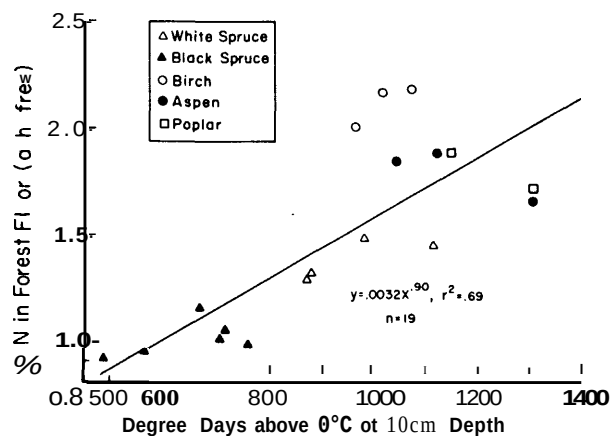


Figure 11—Forest floor nitrogen concentration in relation to temperature for selected interior Alaskan forest types.

tion of sediment appears insufficient to provide mineral soil seedbeds for spruce regeneration.

With one exception, primary production and nutrient cycling processes at this stage reflect the dominance of biochemical control. As succession advances, the forest floor continues to increase in thickness and mass of stored organic matter. In late successional stages, moss contributes an additional layer of organic matter which has low thermal conductivity. Progressively increasing thickness of the forest floor is associated with decline in soil temperatures (Figure 10). We have followed the course of soil temperature at the 10 cm (4 in) depth for the period May 20 to September 10 in a wide range of mature vegetation types on upland and lowland sites. Heat sums calculated above 0°C show that for each one cm (.39 in) increase in forest floor thickness, the heat sum declines by approximately 37 degrees. The decline in soil temperature may cause slowed rates of soil organic matter decomposition and release of mineral elements important in plant nutrition. For example, across the range of upland and lowland forest sites, a fairly strong relationship exists between forest floor nitrogen concentration and soil heat sum (Figure 11). This trend reflects the higher nutritional status of broad-leaved deciduous vegetation type litter. It may also reflect more rapid microbially mediated soil nitrogen turnover on warm compared with cool sites, and larger amounts of N available for use by plants.

Although we have concluded this discussion with the mature white spruce stands the succession does continue on the older terraces. Regeneration of succeeding forests following the mature white spruce stage (VIII) is varied. In some cases these white spruce stands are replaced by black spruce. The mechanisms involved in this change are not thoroughly documented or understood but appear to be related to the formation of permafrost and colder waterlogged soils (Drury, 1956; Gill, 1971; Viereck, 1970). The role of fire on these flood plain forests is less than in upland sites because of the protection afforded by sloughs and river channels. However, fire does occasionally burn through flood plain white spruce stands and may be a factor in conversion to black spruce.

On some protected uplands white spruce stands are known to persist for at least 300 years. In these cases regeneration on windthrow mounds, old logs and other sites where the organic layer is disturbed may result in uneven-aged stands. Also, it is possible that the extreme flood may provide a mineral surface sufficient for the germination of either black or white spruce under the mature white spruce canopy.

FOREST MANAGEMENT IMPLICATIONS

Timber stands along the Tanana River have largely been an ignored resource in the recent past. In the early years of the twentieth century a small amount of harvesting took place for lumber, house logs and riverboat fuel. Since that time, however, there has been almost no activity in timber harvesting or stand management on these sites. In addition, very few silvicultural studies have been under-

taken on river bottom locations. Instead, the majority of tree regeneration and stand growth studies have been concentrated on upland sites adjacent to the Tanana River.

As we have pointed out, research along the Tanana River has concentrated on defining the successional stages and characterizing these stages with respect to structure, function, and controlling mechanisms. What has emerged is a fascinating picture of a highly dynamic system, constantly undergoing change and where major processes are really quite different from those operating on adjacent uplands. Thus, management strategies which are completely different from those employed on upland sites will almost certainly be necessary for the bottom lands.

What management options can we infer from what we already know about ecological relationships on interior Alaskan flood plains? First, and perhaps most important, management practices must conform with the dynamic nature of the ecosystem. In other words, forest land managers should design their treatments to conform to the successional sequences rather than trying to work at cross-purposes to succession. For example, it may very well prove impractical for the forest manager to harvest more than one rotation of balsam poplar from low terrace sites which are still subjected to rather frequent flooding (Stages V and VI). Perhaps continuous uplift by sediment deposition results in sites much better suited to the growth of white spruce and hardwoods other than balsam poplar.

Certain sites along major rivers may be ideally suited for energy plantations, where fast-growing high biomass production is the aim. However, these sites should be chosen carefully to insure maximum productivity. Based on what we have learned thus far about site productivity, it would appear that closed shrub and young balsam poplar sites (Stages IV and V) would be most appropriate for energy plantations.

Another factor which must be taken into account in designing forest management plans is the change in soil properties which occur during the succession sequence. Although balsam poplar would be the most appropriate hardwood to plant on early successional sites, it probably would not be the best suited species to plant after harvesting mature white spruce. In these high terrace locations capillarity no longer maintains consistently high levels of soil moisture; consequently these sites are drier during the growing season, requiring a more drought-tolerant tree species. Perhaps aspen would be a more successful hardwood on these high terrace sites.

As previously mentioned, land managers should be aware of the importance of alder in early succession in supplying soil nitrogen. Accordingly, any practice that precludes the development of alder on sound sediments would seriously jeopardize future soil nutrient supplies and the productive capacity of the site.

A question which arises with increasing frequency is how best to regenerate river terrace sites from which mature white spruce has been harvested. In view of the necessity of exposing bare mineral soil, some sort of site preparation will probably be a necessary step following logging. Perhaps this could best be attained by mechanical treatment or burning. Burning might have the added advantage of resulting in the release of at least a portion of the nutrients previously tied up on the forest floor. Species selection is also open to question and perhaps mixed species management should be the goal rather than re-establishing pure stands of white spruce. The mixture might contain hardwoods, such as aspen and paper birch, as well as white spruce. Such stands would be more similar to those occurring on upland sites and should have a favorable effect on soil nutrient levels.

ACKNOWLEDGMENTS

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REGENERATION PROBLEMS AND OPTIONS FOR WHITE SPRUCE ON RIVER FLOODPLAINS

IN THE YUKON TERRITORY

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INTRODUCTION

Currently the Yukon Territory represents the area of responsibility for research into forest lands north of 60° latitude at the Pacific Forest Research Centre.

The majority of forest operations for industrial wood production are located on the floodplains of the Liard River drainage system in the southeastern portion of the territory around Watson Lake (Figure 1). AS white spruce

(*Picea glauca* [Moench] Voss.) represents the chief commercial species in the area, the majority of reforestation research at this time is centered on investigation of regeneration options for white spruce on these floodplain sites.

White spruce is one of the most interesting species in the boreal forest. Transcontinental in its distribution white spruce is capable of performing well over a wide range of soils and climatic conditions. It is shade tolerant in early life and able to establish and grow under a moderate brush or hardwood canopy. Seed supplies for natural regeneration are generally adequate despite being variable in abundance and of average viability when compared to such species as trembling aspen (*Populus tremuloides* Michx.). Genetic variability is thought to be great enough that considerable gains may be possible through tree improvement programs (Stiell, 1976; Zasada, 1969). Concurrently, this species offers a number of challenges to forest managers concerned with regenerating it on cutover, burned or other temporarily unproductive forest lands. If there are lands designated for reforestation by either natural or artificial seeding, then a carefully coordinated sequence of events must take place. Preferably an adequate amount of viable seed must fall onto a receptive seedbed of mixed mineral-organic soil which, in turn, is as free of vegetative competition as possible yet not so exposed that it becomes susceptible to severe drying and/or repeated frost heaving. If one of these general conditions is out of sequence then an entire reforestation program of this type may achieve less than desired results (Stiell, 1976; Zasada, 1972).

As a plantation species, white spruce requires conditions similar to those necessary for successional seeding. Young planted spruce are vulnerable to early or late frosts, low soil temperatures and rapid reinvasion of competitive vegetation, all or any of which can severely inhibit growth and development until the plants have become well established (Stiell, 1976).

The alluvial floodplain sites in the Yukon Territory, while rated as having the highest potential for growing trees of any area there (Oswald and Senyk, 1977), offer some difficult conditions to work with. They are characterized by a short growing season and cool soils yet they possess good fertility and thus are prone to reinvasion by balsam poplar (*Populus balsamifera* L.), willow (*Salix* spp. L.) and aspen. Periodic spring flooding of the flats, if heavy

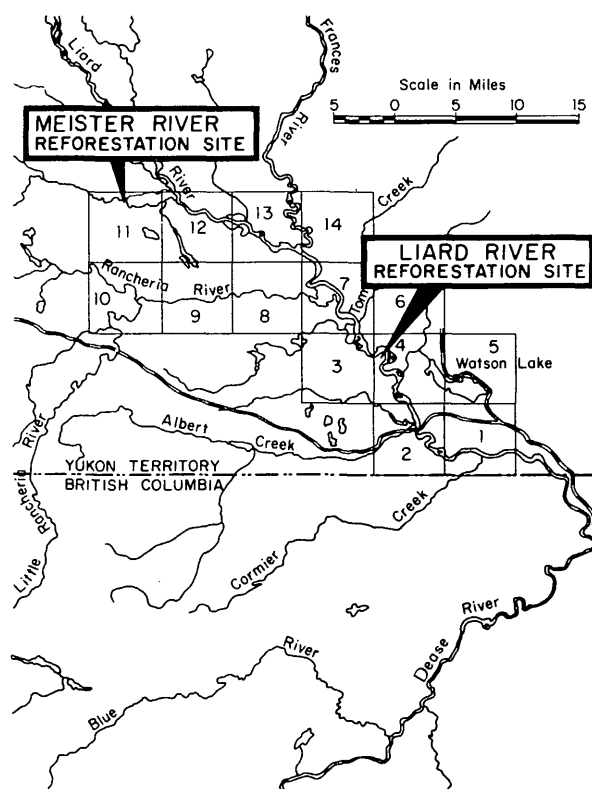


Figure 1.—Location of Pacific Forest Research Centre/ Yukon Lands and Forest Service Watson Lake Reforestation Trials, Liard River drainage system, Yukon Territory, Canada.

and prolonged, may contribute to seedling mortality through drowning or burying the trees in a thick layer of silty debris.

In the fall of 1975 two research installations were established on the Liard and Meister Rivers (Figure 1) in cooperation with the Yukon Lands and Forest Service. The objectives of these trials were to determine the Yukon's regeneration needs, resolve the biological impediments to establishment of trees on the floodplain sites and to broaden fundamental silvicultural knowledge of these forest types.

DESCRIPTION OF THE STUDY AREAS

The Liard River site is located at 60° 08' N, 128° 58' W while the Meister River area is situated at 60° 20' N, 129° 35' W. The two areas fall within the B. 24 section of the boreal forest as described by Rowe (1972) and the Liard River ecoregion as classified by Oswald and Senyk (1977). The floodplains are at elevations of 180-200 m (591-656 ft) and lie within the subarctic climatic zone with a frost free growing period of about 60 days (Hirovonen 1968). Growing season temperatures average 15°C with annual precipitation in the range of 400 to 500 mm (16-20 in). The aspect is level.

The soils of the experimental areas were formed through successive alluvial depositions and are classified as moderately well drained and regosolic (Jeffery 1964). Generally they are rich in bases. However, analysis of soil samples from the Meister indicated a mildly acidic characteristic with an average pH of 6.5. The profile is made up of alternating layers of somewhat coarse-textured sandy loams, silt loams and loamy sands. What could be considered base materials were reached at 86+ cm (34 in) and consisted of gravelly sands and fine to coarse sands with a few rocks.

Data obtained on the Meister River revealed that originally there was a moderately dense stand of white spruce interspersed with willow and a few poplar. Analysis of the data determined stand averages of 23.1 cm (9.09 in) d.b.h., 19.3 m (63.3 ft) height and 64 years of age. Site class was rated at medium with a site index of 26 m (85 ft) at 50 years. Total basal area reached 56.7 m² (610.3 ft²) with a merchantable basal area of 54.8 m² (589.9 ft²) and a merchantable volume of 392.4 m³ (13,855.6 ft³). Both areas were clear-felled; the Meister in April 1974 and the Liard during February-April 1975.

METHODS

The two test sites were selected during the summer of 1975. The reforestation options selected for study included: planting, broadcast seeding, spot seeding and seeding from natural sources on scarified and unscarified ground conditions over two treatment periods; fall and spring. The first replication of the fall treatments was applied in September 1975 and the spring treatments in June 1976. The second replication was applied in the fall of 1976 and the spring of 1977. A total of seven research blocks were established

at each of the sites and they were arranged in randomized complete block design with a split-plot (Arnott et al., 1979). A total of 12.84 ha (31.65 acres) were strip scarified with a Cat. D6C and a Komatsu D60A; both tractors utilized an angled dozer blade in 1975. In 1976 a brush blade was employed and found to be much more effective.

Seed for the trials was collected from two locations: 1) Haines Junction at 60° 45' N, 137° 30' W at an elevation of 619 m (2,030 ft) and 2) Watson Lake at 60° 06' N, 128° 50' W at an elevation of 701 m (2,300 ft). Cones were collected during August and September 1973 and extracted at the Provincial Tree Nursery in Oliver, Alberta (Arnott et al., 1979).

Plots assigned to the spot seeding treatments were hand seeded with an average of six seeds per spot. A Cyclone model 10 seeder was employed for the broadcast seeding at an application rate of 2.24 kg per ha (2 lbs/acre).

Seed from the sources indicated above was used to produce stock for the planting treatments. The seed was sown into BC/CFS Styroblock 2 containers during the spring of 1975 at PFRC, grown there, and transported to Watson Lake in July of that year where they were placed in a shadehouse. The fall treatments were planted in September and the remainder of the stock was overwintered on the ground in a woodlot adjacent to the shadehouse. In June and July of 1976, the spring planting treatments were applied using the overwintered stock. The entire process was repeated during 1976/77 with the fall treatments applied in September 1976 and the spring treatments in June of 1977. On the planted, scarified plots, three microsites were recognized: slope, hump and flat whereby the slope consisted of the side of the scarified trough, the hump was the mound of loose earth between the tracks of the bulldozer and flat areas were made up of the lightly compacted soils of the bulldozer tracks themselves.

The trials are to be assessed biennially for the first five years after establishment. For the planting trials assessment techniques developed at PFRC are used. Basically the sheet records the status of each seedling, any damage or injury it may have sustained, its microsite, shade conditions, total height plus a subjective assessment of its quality (Arnott et al., 1979).

The natural and broadcast seeding treatments are evaluated by selecting 50 half square-metre samples per line randomly allocated within the established subplots. The spot seeded subplots are sampled by randomly selecting 50 of the seeded spots from each subplot. The number of germinants and subsequent seedlings are tallied with height measurements recorded in the third year after establishment (Arnott et al., 1979).

This year, data collected on the plots established in 1976-77 completed the third year assessment of these reforestation trials. Although there is another assessment to be made in the fifth year after establishment data from the third year assessments were subjected to analysis of variance to determine the significance of trends which are becoming obvious in the mid-term of the study.

RESULTS

Tables 1 and 2 present the results of the third year assessment of the seeding and planting trials. Although the study is incomplete there are several significant trends which are worth consideration at this time.

Direct Seeding

1. Stocking. Direct seeding on unscarified ground has failed. Stocking levels ranged from a low of **4.6%** for fall spot seeding to a high of **8.5%** for fall broadcast seeding. When statistically compared to treatments applied on scarified ground all results were significant at the **P = 0.01** level. As a result, no further comparisons were made between scarified and unscarified treatments which accounts for their absence on Table 1.

Direct seeding on scarified ground, although more successful than on unscarified ground, still should not be considered as the ultimate regeneration treatment. Stocking levels ranged from an unacceptable low of **28.8%** for fall spot seeding to a moderately successful **66.5%** for spring broadcast seeding. Statistically significant results were obtained from comparisons of the broadcast seeding treatment with the spot treatments regardless of the time of application (spring or fall). Spring broadcast seeding out

Table 1: Means and significance for scarified treatmentsbf seeding trials three years after establishment at the Liard and Meister Rivers, Yukon Territory.

	Treatment	Treatment Mean	0.05%	0.01%
% of samples with established seedlings (% stocking)	SFS	28.8	a	a
	SSS	33.4	a	ab
	SN	39.6	ab	ab
	SFB	52.2	bc	bc
	SSB	66.5	c	c
Mean number of established seedlings per stocked sample	SFS	2.05	a	a
	SSS	2.35	a	a
	SN	2.88	a	ab
	SFB	3.78	ab	ab
	SSB	5.68	b	b
Mean height of established seedlings (cm)	SFS	3.59	a	a
	SSS	3.77	ab	a
	SN	4.11	ab	a
	SFB	4.38	ab	a
	SSB	4.56	b	a

Treatment codes:

SFS—Scarified Fall Spot
SSS—Scarified Spring Spot
SN—Scarified Natural
SFB—Scarified Fall Broadcast
SSB—Scarified Spring Broadcast

NOTE: Numbers followed by similar letters are not significantly different at the indicated significance level: p = 0.05%; p = 0.01%.

Table 2: Percent survival and average height of seedlings three years after planting at Liard and Meister Rivers Yukon Territory.

Treatment	Treatment Mean	0.05%	0.01%
% SURVIVAL			
UF	84.2	a	a
SFF	85.9	ab	ab
SFS	88.3	ab	ab
SSS	88.7	ab	ab
SSF	88.7	ab	ab
US	88.8	ab	ab
SFH	89.7	ab	ab
SSH	92.6	b	b
AVERAGE HEIGHT (cm)			
US	19.6	a	a
UF	21.4	ab	a
SSF	21.7	abc	ab
SSS	23.1	bc	abc
SFF	24.1	c	bc
SFS	26.1	d	c
SSH	26.3	d	c
SFH	26.7	d	c

Treatment Codes:

US—Unscarified Spring
UF—Unscarified Fall
SFF—Scarified Fall Flat
SSF—Scarified Spring Flat
SFH—Scarified Fall Hump
SSH—Scarified Spring Hump
SFS—Scarified Fall Slope
SSS—Scarified Spring Slope

NOTE: Numbers followed by similar letters are not significantly different at the indicated significance level: p = 0.05%; p = 0.01%.

performed natural seeding at both the p = 0.05 and p = 0.01 levels while fall broadcast seeding did not differ significantly from natural seeding at either level. Differences were not realized between natural seeding and either of the spot seeding treatments with regard to stocking.

2. Establishment of seedlings. Seedlings did not establish well on unscarified soil. Establishment in terms of seedlings per stocked sample ranged from a low of **0.64** for the spring broadcast treatment to a high of **1.10** for fall spot seeding. Again, all scarified treatments significantly outperformed the unscarified treatments.

Comparisons on scarified ground produced few significant results. Spring broadcast seeding produced an average of **5.68** seedlings per stocked sample to better all other treatments except the fall broadcast seeding at the p = 0.05 level. Spring broadcast seeding differed only from the spring spot treatments (p = 0.01). No other differences were realized at either level.

3. Mean height. The unscarified plots produced seedlings with the greatest average height. Unscarified fall broadcast plots produced an average seedling height of **9.71 cm (3.82**

in) followed by the unscarified natural plots at 7.68 cm (3.02 in). Unscarified fall and spring spot treatments produced the smallest seedlings at 2.65 cm (1.04 in) and 2.99 cm (1.18 in), respectively. Average height differed statistically only at the $p = 0.05$ level between scarified plots. Only one difference was obtained whereby spring broadcast seeding (4.65 cm; 1.83 in) out-performed spring spot seeding (3.59 cm; 1.41 in). Because of the poor results obtained from unscarified plots with regard to stocking levels and seedling establishment, statistical comparisons were not obtained among unscarified plots or between these and scarified plots at the time of computer analysis for any of the three performance parameters discussed here. Therefore it is not possible to state whether the large average heights obtained for the two unscarified treatments noted above are statistically significant.

Planting

1. Survival. Among all combinations of microsite and planting season on scarified or unscarified plots only one significant difference was determined. Trees planted on the hump microsite on scarified ground in the spring out-performed trees planted in the fall on unscarified ground at both probability levels ($p = 0.05$ and $p = 0.01$). Survival rates for the two treatments were 92.6% and 84.2%, respectively.

2. Mean height. Unlike survival rates a large amount of variation has been observed with respect to height growth. Most of the highly significant variation is attributable to the main effects of scarification or the absence of it. Less significant variation occurs frequently among microsite treatments and very little occurs as a result of planting season.

Average treatment heights ranged from a low of 19.6 cm (7.72 in) for the unscarified spring planting to a high of 26.7 cm (10.51 in) for the fall planted seedlings on the hump of microsite. This reveals a difference of 7.0 cm (2.76 in) growth which, under these northern conditions, could represent up to an entire season's growth.

Generally there was a progressive increase in height growth variation between the three microsite treatments on unscarified ground. Smaller seedlings were located on the flat microsites, medium seedlings on the sloped microsites and the largest on the humps. On all microsites, including the nonscarified areas the fall planted seedlings out-performed the spring planted seedlings although, statistically, the variation was not as significant as that recorded for microsite or scarified-nonscarified differences.

Plantation seedlings were assessed under four additional parameters: injury, degree of frost heaving, quality and degree of shading. Although no statistical comparisons have yet been made among these factors some general observations are possible.

The most prevalent injury recorded was frost damage. In most instances it was apparent that late spring frosts had killed the current year's buds during the early stages of

flush. The majority of the frost damage occurred on the Liard River site where the scarification runs in an east-west direction and where there is less residual vegetation present producing a more exposed site and possibly poorer air drainage. Other injuries of possible import include damage from insects (aphids, *Chermes abietis*) and problems caused by high water tables and imperfect drainage which, in low-lying pockets leads to drowning. Throughout there were scattered instances of injury caused by drought, browsing, smothering, burying and erosion, none of which would be considered significant.

Frost heaving of the container plugs occurred occasionally but was mainly limited to the most exposed sites. The degree of heaving ranged from 0.5 cm (0.2 in), up to 6.0 cm (2.4 in), and in rare cases the plug had been completely heaved out of the ground. As yet it is not a significant cause of seedling mortality.

Seedling quality ratings are based on a subjective assessment of the seedling's appearance and, frequently, variation occurred among assessors. Where frost damage or heavy vegetative competition was prevalent, seedlings tended to be rated as fair to poor. Where constraints to free growth and development were minimized, seedlings were generally rated as good. Relatively few trees were rated as excellent although there were a few trees which had achieved outstanding growth and development.

Degree of shading is assessed on sliding scale ranging from 0 for open to 2 for full shade. Seedlings on unscarified plots were more often under full or partial shade than those on scarified ground which were most often rated open or partially shaded. The scarification appears to have been very effective in checking the invasion of competitive species three years after treatment. It is also apparent that some shading, at least during these initial years of establishment, is beneficial, especially on the scarified plots. Seedlings under partial shade tend to be less affected by frost than those on exposed sites and in many cases are rated higher in overall quality than those under open or fully shaded conditions.

DISCUSSION

Clearly, the main effects of scarification or the absence of it have exerted the greatest influence to date. With respect to the seeding trials unscarified soil produced the lowest initial stocking and establishment regardless of the type of seeding employed or the season of application (Table 1). When compared to treatments on scarified ground highly significant differences in success resulted, all in favor of the scarified treatments.

That some form of seedbed preparation is necessary for successful seeding operations has been well documented (Arnott, 1973; Griffin and Carr, 1973; Richardson, 1973; Stiell, 1976; Zasada, 1969, 1972). Most researchers indicate that creation of a mixed mineral-organic soil seedbed will satisfy most of the biological requirements of spruce seed necessary for germination. Principally, a seedbed with good moisture retaining capacity, an absence of competi-

tive vegetation and a ready source of soluble nutrients will provide adequate environment. Clearly, unscarified ground provides few, if any, of these requirements. Humus or organic layers are poor moisture retaining media if exposed to direct sunlight and they dry out very quickly. The alluvial floodplain sites in the north are fertile enough that vegetative competition, in the form of shrubs, annual and perennial herbs, establishes quickly through vegetative means or prolific seeding unless the old root stocks and residuals are removed. If the organic layers are thick enough, soil temperatures of the mineral layers below can be very cool or cold which, in turn, may greatly reduce the rate of nutrient cycling and decomposition of the organic material (Zasada et al., 1977).

Scarification was applied, on these areas, by means of an angled dozer blade or brush blade. This form of strip scarification created a swath of bare mineral soil devoid of both vegetation and organic material and provided only two of the aforementioned requirements for successional germination. If the weather remains overcast and rainy the mineral soil retains water well, and because of the scalping nature of the scarification, there is no vegetation in close proximity to the germinants to compete for water, nutrients and light. As the growing season progresses and the weather becomes clear and warm these exposed areas will dry and the soil may form a hardpan (if the clay content is high enough) which becomes cracked and fissured. If the upper soil horizons are composed of silts and/or sands they become dry and loosely bound and are subject to aeolian erosion. As well, these very exposed soils are susceptible to frost heaving which may be detrimental to planting operations. However, as the seeding treatments on scarified ground, in these trials, so vastly out-performed those applied to unscarified ground it must be concluded that the exposure of the mineral soil at the time of application of the seed produced enough beneficial effects to allow a moderate degree of success for the broadcast treatments.

The beneficial effects of mineral soil exposure are well defined by Baker (1950): "The infiltration capacity and aeration is good, yet the soil packs well around the seed, which thus secures close contact with films of moisture. The soil has good heat conducting capacity and will warm up faster than the loose organic horizons. There is no great resistance to the process of germination."

If conditions were favorable to initial germination there must be other reasons why the levels of stocking on the seeding trials are only moderately successful at best. Probably the greatest inhibition to increased levels of initial germination and establishment of seedlings on the test sites was surface drying of the soils during warm summer weather. This predisposed the young germinants to mortality through drought or burying caused by deposition of wind borne soil particles. On the Meister site regrowth of Vegetation has been abundant and some mortality has been incurred due to smothering. As well, on the Meister site, the absence of a residual strip of mature spruce has resulted in a dearth of seed for supplementary stocking of the direct seeded plots or initial stocking of the controls. It is possible that rodents may have consumed large amounts of seed on both sides. However, this is unsubstantiated.

Stocking levels of the spot seeded plots may be artificially low in that an inadequate amount of seed was sown on the spots as opposed to the treatment itself being defective. Lahde and Tuohisaari (1976) report that for open spot seeding 25-30 seeds per spot should be sown for Scotch pine (*Pinus sylvestris* L.). In this study only six seeds per spot were sown and, while direct comparisons with pine may be questionable, it would appear that the rate of seeding should have been doubled at least.

Generally the data indicate that spring seeding treatments out-performed the fall treatments regardless of the type of seeding used. Arnott et al. (1979) suggest that rodent activity in the fall may be responsible for heavy losses of seed. Analysis indicates that for any given seeding treatment the differences in performance are not significant. Whereas germination and initial establishment (survival) of seed appeared to depend on the presence of a mineral soil seedbed made available through scarification such was not the case with planting. Regardless of microsite, season of planting or the presence of scarified soil, survival of the planted stock was very good indicating that the Styroplug 2 seedlings were of good quality and were well planted allowing for quick establishment of the root systems. Spring planting consistently bettered fall planting; where height growth was concerned exactly the opposite occurred for any given microsite. From comparisons of microsite treatments it becomes apparent that planting on humps is beneficial. The highest survival rates and the best subsequent growth rates were recorded on these sites. Growth rates on unscarified ground were significantly reduced. Increased competition for water, light and nutrients and cooler soil temperatures on these areas have combined effects which have reduced height growth. The overall effects of lesser height growth on these sites have been ameliorated somewhat as frost damage and heaving are much less prevalent on unscarified ground.

Height growth on flat microsites was reduced as well. Soil compaction from the weight of the bulldozer may have resulted in decreased soil aeration and water penetration and the roots of seedlings planted on these sites may have encountered difficulty in penetrating and establishing a root-soil interface on these microsites. These effects will be of a temporary nature and a greater threat to these seedlings will come from frost damage as they are situated on lower sites than those planted on slopes or humps.

The sloped microsites have produced fair to good height growth rates. These sites are elevated and well drained but they are located on the edges of the scarification and are in close proximity to residual vegetative competition. Scarification was applied in a north-south direction on the Meister and an east-west direction on the Liard. Field observation indicated that seedlings on southerly aspects generally performed better.

The humped microsites have produced the best conditions for early seedling growth. These elevated, exposed, loosely compacted soils offered good air and water drainage, easy root establishment and freedom from vegetative competition for the greatest length of time. In some instances the extreme exposure of these sites has predisposed

them to frost heaving and surface drying during warm, clear weather. On humps where some herbaceous vegetation had established to provide some partial shading the seedlings have performed quite well.

At this stage of these trials it is apparent that planting of good quality stock on humped mineral soil sites is the most reliable method of regenerating the alluvial river floodplains of the Yukon Territory. However, direct seeding options should not be disregarded totally. Broadcast seeding applied in the spring on scarified soil hold considerable promise as a reforestation technique. Improvements in scarification techniques to produce a better mixture of mineral soils and organics to create a more stable seedbed with optimum water retention capabilities seem to be the most promising route to follow for ensuring greater success of seeding treatments. To complement this an adequate source of viable seed would be required.

Development of seeding techniques may be necessary in the Yukon as it is doubtful that the level of forest industry there generates enough revenue to support a comprehensive reforestation program based on the planting of stock. Estimates made six years ago revealed that in western Canada seeding costs were approximately CAN \$50.65 per hectare (CAN \$20.50 per acre) as opposed to CAN \$135.90 per hectare (CAN \$55.00 per acre) for planting. These figures include the cost of scarification which is the largest single expense in regeneration operations (Richardson, 1973). Other advantages of direct seeding are listed by Robinson (1973) and include: a low requirement for labor and supervision, easy repetition, reasonable cost and convenience for use where access is poor, an important consideration in the Yukon. Some disadvantages of direct seeding include: a tendency towards understocking, high density of stems, uneven distribution, a need for a supply of genetically improved seed, and two or three years' time before adequate stocking is achieved. This latter disadvantage may not be applicable in the Yukon where fall stocking of untreated cutovers may not be achieved on river floodplains for up to 20 years (Nyland 1977).

Other techniques for regeneration may be possible through adept use of alternative harvesting systems such as patch or strip-cutting or through shelterwood cuttings. These systems require an increased level of forest management and as yet have not been investigated in the Yukon.

Regardless of which method is ultimately employed to regenerate river floodplains in the Yukon Territory it is important to recognize that there is a need to do it. Although forests north of 60° latitude constitute a relatively minor portion of the commercial forests in Canada there lies a responsibility with foresters to maintain a viable renewable resource wherever it may be.

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SOME CONSIDERATIONS IN THE NATURAL REGENERATION OF WHITE SPRUCE IN INTERIOR ALASKA

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INTRODUCTION

The creation and maintenance of productive forests is a main goal of foresters throughout the high latitude areas of the world. The top portion of Figure 1 suggests one way of visualizing this process. Two points need to be stressed with regard to this Figure. First the compartments or steps are all inter-related. That is, any particular compartment is affected by those which precede it and the activities which occur during that phase of management affect subsequent management activities. Second, within any compartment, there is an array of potential practices. In addition, each individual management practice can be conducted at one of several intensities. These different intensities of management are evident in the high latitude forests of Alaska, Canada and Scandanavia.

The objective of this, and subsequent workshops, is to examine the regeneration phase of forest management in detail. Forest regeneration can also be considered as a group of inter-related activities (Figure 1, bottom half). The statements made above certainly apply to forest regeneration **also**.

This paper will examine selected aspects of one particular type of regeneration, that is, natural regeneration. For the purpose of this paper natural regeneration refers to those regeneration systems which rely on natural seed-fall for their basic biological input. It also means that various

practices can be used for management or treatment of the soil surface to create conditions favorable for germination and seedling establishment. It is obvious that the practice of artificial seeding varies only in that the seed input is assured. In interior Alaska, natural regeneration has been the only means of forest renewal. Because forests cover much of the landscape, it is often believed that natural regeneration occurs automatically following natural or man-caused disturbance. In many cases this is true, however, when some level of forest management is imposed such considerations as length of regeneration period, forest composition, and stand density are frequently not adequate.

Thus a key question is whether or not foresters and other land managers can take advantage of or direct the regeneration capacity of these forests in order to establish forests of "desirable" composition following harvesting. In other words, can the management alternatives (see Braathe this volume, Zasada et al. 1978a) of harvest and rely on natural regeneration and/or harvest and encourage natural regeneration result in forests of acceptable density and composition?

Natural regeneration of white spruce (*Picea glauca* [Moench] Voss) following harvesting has resulted in varying degress of success. In research studies, where particular care was taken to assure an adequate seed supply and seedbed conditions, large numbers of white spruce seedlings have resulted (Zasada et al. 1978b, Zasada and Grigal 1978, I.N.F. 1979, unpublished). In areas harvested operationally prior to the early 1970s, no particular attention was paid to obtaining regeneration, and white spruce stocking has been less than adequate in many cases (Fox, 1979 personal communication; Clautice, 1979 personal communication, I.N.F. 1979 unpublished).

These Alaska results and observations confirm what has been the general experience with white spruce throughout much of the North American boreal forest and, in particular, western Canada (Dobbs 1972, Zasada and Gregory 1969). That is, adequate natural regeneration of white spruce is difficult to obtain without a management flexibility that includes assuring an adequate seed supply and seedbed conditions.

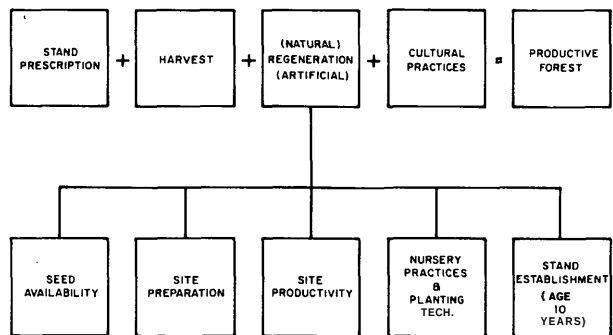


Figure 1.—Elements of productive forest management.

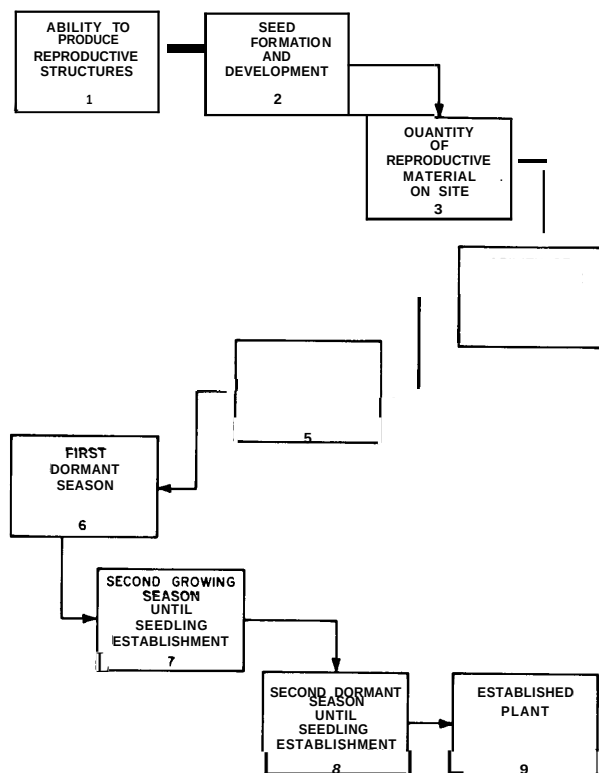


Figure 2.-Diagrammatic representation of natural regeneration of white spruce in Alaska.

Natural regeneration of white spruce is without a doubt a complex process perhaps more complex than for any other tree species in Alaska (Zasada 1971). The process involves a number of discrete but closely related steps (Figure 2). In the following discussions, I would like to consider the aspects of regeneration represented in this diagram. The discussion is by no means exhaustive. I have selected an example for each compartment which indicates the type of considerations necessary for assessing and understanding this regeneration method.

COMPARTMENT 1

Ability to Produce Reproductive Structures

Explanation: The production of white spruce cones varies annually and is dependent on such factors as tree age, the previous years' weather conditions, previous cone and seed crops and other factors (Matthews 1963, Anon 1974).

Example: Table 1 illustrates several points concerning annual variation in cone production. (1) During the 10-year observation period there were 3 years when there was little or no cone production. One feature of these years is that they generally follow years of high cone production. (2) Most of the trees followed the same general pattern of cone production. However 2 of the 15 trees (numbers 13

and 15) appeared to be generally poorer cone producers, particularly, over the last 6 years of the period.

COMPARTMENT 2

Seed Formation and Development

Explanation: This compartment considers all factors which interact to determine the quantity and quality of the seeds available for dispersal in late August or early September. These factors include physical environmental variables (particularly temperature) and biological variables such as insects, disease and squirrels.

Example: Zasada et al. (1978b) have discussed many of the considerations pertinent to this compartment. The effect of temperature on seed quality is one point that needs to be stressed. There are **two** general effects of temperature. First is death caused by subfreezing temperatures. Developing cones are particularly susceptible at the time of pollination. This damage has been observed in Alaska. The second temperature effect is more subtle and occurs when summer temperatures are not warm enough for developing seeds to mature. This phenomenon has been observed in Alaska in higher elevation stands and in some areas north of the Arctic Circle. It is a well-documented and serious problem in northern Scandinavia and needs to be more fully understood in Alaska.

COMPARTMENT 3

Quantity of Reproductive Material on the Site

Explanation: The quantity of seed available for dispersal will be determined by the amount of filled seed on the tree in late August, its dispersal and fate once it reaches the seedbed.

Example: White spruce stands throughout much of interior Alaska are capable of producing large quantities of seed

Table 1.— Annual cone crops for **15** trees in a white spruce stand near Fairbanks, Alaska*

Tree No.	Year									
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	1	500	0	750	82	0	500	0	450	220
2	3	1100	0	1600	0	0	600	0	700	5
3	0	1300	0	500	125	0	375	0	500	10
4	0	700	0	650	46	2	275	0	250	0
5	0	550	0	300	26	0	225	0	260	0
6	32	585	0	500	43	0	225	0	300	30
7	20	415	0	350	15	0	200	0	100	0
8	8	775	0	525	45	0	175	0	150	25
9	0	420	0	650	22	5	425	0	250	50
10	18	360	0	575	10	0	85	0	100	75
11	90	271	0	575	0	0	50	0	300	1
12	1	400	0	525	0	0	175	0	200	0
13	6	850	0	125	0	0	0	0	10	0
14	0	900	0	300	147	1	275	0	450	0
15	29	470	0	325	17	0	65	0	75	12

*Cone counts made from a fixed point for each tree.

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This paper will examine selected aspects of one particular type of regeneration, that is, natural regeneration. For the purpose of this paper natural regeneration refers to those regeneration systems which rely on natural seed-fall for their basic biological input. It also means that various

practices can be used for management or treatment of the soil surface to create conditions favorable for germination and seedling establishment. It is obvious that the practice of artificial seeding varies only in that the seed input is assured. In interior Alaska, natural regeneration has been the only means of forest renewal. Because forests cover much of the landscape, it is often believed that natural regeneration occurs automatically following natural or man-caused disturbance. In many cases this is true, however, when some level of forest management is imposed such considerations as length of regeneration period, forest composition, and stand density are frequently not adequate.

Thus a key question is whether or not foresters and other land managers can take advantage of or direct the regeneration capacity of these forests in order to establish forests of "desirable" composition following harvesting. In other words, can the management alternatives (see Braathe this volume, Zasada et al. 1978a) of harvest and rely on natural regeneration and/or harvest and encourage natural regeneration result in forests of acceptable density and composition?

Natural regeneration of white spruce (*Picea glauca* [Moench] Voss) following harvesting has resulted in varying degress of success. In research studies, where particular care was taken to assure an adequate seed supply and seedbed conditions, large numbers of white spruce seedlings have resulted (Zasada et al. 1978b, Zasada and Grigal 1978, I.N.F. 1979, unpublished). In areas harvested operationally prior to the early 1970s, no particular attention was paid to obtaining regeneration, and white spruce stocking has been less than adequate in many cases (Fox, 1979 personal communication; Clautice, 1979 personal communication, I.N.F. 1979 unpublished).

These Alaska results and observations confirm what has been the general experience with white spruce throughout much of the North American boreal forest and, in particular, western Canada (Dobbs 1972, Zasada and Gregory 1969). That is, adequate natural regeneration of white spruce is difficult to obtain without a management flexibility that includes assuring an adequate seed supply and seedbed conditions.

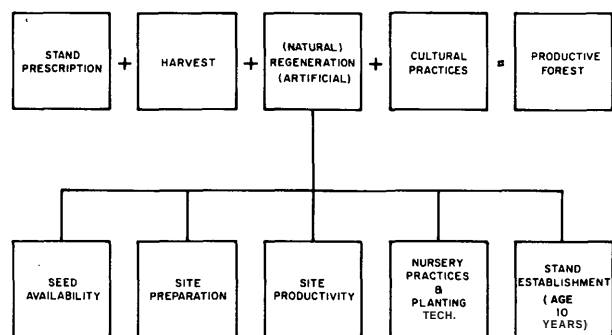


Figure 1.—Elements of productive forest management.

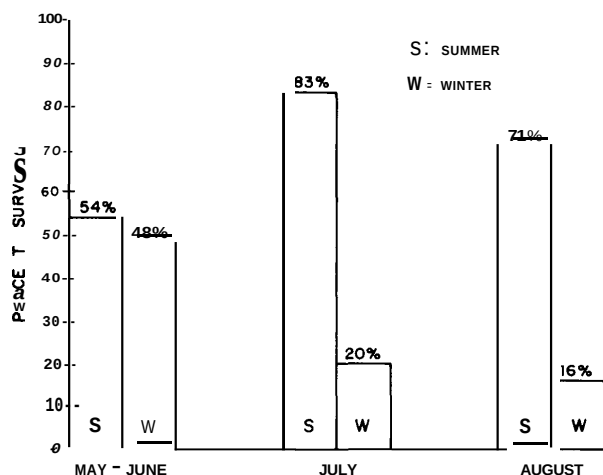


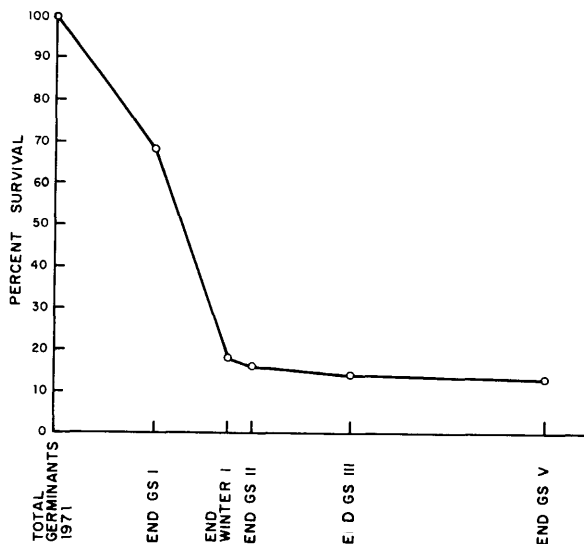
Figure 5.—Summer and winter survival of white spruce seedlings germinating during May-June, July, and August.

or the other of these periods suggest that different sources of environmental interference are affecting establishment.

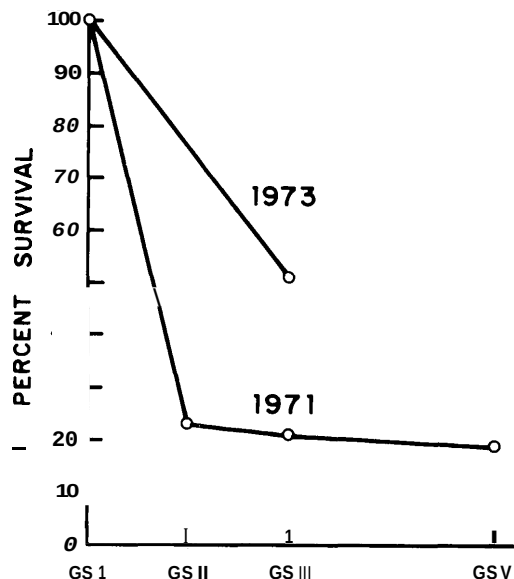
Example: Seedling survival and seedling growth are separate yet related considerations in compartments 7 and 8. From the information available for Alaska, there are several points that can be stressed concerning survival. First although mortality occurs during this period it is greatly diminished from that which occurs during the first year after germination (Figure 6; Zasada et al. 1978b, I.N.F. 1979, unpublished data). Second the mortality that occurs appears to be greatest among those seedlings that germinated late in the first growing season (Figure 7). Finally, seedlings produced from seed of later crops is less efficient in terms of the number of seeds/seedling. This indicates that seedbed conditions deteriorate rapidly.

Seedling growth is affected by the type of seedbed. The location of the seedling on the scarified seedbed may affect the growth rate and thus seedling establishment. Zasada and Grigal (1978) reported that 3-year-old seedlings were over two times larger (dry weight) on mineral soil surfaces than on debris surfaces. Unpublished data show that after 5 years white spruce seedlings are significantly taller and have a larger based diameter than those on organic matter surfaces.

Because of the greatly improved success of white spruce regeneration on mineral soil surfaces some mention must be made of this as it relates to compartments 5-8. First of all there are going to be obvious differences in mineral soil quality between soil types (e.g. upland soils compared to floodplain soils). Within a general soil type, in fact, within a scalped area there may be a number of different site conditions with regard to seed germination and seedling growth and establishment. Figures 8 and 9 indicate



A: 1971 white spruce germinants.



B: 1971 and 1973 white spruce germinants.

Figure 6.—White spruce seedling survival over five growing seasons.

large point to point differences that can occur in white spruce (and paper birch) seedling density and height. In other words these data suggest that although mineral soil surfaces may seem homogeneous relatively large microsite differences can occur over a short distance and have a large effect on seedling survival and growth. Finally seedlings of other trees and shrubs also regenerate best on mineral soil seedbeds and will compete to varying degrees with various environmental resources.

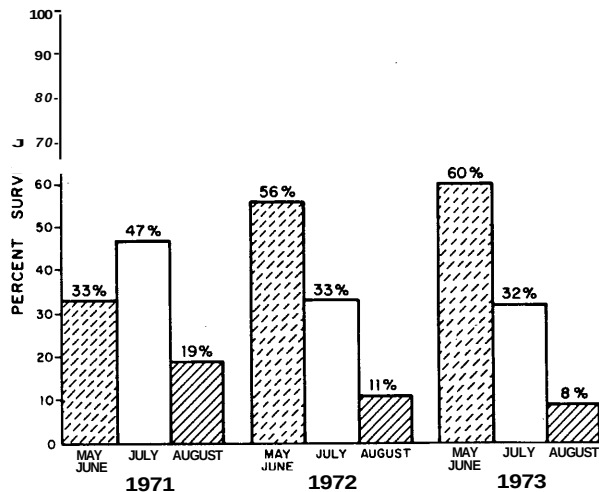


Figure 7.—Composition of white spruce seedling population in 1971, 1972, and 1973 by period which germination occurred.

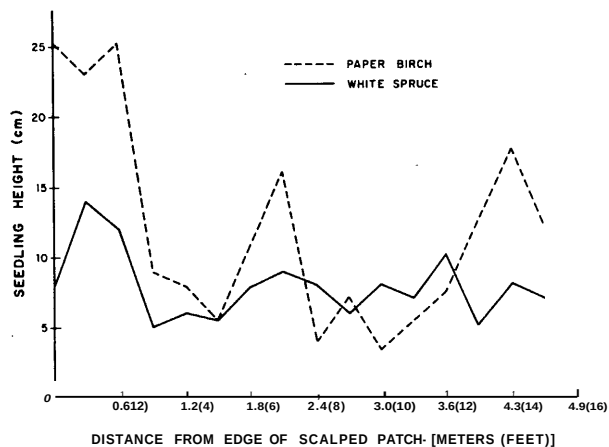


Figure 8.—Variation in seedling height on a scalped seedbed.

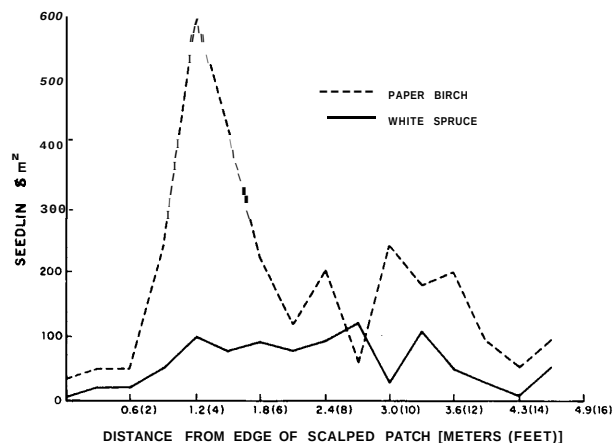


Figure 9.—Variation in average seedling density on a scalped seedbed.

SUMMARY

Natural regeneration of white spruce is a complex process. However, it has been demonstrated that abundant natural regeneration can be obtained given a good seed source and a mineral soil seedbed. The method of regeneration is a viable alternative on those sites where the land manager has the flexibility to time site preparation with the occurrence of seed years.

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ALASKA REGENERATION: STATE POLICY AND PROBLEMS

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INTRODUCTION

Alaska is a vast state with a total land area of 148 million hectares (365.5 million acres), about 16% of the total land area in the United States. Its forested land, both coastal and interior, totals 48.2 million hectares (119 million acres), which is about 16% of all forest land area in the United States. Of this 48.2 million hectares, only 11.4 million are considered commercial, defined as capable of growing 1.4 cubic meters of wood per hectare per year (20 cubic feet/acre/year). British Columbia, by comparison, has 25.65 million hectares of forest lands producing over 1.12 cubic meters per hectare per year (16 cubic feet/acre/year) (Reed and Associates, 1978). Alaska's coastal forest contains 5.363 million hectares (13.25 million acres) of which 2.3 million hectares (5.75 million acres) are commercial. This area is only 20.4 % of Alaska's total commercial forest area, but it is the most productive, containing almost 85.6% of the net saw log volume and 70.8% of the growing stock (Hutchison, 1967). The remainder is Alaska's interior forests. Alaska's forests have been fairly well defined but their ownership is not.

The Alaska Statehood Act of 1959 allowed the state to select 41.8 million hectares (103.3 million acres) of land from the federal domain. Twenty years after the Statehood Act, there is still about 65% of the state's entitlement to be transferred. As of October 31, 1979, the state has only received final patent on 8.2 million hectares (20.2 million acres) and has tentative approval on an additional 6.7 million hectares (16.5 million acres). Much of the state-selected land has been chosen for non-forestry uses. A good example is the state's ownership of the Prudhoe Bay oil fields on the north slope of the Brooks Range. Another factor is the Alaska Native Claims Settlement Act (ANCSA) of 1971 which allows Alaskan Natives to select 16.2 million hectares (40 million acres) of the public domain in exchange for relinquishing all future land claims. Under this law the Natives have selection priority; they have selected large amounts of profitable forested land in Southeast Alaska and, to a lesser extent, done the same within the interior.

In short, Alaska's interior forests are generally undefined and unmanaged. They will remain so until the issue of who owns and who will manage them is determined.

FOREST MANAGEMENT

There are four principle public land management agencies within the State of Alaska: the U.S. Forest Service, the Federal Bureau of Land Management, the Federal Bureau of Indian Affairs, and the Alaska Department of Natural Resources (Division of Forest, Land and Water Management). All of these agencies are, to one extent or another, involved in harvest and regeneration of forest lands within Alaska. The relative size of the management efforts of each agency is shown in Table 1. These volumes reflect sales, not actual harvest, of the four agencies since 1969. As such, they reflect management policy. Note the effect of the Alaska Native Claims Act after 1971.

Management activity developed within the more accessible, productive forest of coastal Alaska. The major stimulus was the U.S. Forest Service's fifty year contract with the Ketchikan Pulp Company for 42.5 million cubic meters (1,500 million cubic feet) of wood. It was signed in 1951 and a pulp mill was built by 1954. Another large contract was signed by the Forest Service in 1956 with the Alaska Lumber and Pulp Company for 27 million cubic meters (5.25 billion board feet). This wood was primarily destined for Japanese markets. The State of Alaska signed a negotiated long-term 15-year contract in August 1979 with the Schnabel Lumber Company, Haines, Alaska. Under provisions of this contract, the purchaser will harvest 5,600 cubic meters annually (10.8 million board feet). Natural regeneration on these coastal forests has been very successful because of high rainfall, mild climate, and excellent seed years. Alaska's interior forests, however, are more remote, less productive, and climatically more severe (Zasada, 1976). They have less management activity and more difficult regeneration. These problems will be addressed as they relate to state-managed forest land.

The State of Alaska manages forest land within both the coastal and interior forests. With the exception of the state's long-term timber sale at Haines, there is relatively little state forest land in the coastal forest. The greatest amount of state forest land is (and will be) in the interior. Figure 1 illustrates the relative amounts of actual, harvested wood from the two different forest types. State management policy for these lands derives from sections one and four of the Alaska Constitution:

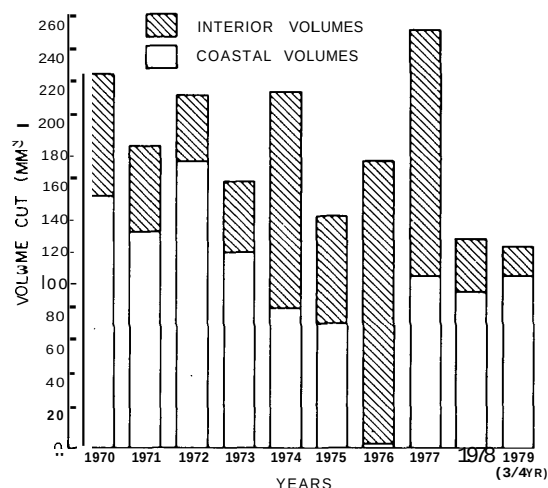


Figure 1.—Volume cut, Alaska state lands, 1970-1979.
SOURCE: Monthly Cut-and-Sold Reports, Department of Natural Resources, State of Alaska.

Section 1. It is the policy of the State to encourage the settlement of land and the development of its resources by making them available for maximum use consistent with public interest.

Section 4. Fish, forests, wildlife, grasslands and all other replenishable resources belonging to the State should be utilized, developed, and maintained on a sustained yield principle, subject to preferences among beneficial uses.

Alaska has fewer than 809,000 hectares (2,000,000 acres) classified for state forest management. As a result, there are few inventories, no forest management plans and, until recently, no written regeneration policy. Sales have generally been the result of economic and political pressure. Until a stable forest land base is designated, the situation is likely to remain this way.

The major harvest activity within the Interior is the State's Westside Salvage Sale located west of Anchorage, across Cook Inlet. Over 90,000 hectares (223,000 acres) of mixed white spruce (*Picea glauca* [Moench.] Voss) and

Table 1: Volume of timber sold on publicly owned or managed lands in Alaska, 1969-1978.

Year	U.S. Forest Service		State of Alaska		BLM		U.S. Bureau of Indian Affairs	
	MBF	MM ³	MBF	MM ³	MBF	MM ³	MBF	MM ³
1969	214,436	1,104.02	247,679	1,275.17	447	2.30	2,931	15.09
1970	349,066	1,797.16	14,926	76.85	554	2.85	9,885	50.89
1971	79,586	409.75	40,510	208.56	346	1.78	2,338	12.04
1972	33,445	172.19	23,109	118.98	4	0.02	40,052	206.21
1973	73,781	379.86	309,451	1,593.20	5	0.03	3,342	17.21
1974	127,941	658.70	21,146	108.87	174	0.90	8,787	45.24
1975	147,018	756.92	4,655	23.97	930	4.79	7,060	36.35
1976	15,619	80.41	2,358	12.14	215	1.11	0	0
1977	80	0.41	2,412	12.42	54	0.28	0	0
1978	170,790	879.31	6,932	35.69	142	0.73	440	2.27
Total	1,211,762	6,238.73	673,178	3,465.85	2,871	14.79	74,835	385.30

:Thousands of board feet, Scribner log rule.

Board foot conversion: 1M3 = 35.315 ft3, board foot to cubic foot ratio = 5.5 BF/ICF.

SOURCE: Ruderman, 1978.

Table 2: Harvest area and volumes at Westside Salvage Sale, Tyonek, Alaska.

	AREA		VOLUME					
	Hectares	Acres	Spruce		Hardwoods		Total	
			MBF	MM ³	MBF	MM ³	MBF	MM ³
1975	1,323	3,269	10,720	45.99	0	0	10,720	45.99
1976	2,807	6,936	31,702	136.01	7,629	32.73	39,331	168.74
1977	2,456	6,070	14,952	64.15	19,013	81.57	33,965	145.72
1978	686	1,695	2,812	12.06	2,078	8.92	4,890	20.98
1979	476	1,177	3,196	13.71	1,776	7.62	4,972	21.33
Total	7,748	19,147	63,382	271.92	30,496	130.84	93,878	402.76

SOURCE: State of Alaska, Department of Natural Resources, Division of Forest, Land, and Water Management, South-central District.

hardwood forest was attacked near Tyonek by spruce bark beetles (*Denroctonus rufipennis* Kby.) between 1969 and 1972. This area was reattacked in late 1978 and 1979, resulting in an additional 121,000 hectares (300,000 acres) of newly killed spruce. Because of the severity of the attack, there are few natural seed sources and most regeneration is either residual conifers or hardwoods. No natural white spruce seedlings have been found. Table 2 shows harvest volume and area for this sale. Regeneration efforts have been limited to small test plantings, a direct seeding trial, proposed prescribed burning and mechanical scarification tests, and a proposed seed tree regeneration cut. Much of the adjacent land was selected by the Cook Inlet Native Corporation and two municipal boroughs (i.e., counties). These selections will require cooperation and closely coordinated efforts to retain productivity of these immense forested areas.

The lack of regeneration within the interior is widespread. An examination near Fairbanks indicates only 30% of the harvested areas were stocked with acceptable seedlings. It is likely that silvicultural systems and direct seeding on scarified areas will be a solution to this problem. Hand planting will be needed in some areas. Efforts toward solving these problems have been further emphasized by the State's Forest Resources and Practices Act.

FOREST RESOURCES AND PRACTICES ACT

The Forest Resources and Practices Act became effective January 1, 1979. It reflects four years of review by many concerned individuals and interest groups. Basically, it has two purposes: it is enabling legislation for state forest management and it is regulatory legislation for forest practices. Draft regulations are currently being written for public review and comment; however, the regeneration provisions of the act now state:

With respect to state, municipal and private forest land the following standards apply:

(4) To the fullest extent practicable harvested land should be reforested, naturally or artificially, so as to result in a sustained yield of merchantable timber from that land; if artificial planting is required, silviculturally acceptable seedlings must first be available for planting at an economically fair price in Alaska. With respect to state and municipal forested land only, the following standards also apply:

(1) Forest land shall be administered for the multiple use of the nonrenewable resources and for the sustained yield of the renewable resources of the land in the manner which best provides for the present and preserves the future options of the people of the State of Alaska.

(4) Timber harvesting is limited to areas where data and information demonstrate natural or artificial reforestation techniques will result in the production of a sustained yield of merchantable timber from that area.

(5) There shall be no significant impairment of the productivity of the land and water with respect to renewable resources.

This act sets forth clear-policy for the management of the state's forested lands. It also emphasizes reforestation on private lands within Alaska. A prime tool for implementing this policy is the State Forest Nursery at Palmer. Without this facility, management options are severely limited. A capital budget was recently compiled and submitted by the Division of Forest, Land and Water Management. In part, it stipulated moving the nursery to Eagle River to heat with lower cost natural gas, thereby meeting the "economically fair price" provisions of the act.

Direct Seeding

Direct seeding is still basically a research activity in Alaska. Most of the work has been conducted by Dr. John Zasada at the Institute of Northern Forestry (U.S. Forest Service). The state has conducted direct seeding trials at the Willow Experimental Forest northwest of Anchorage, and at the Westside Salvage Sale. Tests include both artificial and natural seeding on scarified and nonscarified ground. Application rates at the Westside Salvage Sale were 1.14 kilograms/hectare (2.5 pounds/acre) and 0.57 kilograms/hectare (1.3 pounds/acre) of white spruce seed from a Kenai Peninsula seed source.

Direct seeding success elsewhere shows much promise. A critical factor in Alaska is available seed for production work. Variables affecting Alaskan cone crops are largely unresearched and need much closer examination; research near Fairbanks, for example, indicates high variability of cone production within a single year (Zasada, 1978).

Silvicultural Systems

Preliminary trials of various silvicultural systems within the interior indicate some success. Shelterwood cutting near Fairbanks produced regeneration of both hardwoods and softwoods (Zasada, 1978). A proposed seed tree cut of white spruce at the Westside Salvage Sale will be implemented soon. Hardwood regeneration has shown variable response in Alaska and much development in this area is likely as the costs of artificial conifer regeneration remain high.

Tree Improvement

The first exotic trees planted in Alaska were Sitka spruce (*Picea sitchensis* [Bong.] arr) transplanted from Sitka to Unalaska (on the Aleutian Chain) by a Russian priest in 1805 (Lutz, 1963). Several are still growing today (Tindall, 1979). Preliminary research indicates several species have much potential in Alaska. Species tested so far include Siberian larch (*Larix sibirica* L. deb.), Scotch pine (*Pinus sylvestris* L.), lodgepole pine (*Pinus contorta* Dougl. ex Laud), and Norway spruce (*Picea abies* [L.] Karst).

Reforestation needs indicate planting of genetically improved trees is likely. A potential 10% increase in yield makes this program very appealing to forest managers. The developing land base suggests cooperative efforts among the various government agencies, large Native land holders, and other individuals are possible. For the present, basic genetic improvement steps, such as writing preliminary seed zones and transfer rules, are being developed.

FUTURE PROGRAM DEVELOPMENT

Policy

Draft legislation was submitted in September 1979 for a State Reforestation Fund. As conceived, this fund would set aside 50% of the gross stumpage receipts for reforestation purposes. The three state land management districts would develop a reforestation plan for each sale and draw necessary money from the fund. It is similar to other funds such as the Federal Knutson-Vandenburg Fund. This Reforestation Fund would provide the firm economic base needed to implement reforestation provisions of the Forest Resources and Practices Act.

Research

There is a continuing need for applied research on site scarification, prescribed burning, mechanized planting, basic planting technology, and further testing of containerized seedlings. Much research will be needed in the harvest process as it relates to stand establishment. The forest manager must continue administrative studies on plantation survival and growth. The cost of planting, time required, most likely planting periods, and characteristics of planting stock must be analyzed and recorded. In addition, managers must continue testing regeneration survey techniques.

SUMMARY

The Alaska Native Claims Settlement Act and the Alaska Statehood Act determine ownership and management of Alaska's 42.8 million hectares (116 million acres)

of interior forests. Of the four public forest land management agencies, the State Division of Forest, Land and Water Management is responsible for implementation of the recent State Forest Resources and Practices Act. Its reforestation provisions create clear policy for state, municipal and private forest land. Other reforestation program elements are the State Forest Nursery, testing (direct seeding, silvicultural systems) and a tree improvement program. Future research will answer many management questions and the proposed Reforestation Fund will help fund them.

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EXPERIENCES AND PRACTICES RELATED TO FOREST REGENERATION IN NORTHERN SWEDEN

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THE PICTURE AND THE FRAMES

Sweden is a very long country and the climatic, geologic and economic conditions for forestry vary greatly. In the south there are Beech forests and high productive spruce sites. In the north is the natural northern limit of the coniferous forests with a hard climate, short growing season and low yield. Up here both biologic and economic problems of survival are dominating.

The following will mainly deal with the forests north of latitude 60°N. Approximately at this latitude one finds a plant-ecologic and climatic border line that well separates the less productive and more sparsely populated northern forests.

Within this region forests with Scotch Pine (*Pinus sylvestris* L.) and Norway Spruce (*Picea abies* [L.] Karst), mixed with 10-20% hardwoods, are dominating. There are soils from sandy sediments to dense moraines. The most common is the sandy-loamy moraine. There are forest vegetation types from wet peatlands to extremely dry lichen heaths. The most common is the mesic *Vaccinium* dwarf-shrub type. The landscape is not very mountainous. The elevation raises from the coast in the east up to the tree limit at 600-700 m (2000-2300 ft) in the mountain range in the west. The precipitation varies between 400 and 700 mm per year (16-28 in/year) and the length of the growing season decreases from 130-140 days in southeast to about 100 days in northwest. The average wood production on productive forest land is 2-3 cubic meters per hectare per year (30-40 cubic feet/acre/year). The annual cut is about 35 million cubic meters (1.2 billion cubic feet) which is about the same as the total annual growth. Several factors, such as long transportation distances, difficult snow conditions, cold and short winter days and high silvicultural costs guarantee a weak economy with low returns. When timber prices and business cycles are varying, an economic roller-blind is drawn back and forth over the inner parts of the area.

In the west and the north along the mountain range there is another important border—the exploitation limit. It is situated 100-200 m (330-660 ft) below the upper tree limit. It was drawn across all Forest Service land some 30 years ago and it eliminates 600,000 hectares (1,482,600 acres) of forest land. No clear-cuts are permitted above this

limit. Long experience has shown that at those extreme sites it is so difficult, risky and expensive to regenerate new forests within a reasonable time that we must wait until better methods have been developed. Some research projects with, for instance, exotic tree species are going on.

According to the Swedish Forestry Act every cut down forest must be replaced with a new one with high and valuable yield. The act also prescribes the lowest ages for final felling and rules for rationing the fellings in order to get an even and sustained yield.

THE HISTORY

During the 19th century the sawmilling industry grew up and the biggest and best trees were picked out from the forests. This high grading of vast areas resulted in gradually more open and older forests. The situation became unsatisfactory. At the turn of the century the pulp industry was born which created a need for smaller trees and tree parts as well. The preconditions for modern forestry were established. But how should the forests be regenerated? The debate was hard between the “clear-cutters” and the “selection-fellers.” The latter wanted to continue the gradual thinning of the stands in order to get new plants in the openings without any costs for planting or seeding. This method dominated from 1920 to 1940 but the result was a disaster. No plants appeared and the back of the old stand was broken.

The reason was a lack of understanding for the ecological conditions of forest regeneration in these poor areas. In the stand exists a hard competition for the limited conditions of life, especially accessible nitrogen. Different species and individuals are living in a narrowly regulated balance. The small and the weak have no chance to break through.

Research and experience have shown that the key problem was to regulate this competition in favor of the new stand. The balance must be radically altered. This altering starts with a total final felling and is fulfilled with different complementary measures, e.g. burning or scarification, depending on the vegetation type and thickness of the humus layer. In this way the principles of today’s clear-cut method were developed.

THE GOALS

The forest of today offers a variety of useful products. Tomorrow we might use it in another way. By establishing new stands and managing them we can influence and direct the growth towards certain goals.

Some principal goals for the Forest Service are:

1. The vitality of the forest shall be maintained and preferably improved.
2. The production in older and middleage stands shall be directed towards high quality sawtimber.
3. Coniferous species shall be used mixed with 10-15% hardwoods.
4. The new stands shall be managed to offer a future freedom of choice of the final goals so that the wood production capacity of the site is well utilized.
5. The uneven age class distribution shall be compensated by a planned set of measures which result in shorter rotation periods and higher yield.
6. The beauty of the landscape shall be preserved as far as possible and people's recreation and outdoor life shall be facilitated.

THE SILVICULTURAL PROGRAM

About half the clear-cut area is naturally regenerated with seed trees (50-75 trees per hectare; 20-30 trees per acre). Most of this area is dry and poor pine sites. The other half is artificially regenerated by planting or direct seeding. In most cases pre-regeneration cleaning and scarification is made.

Today scarification is mainly done with continuously working harrow type scarifier. The use of patch scarifiers has decreased. Limited areas with wet and cold soils are ploughed with deep cultivators. Burning has almost ceased.

Planting is the dominating method in artificial regeneration. Direct seeding is used only on a small percent of the area. Containerized seedlings from greenhouse nurseries are dominating.

The goal of the regeneration is about 2,000 main crop plants per hectare (800 per acre). A systematic plant survey followed by necessary repair planting is made after 2-3 years. On 10-15% of the land the hardwood slash vegetation usually makes a special spraying with herbicides necessary.

When the trees reach the height of 2-4m (7-13 ft) a pre-commercial thinning is made which reduces the number of stems to 1,200-1,800 per hectare (485-730/acre). The lowest figure stands for the poorest and technically difficult sites where a further thinning will be economically dubious. The first commercial thinning is done at the height

of 13-14 m (43-46 ft) and the number of stems by the final felling usually is 400-700 per hectare (160-280/acre).

Well situated older and middleaged stands are fertilized every 6-7 years with 150 kg nitrogen (N) per hectare (134 lbs/acre).

THE PROBLEMS

No activity is without problems and each problem initiates development of new methods. In the following the main problems and some development activities are described.

Bad Regeneration Results

To establish a new forest is difficult. It is very easy to fail. A lot of money is used for repair planting. The trend is positive today but the result can still be improved. Some important subjects are: seed problems, site preparation methods and plant supply.

Seed problems: The closer the natural tree limit the rarer the trees will flower and the more unsufficient will the conditions for good seed ripening be. There are often 10 years between average seed years and 20 years between peak years. Figure 1 shows the seed ripening of Scotch pine 1979. There are some possibilities to pick the cones early and let them ripen during proper storage before the extraction.

The difficult situation of seed supply is a temptation to get ripe seed from southern areas. The experiences of this is disastrous. Large areas of young pine plantations have gradually died during the first 20 years after planting due to wrong selection of provenances and to low hardiness.

Figure 2 summarizes the result from a 20 year old test plantation at Bjorkvattnet. This is a typical result. The problem of provenance choice in northern Sweden is to optimize the demand for hardiness and the demand for good growth of the individual tree. The figure illustrates this optimization problem. It can be looked upon as a map. Along the X-axis, the coastline as well, the latitudes are marked and along the Y-axis the altitudes are marked.

The elevational tree line is also marked and the area beneath this line is the natural area of Scotch pine in northern Sweden. The location of the test site is marked with a shaded square. The solid lines are regression lines, showing the variation in survival ability with regard to the original latitude and the altitude of the tested provenances. For instance, provenances which originate from localities along the solid line marked "50%" will survive to approximately 50% after 21 years when planted at Bjorkvattnet. Provenances originating from localities along the line marked "75%" and "90%" will survive to 75% and 90%, respectively, if moved to Bjorkvattnet. It is obvious that provenances from the north have survived better. Provenances from the areas surrounding the experiment have

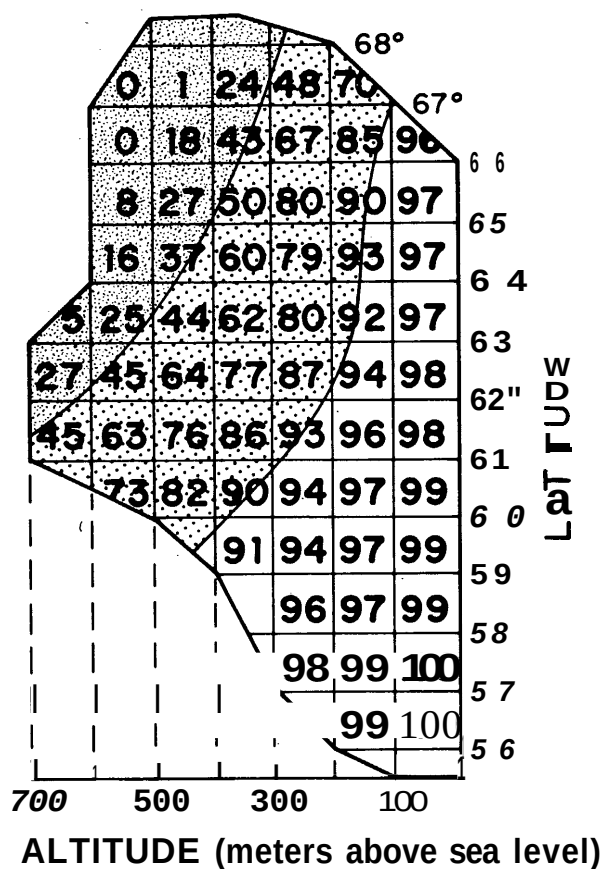


Figure 1.—Expected germination, per cent of seed from' different latitudes and altitudes, 1979-80.

survived to about 60-50%. Concerning survival ability pine seed should be moved from north to south.

However, the demand for hardiness must not be given such a high priority that the individual trees utilize the vegetation period inefficiently, which results in poor growth. Every tree has a genetically dependent growth rhythm, which means that the trees start and terminate their annual growth in a programmed manner. Provenances too far from the north contain a large share of early terminating individuals which do not utilize the growing season well and therefore will grow slowly.

The upper broken line in Figure 2 shows the relationship between the mean height of the provenances and their original latitude. It is obvious that southernmost provenances have a lower height. They are not hardy enough and therefore their condition is not the best. It is also obvious that the most northern provenances have a lower mean height as well. This agrees very well with the theory above. However, the curve has no clear maximum. Within the optimum interval the values of the different provenances have a fairly large variation around the curve, which may be considered as an expression of specific genetic values for different progenies.

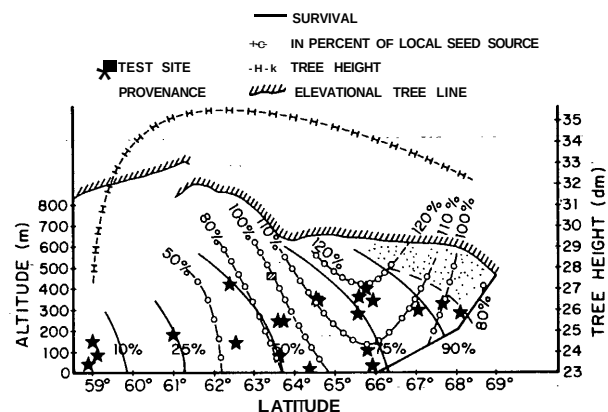


Figure 2.—Survival, tree height, and wood production per hectare in Bjorkvattnet related to the origin of the provenances.

The best criterion when choosing the right provenance is, however, the highest wood production per hectare. The lines with dashes and rings (Figure 2) illustrate this production in the following manner. Provenances which originate from localities along the line which passes through the square of the test site will produce approximately as much as the local provenance (= 100) if grown at Bjorkvattnet.

Provenances which originate from the same altitude but about two degrees of latitude further north will apparently produce 20% more when grown at Bjorkvattnet. When moving provenances even further from the north the production will decrease again.

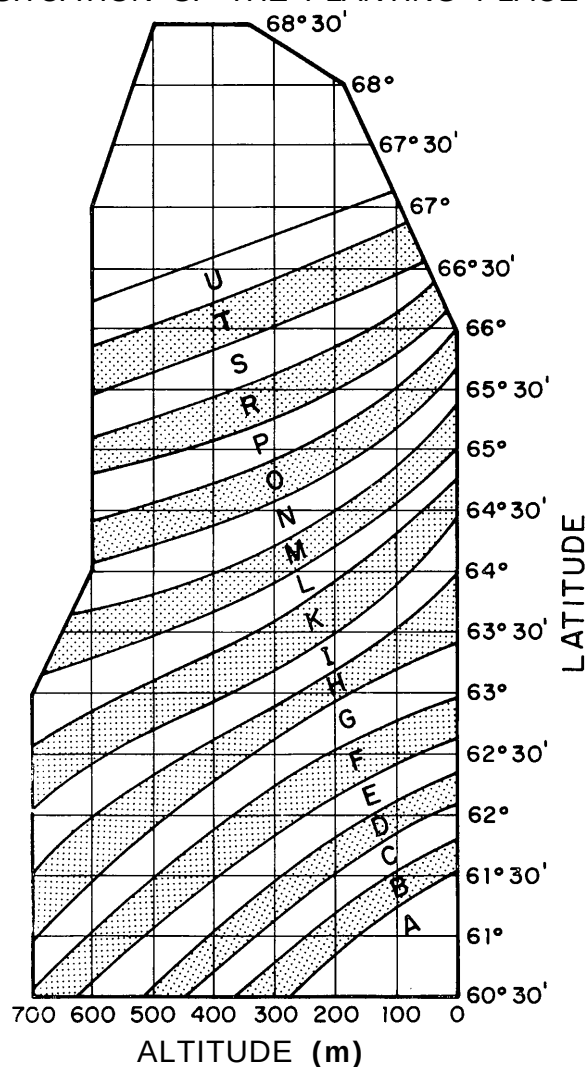
The results have been summarized in a "Seed transfer scheme" (Figure 3) which in concise terms shows that pine seed in northern Sweden should always be moved from north to south and the further from the north the closer to the tree line or further to the north the planting site is situated. On the average the scheme will result in 70-80% surviving plants after 20 years in the field.

Such seed transfer schemes have been developed for Norway spruce and lodgepole pine (*Pinus contorta* Dougl. ex Laud.) as well. They are critical tools in the regeneration work.

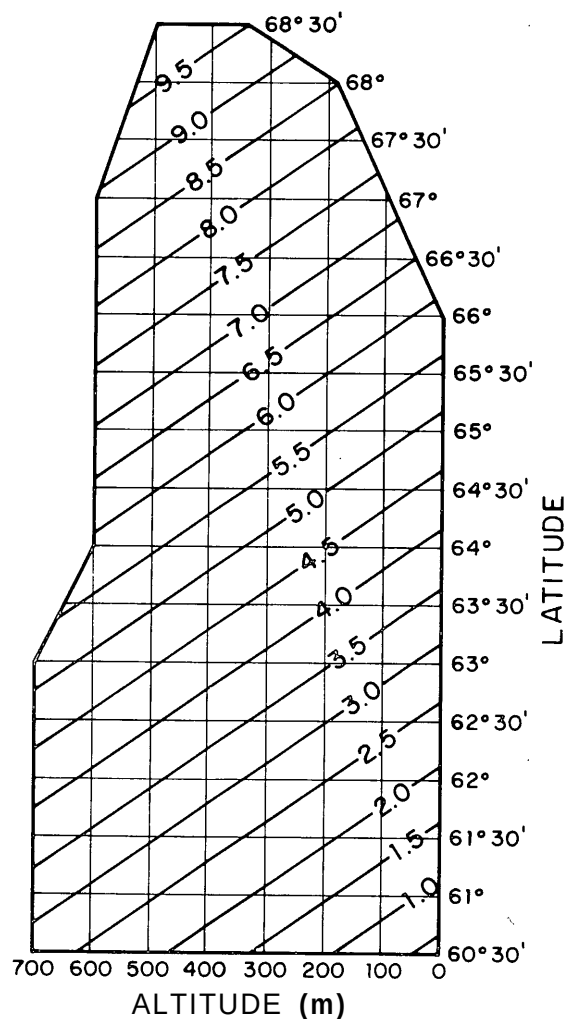
An extensive seed orchard program has been established through selection of plus trees within different zones, grafting and so on. About 50% of the pine seed supply comes from those orchards today and the crops are increasing. In northern Sweden, of course, it is of special value to have an even supply of ripe seed from seed orchards situated in areas with good climate. Besides that the new seed results in new forests with 20% better growth.

Site preparation methods: A good site preparation is of fundamental importance for the establishment of plants or seeds. It breaks the competition from other vegetation, improves the supply of nutrients, raises the soil temperature, improves the drainage, reduces the risk for frost and facilitates the planting.

SITUATION OF THE PLANTING PLACE



HARDINESS-INDEX OF THE PROVENANCE



AREA	Recommended hardness—index
A	0—1.5
B	1.0—2.0
C	1.5—2.5
D	2.0—3.0
E	2.5—3.5
F	3.0—4.0
G	3.5—4.5
H	4.0—5.0
I	4.5—5.5
K	5.0—6.0
L	5.5—6.5
M	6.0—7.0
N	6.5—7.5
O	7.0—8.0
P	7.5—8.5
K	8.0—9.0
S	8.5—9.5
T	9.0—10.0
U	9.5—10.5

Figure 3.—Seed transfer scheme by planting Scotch pine in northern Sweden. NOTE: One unit higher hardness-index than recommended means about 10% lower production due to slow growth. One unit lower hardness-index than recommended means about 10% lower production due to bad survival.

Some of our specified demands to the manufacturers of machines are:

1. Expose mineral soil on an area of at least 30 dm² (46.5 in²).
2. Loosen the soil to the depth of 10 cm (4 in).
3. Make small piles or other elevated planting spots.
4. Cause as little disturbance of the environment and the landscape as needed.

Earlier burning was very commonly used and the results on the right kind of sites are very good. Lack of labor and a troublesome time planning situation has made burning expensive and difficult to organize. Development projects, e.g. with lighting and extinction from helicopter, are going on.

A couple of site preparation machines with movable buckets which are making soil piles are being developed. The result is very promising. On technically very difficult or on frost sensitive sites especially equipped bucket-excavators are used for making strips or piles. The new methods will likely become more expensive but might still be motivated if they can make a successful result possible.

Supply of plants: Supply of plants is a sensitive chain from the seed to the planted seedling on the planting site. Great demands are made upon cultivating the plants, distribution, storage and handling as well as upon organization and supervision. Very often the question is not to develop new knowledge but to teach and distribute old basic knowledge about plant care and planting technique through well organized education activities.

This is especially important within an area with often long storing times between the date of lifting in the climatically well situated nursery and the date of planting out. The transports are also long. In the fall there is a problem, when the plants from the "summer" climate of the nursery are not enough lignified when they set out within areas with "autumn" climate and often frosty nights. Research has shown that by means of artificial darkening and regulation of the daylength it is possible to initiate an earlier budset and termination of the growth. The method is now being introduced on a larger scale.

A number of highly industrialized plant production systems with container plants are developed and tested continuously. They vary as far as economy, technical and practical perfection, but all have the same problem—to adapt the growing status and condition of the plant to the unoptimal conditions in the forest. Today this area seems to be one of the most important.

Increasing Regeneration Costs

Compared to the logging costs, regeneration costs have been increasing significantly faster. The productivity has decreased. This trend is seriously/ troublesome since a large part of all silvicultural measures still consists of manual labor. A growing part of the stumpage value is needed for regeneration. If this trend cannot be broken there is both an obvious risk of a generally lower ability and ambition to invest and the danger that some areas will become impossible to utilize from a production economy point of view.

Above all, the planting is expensive. Today's methods can be somewhat more developed but the aim is to change to radically new methods. On poor sites new direct seeding methods are interesting. Automatic seeding devices which can be attached to the scarifying harrows are being tested.

They continuously feed one seed per 1-2 dm (4-8 in). The present biological results are promising and it may be possible to cut the regeneration costs by 50% through this method. The bottleneck is seed supply with bad seed ripening and rare cone years.

On better sites great hopes are set on planting machines. An extensive development has been going on for more than 10 years. Planting has however turned out to be the most difficult operation by far to mechanize in the forest and we still do not have usable machines for ordinary Swedish forest land. The development is going on along two main lines: scarifying, and hole-making—planting machines and machines which are building up soil piles around the plants.

A very interesting idea is the "Hasselfors plant." A plant is produced in a compressed and plastic covered peat plate (7 x 7 cm; 3 x 3 in). The plate is with its plant placed out on exposed mineral soil and becomes firmly rooted to ground. If this method biologically fulfills its promises, entirely new possibilities are offered for both fully and partially mechanized planting systems.

Increasing Hardwood Stock

Available statistics show that in spite of active control the hardwood part of the growing stock has increased, especially in the younger stands. The reason could be bad market for hardwood timber but also low efficiency when fighting the slash vegetation on some of the clear cut areas. This trend is very serious and will in the long run create a lower total production capacity. An increase of the hardwood share of the young stands from 10-15% to 20-25% after 70 years causes about 10% less total yield. To avoid this an active use of herbicides is needed. It is not practical or economically possible to obtain the same effect with manual methods. The future of the chemical methods is, however, for a number of reasons, uncertain and restricted.

With this background the development within the sector of energy is particularly interesting. In several development projects we investigate if and how different parts of the forest biomass can be used as fuel. New markets have also opened up new possibilities for silviculture and wood production.

Shortage of Middleage Forests

In Swedish forestry a dominating problem is the shortage of middle age stands and what kind of measures and adjustments must be considered in order to reduce the coming effects of the so called "timber supply depression," Figure 4 shows the age class distribution. Of special interest are all measures that improve the yield. These shall either directly produce more timber ready to be cut when the depression comes or raise the general growth level so that the adjustment of the felling volumes can be acceptable to all parties concerned.

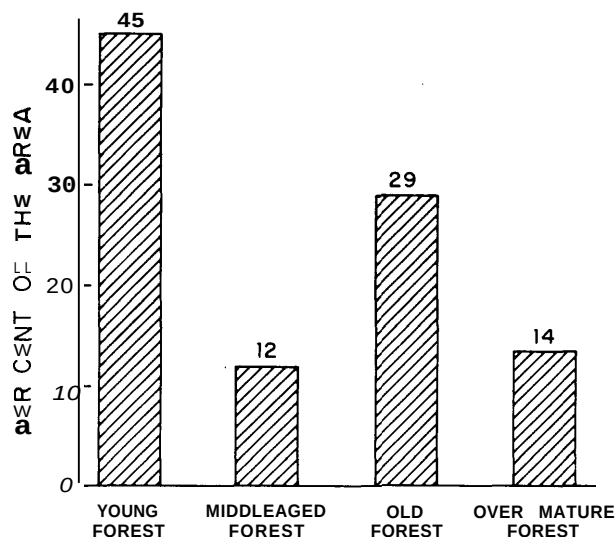


Figure 4.—Relative age class distribution of the forests. The distribution is based upon the age of each stand in relation to normal rotation period.

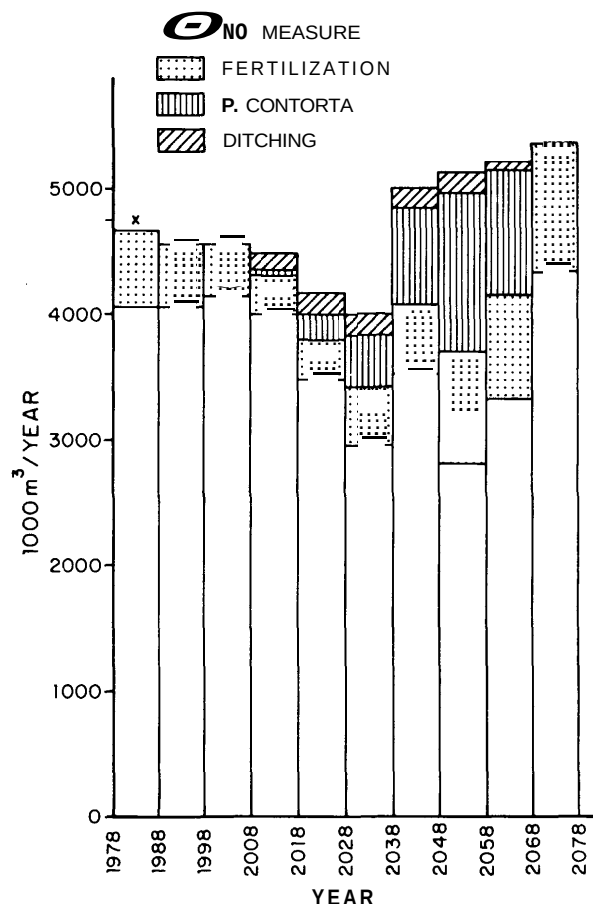


Figure 5.—Felling volumes, 1978-2070, northern Sweden.

The three most important measures which are systematically used today are planting trees and species with better growth, fertilization of stands on mineral soil, and improvement of the growth on waterlogged forest land. The measures not only make the depression more shallow but will also result in a future yield level that is higher than today's. Figure 5 shows an example from northern Sweden.

The intensive program of forest tree improvement has already been described. An increasing share of the need of seed is supplied from orchards and the new stands are expected to produce 20% more wood.

Lodgepole pine (*Pinus contorta* Dougl. ex Laud.) from the interior of British Columbia and the Yukon Territory is the only exotic species of practical value. On most sites in northern Sweden it produces 30-50% more than Scotch pine. The rotation period will be 15-25 years shorter. This gain of production must be balanced against all known and potential risks. Up until today proper provenances of lodgepole pine has not shown any severe drawbacks. One possible weakness is a more concentrated root system and therefore lower stability. During the next five years the Forest Service will plant 20% (= 8,000 hectares; 19,770 acres) of the annual regeneration area in northern Sweden with lodgepole pine.

Fertilization of mineral soils with nitrogen is also described above. This routine fertilization with 6-7 years intervals is an absolute precondition for the yield level and felling volume of today. Reduce fertilization immediately must be followed by reduced felling.

In northern Sweden there are large areas of peat land. Great efforts have been made to start forest production on these areas by draining and fertilization. Experience shows however that the biological and economical possibilities are very limited for most of the northern peat lands. Only the very best situated and nutritious have a good prognosis. Particularly some areas ditched in earlier periods in the lower parts of the area have a very great yield potential. Following ditching and fertilization with phosphorous and potash the whole bog is activated. Mineralization processes start which release nitrogen. The trees react immediately and a very rapid growth starts. These measures are not to a great extent expected to compete with other environmental interests since these interests mainly comprise other peat land types.

The waterlogged areas around the bogs as well as more shallow peatland where the roots of the trees can reach the mineral soil is a large hidden reserve. Here a proper ditching can raise the growth substantially and add new areas of productive forest land.

Criticism of Our Methods

It is fully evident that an active forestry influences and changes the untouched natural development of the forest, (If there exists such a thing?) Every change causes apprehension and protests. Familiar landscapes and paths are

changed. Very often it is felt that something primitive and natural is replaced by intensive timber production. Fast growing species, site preparation, herbicides, fertilization and ditching are differently looked upon by the ambitious silviculturist, wanting to grow a lot of timber for generations to come, and the Sunday wanderer who wants to pick the blueberries.

Sometimes these conflicts are real and sometimes fabricated. The critics of the largescale growing methods of forestry have roused and/or increased strong public opin-

ions. Sometimes these opinions have led to restrictions in the use of rational methods. Then very often the alternative has not been to use another more expensive method but to accept a loweryield ambition.

Such constant adjustments and demarcations are probably inevitable and lead to a great responsibility for the silviculturists to inform about the background, extent and consequences of different measures. It is also important that we in a professional manner take part in the debate concerning the use of the forests in the best way.

SITE PREPARATION TECHNIQUES FOR REFORESTATION

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BACKGROUND

When regenerating forests, there are two alternative methods, natural regeneration and artificial regeneration. The first mentioned method may be applied in the case of tree species producing sufficient amounts of seeds with good germinability, and on sites that become easily stocked with seedlings. It is possible to improve the regeneration with some treatment of a forest, for instance, by carrying out the final felling in a form of little openings or strips, so that the surrounding trees seed the area cut, or by leaving particular seed trees left in the area. With regard to shade bearing trees, young growth may spring up under the growing trees, if thinning is performed in an adequate way. In Finland, natural regeneration is applicable to all of the main tree species: Scotch pine (*Pinus silvestris* L.), Norway spruce (*Picea abies* [L.] Karst), and European white birch (*Betula verrucosa* Ehrh.), only. If although, it is mainly used for pine and birch only. If needed, natural regeneration can be promoted by site preparation, e.g., by breaking the humus layer.

Some tree species—especially broad-leaved trees—regenerate naturally of stump or root sprouts. Unfortunately, these kinds of trees are often of poorer quality than those grown from a seed or a seedling.

Methods used in artificial regeneration are sowing and planting, commonly called stand establishment. It is applicable both to reforesting openings after natural regeneration and to growing a new tree generation on clear cut areas. When compared with natural regeneration, forest soil cultivation offers the following advantages:

1. Seed and seedling material can be produced by certified trees, which guarantees the faster growth and better quality of wood.
2. Changing of tree species becomes possible.
3. Regeneration can be certified under circumstances, in which successful natural regeneration is uncertain (although failure of artificial regeneration cannot always be avoided, either).
4. To a certain extent, it is possible to control the growing sites and the density of trees, so that the need of

plantation management and intermediate cuttings diminishes, and harvesting of thinning wood can be carried out more advantageously. It must be noted, however, that “extra seeds” often come to the regeneration area from the surrounding forests, and they produce young growth and trees not desirable.

5. In many cases, the rotation time from one final felling to another becomes shorter—in Finnish conditions usually 5-15 years.

High expenses are a disadvantage of artificial regeneration, if compared with those of natural regeneration. Thus, when choosing a reforestation method, it is necessary to consider, if the monetary advantages of artificial regeneration are greater than the costs caused by it.

As mentioned earlier, site preparation is advantageous for natural regeneration in many cases. If artificial regeneration is applied, the soil preparation of the regeneration area for this purpose is almost a basic rule.

OBJECTIVES OF SITE PREPARATION

The most important objectives of site preparation are the following:

1. Improving the capability of seedlings to compete with other vegetation. There is an effort to eliminate or at least diminish other vegetation near the growth site of a seedling, or make its growing capacity poorer.
2. Improving the growth conditions of seedlings by curing the heat economy of the ground.
3. Improving the water economy of the ground in order to advance the development of the young growth. If the ground is too wet, it is possible to drain it, or make hummocks (tilts) to be used as planting sites. If the ground is too dry, furrows or patches gathering the moisture may be considered as planting sites.
4. Changing the physical structure of the ground so that the development possibilities of the roots of seedlings become better.

5. Improving the nutritional state of the soil. The nutrient economy becomes better only, if the soil is prepared so that the humus layer rich in nutrients is mixed with mineral soil. Even if this does not happen, the seedlings growing in pure mineral soil develop better than those planted in places not prepared at all.
6. Improving the light supply to seedlings.
7. Increasing the oxygen content of growth sites.
8. Decreasing frost damages.
9. Decreasing danger of insect damages.

Regeneration areas vary considerably with regard to the soil type, moisture content of the soil, microclimate, etc. So the objectives of site preparation are different in different cases. An objective common in all the cases is, however, an effort to ensure the development of a new tree generation.

SITE PREPARATION TECHNIQUES

Broadcast burning is one of nature's own means to improve the regeneration conditions of forests. Investigations have showed that in Finland, for instance, the forests were thoroughly burnt by lightning or some other reason once every 300 years. The fire does not only improve the site for seed germination, but it also returns the health balance of a forest area (reduces damages by fungi or insects). Forest fires are nowadays relatively rare in Finland. This is due to the fact that, thanks to thinning cuts, very little dry wood is found in the forest.

As late as the 1950s, controlled broadcast burning was very commonly used in preparation of regeneration areas. After this it was almost totally given up, mainly because insurance companies no longer offered insurance for the areas to be burnt. Fire controlling techniques have very much developed within the recent years, and it seems to be obvious, that controlled burning will again be taken into use in preparation of regeneration areas.

Scarifying is an old method of soil preparation. In this method, patches for planting or sowing are scalped on the ground at pre-determined spacing. The humus layer is removed from the patches. Scarifying is applicable to soils pervious to water, but in clayey soil, for example, the patches may form water holes, in which seedlings are not able to develop. This method has been in use as early as in the times of horsedrawn equipment, and, under certain circumstances, good results have been gained. The most developed scarifiers are drawn by forest tractors, and they automatically make two rows of patches simultaneously. Scarifiers are usually equipped with two or four, 4-toothed ripping wheels, the rotation of which is stopped automatically at fixed distances with the help of hydraulic brakes. At this stage the teeth scalp the patch to the ground and turn the humus layer toward the driving direction as seen from the patch. The distance between patches is adjustable.

The power take-off of the pulling tractor must be about 30 kw, i.e., its engine power ought to be about 60 kw or more (80 HP). In recent years, this method has given way to harrowing and plowing, because these two methods prepare the site so that well-prepared sowing or planting spots are found independently of the soil type. The prices of scarifiers are more moderate than those of forest harrows or plows.

When harrowing soil (Figures 1, 2 and 3, Table 1), rather continuous furrows are formed, and the mineral soil is thus uncovered in the bottom of them. The humus soil, as well as the possible slash, are thrown to the other side of the furrow (Figure 4). The most commonly used harrows are disc trenchers, which are equipped with two or four toothed discs. In the most modern models the plowing angle and the load on the discs are hydraulically controlled by the operator in his cabin. Rolling of discs happens by a hydraulic engine connected with them. The power required for this disc hydraulic motor can be produced either by the tractor or by a separate engine. The pulling tractor



Figure 1.—TTS disc tiller.



Figure 2.—TTS disc plow.



Figure 3.—TTS disc trencher

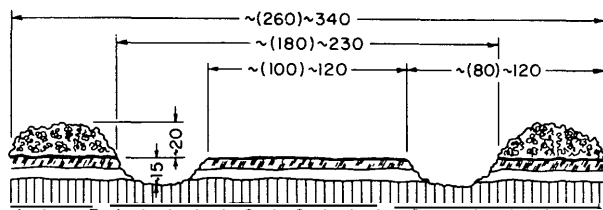


Figure 4.—Furrows made by TTS disc trencher.

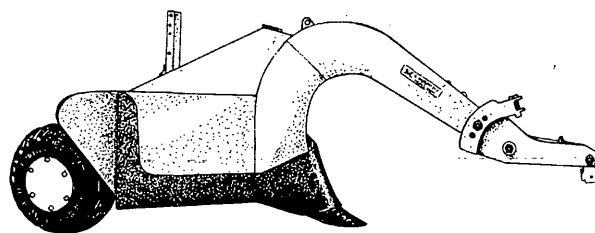


Figure 5.—Site preparation plow, Marttiini m/KLM-170

required may be either a forwarder or a skidder. The required power take-off is about 50 kw (67 HP) and the engine power about 100kw (134 HP). There are several types of harrows for different conditions. The most modern types are provided with a special equipment for making hummocks, because the biological result has in some cases proved to be best, if seedlings are planted on a hummock.

The most efficient equipment for forest soil preparation is a reforestation plow (Figure 5). It makes a furrow, the depth of which is 20-60 cm (8-24 in), and the upper width is about 80 cm (32 in). The soil is lifted from the ditch to both sides to a distance of about 60 cm (24 in) from the edge of the furrow. So a bed of this width is left between the lifted soil and the edge of the ditch in which the mineral soil is uncovered. The tractor required is either a crawler tractor or a wheeled forest tractor with an engine

Table 1: Technical specifications of some Finnish soil preparation machines.

SCARIFIERS							
Model	Length ¹ cm	Width ² cm	Height cm	Weight kg:	Length of tooth cm	Diameter of drum cm	Oil volume l
Light tractor scarifier	160	45	120	260	40	56	30
m/Sinkkila	245	235	120	1,130	40	56	78
HARROWS							
Model	Length cm	Width cm	Height cm	Weight kg	Length of disc spaces cm	Diameter of disc cm	Furrow cm
TTS Disc Tiller	230	210	240	3,500	7	101	2x150-235
TTS Disc Trencher							
m/TTS-25	210	250	210	1,250 ³	20	82	2x80
m/TTS-35	210	300	210	1,750 ⁴	27	106 or 120	2x120
m/TTS-35H	230	210	240	3,000	27	106 or 120	2x150-235
PLOWS							
Model	Length cm	Width cm	Height cm	Weight kg	Depth of furrow cm	Width of furrow (cm) At top	At bottom
Fiskars-Karhu	457	280	240	1,900	35	80	11
Marttiini							
m/KLM-170	450	170	230	1,500	25-30	50	10
m/PP-I	500	240	230	2,100	40	80	10-15
m/PP-II	470	220	230	1,900	40	60	10-15
TTS Bedding Plow'	320	166	145	2,000	20	75	50

¹The length of spots: adjustable.

²The width of spots: 50 cm or more.

³With additional weight 2,500 kg.

⁴With additional weight 3,500 kg.

⁵Site preparation devices: 1 coulter and 4 discs, diameter of discs 106 cm.

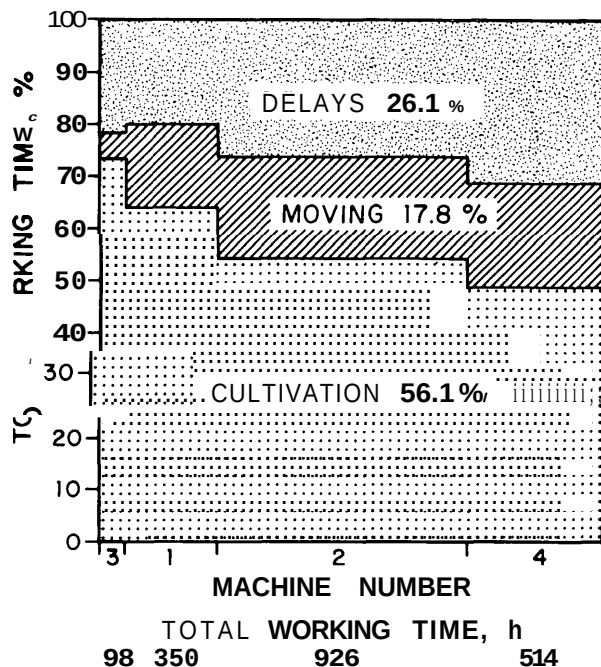


Figure 6.--Relative distribution of the total working time in harrowing, SOURCE: Kaila and Paivanen, 1978.

of at least 160 kw (215 HP). Plowing is a method used on wet sites with a thick peat layer. It may be mentioned, that the work trace of some forest harrows reminds that of plowing.

Ditching is mainly applied to draining peatland for forest growing. In Finland, for example, nearly 5 million ha (12,355,000 acres) of peatland has been drained for this purpose. Draining technique is such a wide problem, due to its nature, that it is not possible to deal with it in detail in this connection. It is worth mentioning, however, that ditches are made either with a forest ditch plow or with an excavator equipped with a shaped bucket. Rotary ditchers may also be used.

Drawing of site preparation equipment is possible on a side slope of 10% at the most. The limit of uphill slope is about 20%. If the slope is steeper, performing of soil preparation is possible only when driving downhill. In general, slopes steeper than 35% ought to be avoided for reasons.

The density of preparation traces depends on how many seedlings is wanted to be planted per unit area. In Finland, the desired number of seedlings is usually 1,400-2,800/ha (570-1,130/ac), but the most common amount planted is 2,000 seedlings/ha (800/ac). In this case the distance between prepared points (rows) ought to be about 5 meters (16 feet), if measured from the middle of them. In practice, this means driving of about 2 km/ha (.5 mi/ac).

The form of driving for soil preparation may vary according to the size and shape of the area to be prepared.

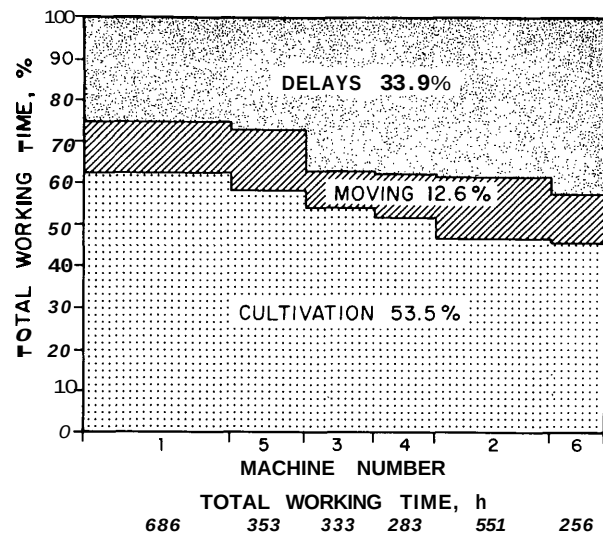


Figure 7.--Relative distribution of the total working time in wing plowing. SOURCE: Kaila and Paivanen, 1978.

If the length of the area is more than 100 m (330 ft), the usual way of driving is in the same direction, one furrow beside another. In roundish areas it is possible to "drive around" in a cricle beginning from the outer side of the area for reducing turnings. Other types of driving figures may also be used.

SOME RESULTS OF WORK STUDIES ON SITE PREPARATION

Several work studies have been carried out in the field of soil preparation in Finland (e.g. Eskelinen et al. 1976, Haarlää 1973, Seppälä 1975, Tynkkynen 1974, and Kaila and Paivanen, 1978). The following information is based on the last mentioned publication. The study dealt with six plowing units and four harrowing units. All the drawing machines were wheeled forest tractors. The relative distribution of the total working time of forest disc trenchers is presented in Figure 6 and the same for forest plows in Figure 7.

The shares of the soil preparation time were 56.1% (harrowed) and 53.5% (plows). The share of different delays was 26.1% of the total time for harrows and 33.9% for plows. The share of moving time mainly depends on the distances between the working sites, and on the quality of the route used for moving. In cases studied it was 17.8% for harrows and 12.6% for plows.

The outputs per working hour of these methods were the following:

	Average output/ha	Variation between machine units
Harrows	0.89 ha (2.20 acres)	0.76-1.03 ha/h (2.55 a/h)
Plows	0.60 ha (1.48 acres)	0.36-0.81 ha/h (2.0 a/h)

It may be found that the average output of harrows is clearly higher than that of plows. Furthermore, if the last mentioned method is used, the variation of output is greater than that of harrowing. The factors having effect on the output rate are the size and shape of the preparation area, soil type, relative slopes, amount of stones, stumps and slash, the technical construction of the machine unit, and the skill of the operator. If the size of the area is less than 2 ha, the output decreases from the average. The smaller the area is, the more the output decreases. It may be worth mentioning, that the average sizes of the regeneration sites in the studied working areas were 2.1 ha (5.2 acres) when harrowed and 3.0 ha (7.4 acres) when plowed. The irregular shape of the area also reduces the output, if the area is small.

For one harrowed unit, the following straight correlation between the preparation time (y hours) and the size of the regeneration site (x ha) was gained:

$$y = 0.26 + 0.85 x$$

One variable explaining the lower hourly outputs of plowing is the ground. This method is usually employed on soft ground with a poor bearing capacity (peatland).

The share of preparing and service of the machines of the total delay time was 68.5% for harrowing equipment and 76.4% for plowing equipment. The share of the time that the machines were stuck was about 14% in both cases.

Moving is somewhat slower with a plow than in question of a harrow, excepting the distances shorter than 15 km (9 miles). The moving time includes the preparations, which means, e.g., removing the tracks from the bogie, and the actual time of moving. The first mentioned of these takes about 1.1 ha/case in average. The actual speed of moving (driving speed) is 8-12 km/h (6-7.5 mi/h) for distances shorter than 10 km (6 mi) and 18-21 km/h (11-13 mi/h) for distances longer than 40 km (25 mi). The dependence between the driving time of moving and the length of the distance is linear.

COMPARISONS BETWEEN DIFFERENT TECHNIQUES OF PREPARATION OF REGENERATION AREAS

Before starting of site preparation, some preparatory actions may have been taken in the area. These are called clearing of the regeneration site. In the Soviet Union, for example, slash is gathered into heaps and burnt. In Poland, at least in some cases, stumps are lifted and transported away from the area. In some other countries the slash is smashed, etc. In Finland, the slash is usually left on the area, because the danger of insect damages caused by it is small, and the soil fertilizing effect of slash, when decomposing, is regarded to be good. Furthermore, the treatment and removing of it is thought to be too expensive. If some worthless trees have been left to grow after the final cutting, they are felled, as well as bushes. If there is plenty of slash in a regeneration area, it is reasonable to wait for 1-2 years before beginning of soil preparation, so that the slash is decomposed, at least partly.

When comparing different techniques of soil preparation in regeneration areas with each other, attention must be paid at least to the following facts:

1. What kind of method is applied in possible planting? Due to the stoniness of the soil in Finland (moraine) mechanized planting may be considered only on peatlands and in afforestation of fields. The reason for this is that constructing of planting equipment for stony soils has not yet succeeded. A quite common method of planting is that of using peatpot and paperpot seedlings. In that case, a planting tube is used. Thus, the soil preparation techniques necessary for mechanical planting are only exceptionally applied.
2. Does the soil preparation trace offer different alternatives for planting so that the moisture content, permeability to water, inclination to frost, etc., of the soil can be taken into account when choosing planting spots? From this point of view, both harrowing and plowing are good methods. Harrowing is a good method especially, if the harrow is provided with an attachment for making hummocks. Instead, alternatives offered by a scarifier are few in this sense (bottom of a patch, edge, hummock lifted by a colter).
3. Does the equipment used remove the competing vegetation and slash in an area large enough? From this point of view, plowing is the best method, but harrowing is a good one, too. The question also refers to the number of alternative planting spots.
4. Is the method applicable in different soil and terrain conditions so that many types of soil preparation equipment are not needed? From this point of view, harrows are the most versatile of the machines mentioned.
5. What are the costs of the equipment per output unit (for example, ha)? Scarifying is the cheapest and plowing the most expensive of the alternative methods mentioned. The most important objective is, however, the successful stand establishment, and, from this point of view, the differences in output costs per unit are insignificant.

Generally speaking, it may be said that harrowing applies to almost or quite dry mineral soils, and on moldery and stony upland forest soils with grass-herb vegetation. The objectives of plowing are loosening of the soil, diminishing the moisture of the surface layer and raising the temperature of the soil, and so it is applicable to fresh and solid or fine-textured mineral soils, and, as so called tilt-plowing, on water-logged soils with a thick raw humus layer. Making hummocks may be combined with peatland drainage when an excavator is used. A condition of controlled burning is a good water supply. This method covers both clearing and preparation of a regeneration area, and is applicable to areas with a thick raw humus layer and to stony soils, especially if there is plenty of slash or the area is damaged by the fungus *Fomes annosus*.

TERRAIN CHARACTERISTICS FOR SITE PREPARATION

The Nordic countries have worked in cooperation in order to develop a classification system applicable to all the operations of forestry, including the stand establishment (Eriksson, Nilsson and Skramo, 1978). The problem of forest classification is very complicated, because, in practice, there is an unlimited number of different combinations of terrain factors to be found. In this connection, it is impossible to deal with this wide problem except referring to some main principles.

The first thing to note is that the need of classifying the terrain consists of two stages. The first one is the description and classification of the terrain as it is. This classification, called a primary classification system, preserves its validity in time, because most of the terrain factors are stable and very slowly changing. The second stage is called either secondary or operational classification. The problem dealt with at this stage is the relation between different terrain classes and different operations carried out in the terrain, like terrain transport, forest soil preparation, forest road construction, etc. This classification must be transformed every now and then, when essential changes of operation techniques take place. In practical working life, the second stage is the one mainly needed. In case of soil preparation, for instance, information is needed about the dependence of the output, costs, quality of the work trace, etc., on the variation of the terrain.

The basic factors of the classification are the following:

1. Ground conditions and soil types
2. Ground roughness
3. Slope Conditions.

The completing factors are:

1. Stoniness of the ground surface
2. Humus layer and ground vegetation
3. Slash and stumps.

Both basic and completing factors are described using a scale of 1-5, where 1 indicates the best conditions and 5 the most difficult ones. For defining the different factors in the field, field work instructions have been written

(Nilsson 1979). The final class is reached as a result of counting by points.

CONCLUSIONS

It seems to be obvious that artificial regeneration all the more replaces natural regeneration in Finland. Nowadays the area regenerated annually is about 100,000 hectares (247,100 acres). How applicable the Finnish site preparation techniques are in the conditions of Alaska, is a question impossible to be answered at first glance. However, our methods might offer a useful starting point to experimental actions, if some are regarded worth starting.

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SOME PRACTICAL METHODS FOR SECURING ADEQUATE POSTCUT FOREST REPRODUCTION IN CANADA

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THE FOREST RESOURCE

Canada's forest land occupies an area of 3,417,000 km² (1,319,300 mi²), which is about 37% of the nation's total land area (9,218,000 km² [3,559,000 mi²]), nearly 4.7 times the area of agricultural land (730,000 km² [281,800 mi²]), and second only to the combined area of tundra, barrens, alpine, and other similar wildlands (4,334,000 km² [1,673,400 mi²]). About 3,141,000 km² (1,212,700 mi²) of the forest land are classified as an unreserved production land that can be used for growing timber. However, only 1,984,000 km² (766,000 mi²) of the production land are inventoried as currently productive forest land, of which 1,611,000 km² (622,000 mi²) are economically accessible (Bowen 1978).

The wood volume of the productive and economically accessible forest land is estimated at 17,229,000,000 m³ (60,835,599,000 ft³) (Bowen 1978). About 80% of this wood volume is in softwoods, with the most abundant species being black spruce (*Picea marianu* [Mill.] BSP.), white spruce (*Picea glauca* [Moench] Voss), jack pine (*Pinus banksiana* Lamb.), lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), balsam fir (*Abies balsamea* [L.] Mill.), eastern hemlock (*Tsuga canadensis* [L.] Carr.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), eastern white cedar (*Thuja occidentalis* L.), western red cedar (*Thuja plicata* Donn), and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). The remaining 20% of the wood volume is in hardwoods, with poplar species (*Populus tremuloides* Michx. plus some *Populus balsamifera* L.) and white birch (*Betula papyrifera* Marsh.) predominating (Cayford and Bickerstaff 1968; Bowen 1978).

As calculated for the area south of 60° N latitude, where in fact most of Canada's forests are located, the annual allowable cut and the average annual timber harvest are 256,305,000 m³ (9,050,129,600 ft³) and 156,383,000 m³ (5,521, 883,700 ft³), respectively, leaving some 99,922,000 m³ (3,529,245,800 ft³) in reserve. The implied availability of this reserve, however, is somewhat deceiving because about 43% of the wood volume that remains uncut is economically inaccessible. Moreover, timber deficits begin to occur at a more localized level, and softwood supply problems are on the increase (Reed et al. 1978a; Newnham 1978).

THE STATE OF FOREST REGENERATION

Although Canada is still one of the world's leading forest nations, there is an increasing general apprehension that this favorable position may be lost in the not-too-distant future unless substantial improvements are made right now in the overall reforestation of problem cutovers and other fail areas. The backlog of such areas, variously estimated in excess of 44,515 km² (17,190 mi²), is increasing at an average annual rate of about 2,728 km² (1,053 mi²). Roughly 56% of this increase is attributable to regeneration deficiency after harvest cutting, and a further 44% is attributable to other causes such as insect and disease infestations or the occurrence of certain types of wildfire. It is estimated roughly that about 20% of the total annual harvest area fails to regenerate adequately to the desired tree species, while the remaining 80% of such area regenerates at an acceptable level either by unaided means such as natural seeding, resprouting, etc., or through the use of mechanical scarification, controlled burning, planting, direct seeding, etc. in various combinations (Paille 1977).

Most of the productive forest land in Canada is under provincial jurisdiction (87%) (Bowen 1978), and practically all primary wood-processing industries within such lands operate on the basis of long-term leases. This arrangement is often severely criticized because it seldom results in the practice of proper land management, including the very fundamental task of forest regeneration. Some provincial forest services are doing better jobs of managing their lands than are the others, but still there is not even one provincial organization that can claim consistently adequate forest regeneration following any kind of disturbance, and this includes harvest cutting (Reed et al. 1978a; Newnham 1978). As for the federally (6%) and the privately (8%) owned productive forest land (Bowen 1978), the overall managerial performance in both these cases is not better than that on the provincial land. In only one or two instances, the privately owned land appears to be managed at an acceptable level. However, the provinces, the private sector, and the federal government departments now are beginning to recognize the urgent need for more intensive management, including work on forest regeneration (Reed et al. 1978a, 1978b; Newnham 1978). Let us hope that the participants involved will agree soon on the proper funding necessary for effective implementation of the intended programs.

MAJOR CAUSES OF REGENERATION FAILURE

Many softwood species fail to regenerate adequately after harvest cutting mainly because most of the loose, surface forest-floor materials remain undisturbed. The surface materials, consisting often of feather moss (*Pleurozium schreberi* [Brid.] Mitt. occasionally with some *Hylocomium splendens* [Hedw.] B.S.G. and *Ptilium crista-castrensis* [Hedw.] De Not.) and foliar litter that merge downward into either an upland mor or a lowland peat, are subject to rapid losses of moisture when exposed to increased solar radiation and ventilation. This alone makes them extremely poor media for seed germination and seedling survival. Moreover, the overshadowing created by logging slash and the often severe competition from deciduous vegetation can further hinder the reestablishment of softwoods after cutting. These conditions can be rectified, however, by either mechanical scarification or controlled burning, with provisions for subsequent planting or seeding.

The regeneration failures may also occur when, in absence of marginal seed sources, wildfires destroy young softwood stands or they burn through softwood clear-cut areas. In both instances, prompt replanting or reseedling is required before plant competition becomes too severe.

Adequate protection from insects, disease, and mammals must be provided under all circumstances to minimize the regeneration losses. Occasionally, the losses may lead to total devastation in the absence of such protection.

Among the hardwoods, poplar species regenerate very well after cutting, mainly through root suckering, and they usually become a hindrance to the reproduction of softwoods. Most other hardwoods encounter practically the same difficulties as the softwoods in reproducing themselves after cutting.

MAJOR REMEDIAL TREATMENTS

Ideally, a regeneration plan is formulated well in advance of timber harvesting. The first prerequisite is that the plan must be based on a thorough evaluation of the forest ecosystem under consideration, with particular attention given to its productive capacity (wood volume per unit area, or tree height/age relationships), its soil (type and depth of organic overburden, texture, structure, petrography and depth of mineral materials, position of water table, and long-term moisture regime), its topographic position and microclimate, and its successional tendency in terms of vegetation changes after disturbance. The regeneration plan is then to include specifications pertaining to the type and season of harvest cutting plus the types and sequence of silvicultural treatments needed—all in view of the preselected tree species that best fit the anticipated environmental conditions.

Throughout Canada, clear-cutting is the most common method of harvesting softwood timber, although cutting in a strip-like fashion is slowly gaining popularity under some conditions. In mixed stands, selection cuts are often prac-

ticed, but only to the extent that the more valuable individuals are removed while the others are left standing. The use of seed-tree systems is restricted to a few isolated instances.

Good records of treatment costs and results in terms of regeneration are extremely beneficial, because they aid in planning future operations. However, a knowledge of the costs alone verifies the expenditures and nothing else. It may cost, for example, about twice as much to scarify and plant than to scarify and seed (Waldron 1973). Scarification costs alone can be somewhat less than one-third the total cost of scarification plus planting and somewhat more than one-half the total cost of scarification plus seeding (Richardson 1973). Moreover, the cost of burning can be about one-third or less the cost of scarification. In short, none of this shows how much really can be accomplished by manipulating the treatments according to the costs unless one has reliable data on the conditions of the resulting young stands some 10 years or more after the treatments. Unfortunately, very few data of this kind are currently available, and results of much shorter duration will have to be used in selecting treatment combinations.

Mechanical Scarification

In practice, scarification includes all degrees of mineral soil exposure, from very minimal to extreme. It is designated to improve the conditions for either planting or seeding. The exposure may be at random with considerable intermixing of organic materials, in parallel furrows, or in uniformly spaced scalps. Among the equipment currently used are: (1) diverse bulldozer blades, multiple disks, drums, and anchor chains for more or less random scarification; (2) plows, rippers, and disk trenchers for scarification in furrows; and (3) various spot cultivators for scarification in scalps (Cayford et al. 1967; Cayford and Bickstaff 1968; Hellum 1973; Richardson 1973; Rudolf 1973; Waldron 1973; Norman 1978). The use of anchor chains for simultaneous scarification and slash redistribution on jack pine sites soon after cutting usually results in good regeneration without additional treatments (Ball 1975). The seed in this instance is released from cones in slash by the heat of solar radiation.

Controlled Burning

The use of burning for silvicultural purposes is proving to be of considerable value. A controlled fire usually burns the slash, aerial parts of vegetation, surface moss and litter, and depending on site and weather, varying quantities of the underlying mor or peat. The organic materials remaining after the fire normally include charred stumps and other large pieces of wood, partially burned mor or peat and unburned plant roots in such mor or peat. These conditions are usually adequate for planting softwoods, and if the fire burns deep enough into the mor or peat, they can be favorable also for the reproduction of softwood by seeding. However, complete burning of the forest-floor materials is neither required nor desirable. The best fire-produced seed-

beds on moderately dry to moderately moist upland sites are in those situations where exposed mineral soil and thin residual mor alternate, and both have uniform areal distribution. Deeper mors and lowland peats, which normally occur on moist to very moist sites, become favorable seed-beds as soon as the fire burns off the loose, surface moss and litter. Means of selecting the proper conditions for burning the desired amounts of mor or peat are already available (Chrosciewicz 1959, 1967, 1968, 1974, 1976, 1978a, 1978b, 1978c).

Planting

Nearly all regeneration programs involve planting bare-root stock, and the most common practice is to plant by hand using the slit method (Cayford and Bickerstaff 1968). Poor tree survival in some of the older plantations is attributable to excessive plant competition and deficient site preparation. However, survival substantially improves when the planting follows mechanical scarification or plowing. The results are also generally better when the stock is planted early in spring instead of in the fall (Froning 1972). Planting the bare-root stock on controlled-burn sites normally leads to good tree survival and good rates of growth (Chrosciewicz 1978d). The common occurrence of "J-roots" (Van Eerden 1978) can be eliminated by proper positioning of the transplants when the slit method is used.

After years of experimentation with various container-grown stock, it appears now that the provision of vertical ribs within both the BC/CFS styroblocks and the Spencer-Lamaire root trainers (Carlson 1979) should solve the problem of major root deformities such as spiralling and kinking (Johnson and Walker 1976; Carlson and Nairn 1977). Both of these containers are used to produce "plugs" that are outplanted in the field without the containers.

Direct Seeding

This operation may involve spot seeding with special cultivators that automatically release a few seeds on each scarified scalp. It may be done as row seeding by using some other devices that space the seeds evenly along the plowed furrows. In addition, standard cyclone seeders may be used in some situations where postscarification broadcast seeding is the objective; this can be carried out by covering the ground on foot, by snowmobile, or by aircraft. Because the amount of seed sown and the season of seeding vary considerably from operation to operation and from species to species, the results are extremely erratic. Understocking seems to be the most frequent problem, although when a seeding operation is successful there may be a problem of overcrowding. Density adjustments, either by filling in the regeneration gaps or by thinning the overcrowding when it occurs, often are required following direct seeding (Hellum 1973; Richardson 1973; Rudolf 1973; Waldron 1973). Spring broadcast seeding on controlled-burn sites usually results in successful regeneration, in terms of both adequate stocking and rapid growth

(Chrosciewicz 1970, 1974, 1978d). Indications are that, with improvements in timing and application, direct seeding can become a very useful alternative to planting.

Seed-Tree Systems

Generally, very little work is being done using this method, although controlled burning under seed trees is usually highly successful in terms of forest regeneration (Chrosciewicz 1959, 1976, 1978d). The seed-tree method, however, is applicable primarily to the tree species such as jack pine, lodgepole pine, and to some degree black spruce that develop and store large quantities of seed in tightly closed cones. When fire burns underneath, the heat triggers cone opening and thus aids in seed dispersal. Other species such as white spruce, for example, do not possess this capacity but develop and freely disperse their seed at irregular intervals. This differentiation in both production and storage of seed must be considered when the use of seed-tree systems is contemplated.

FUTURE RESEARCH

In conclusion, this brief overview shows that there is a considerable body of knowledge in the field of forest regeneration, but it has to be better utilized for the site-specific needs that may arise. The time of intensive forest management is not too far away, and we must be prepared through research to take a meaningful part in its implementation.

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