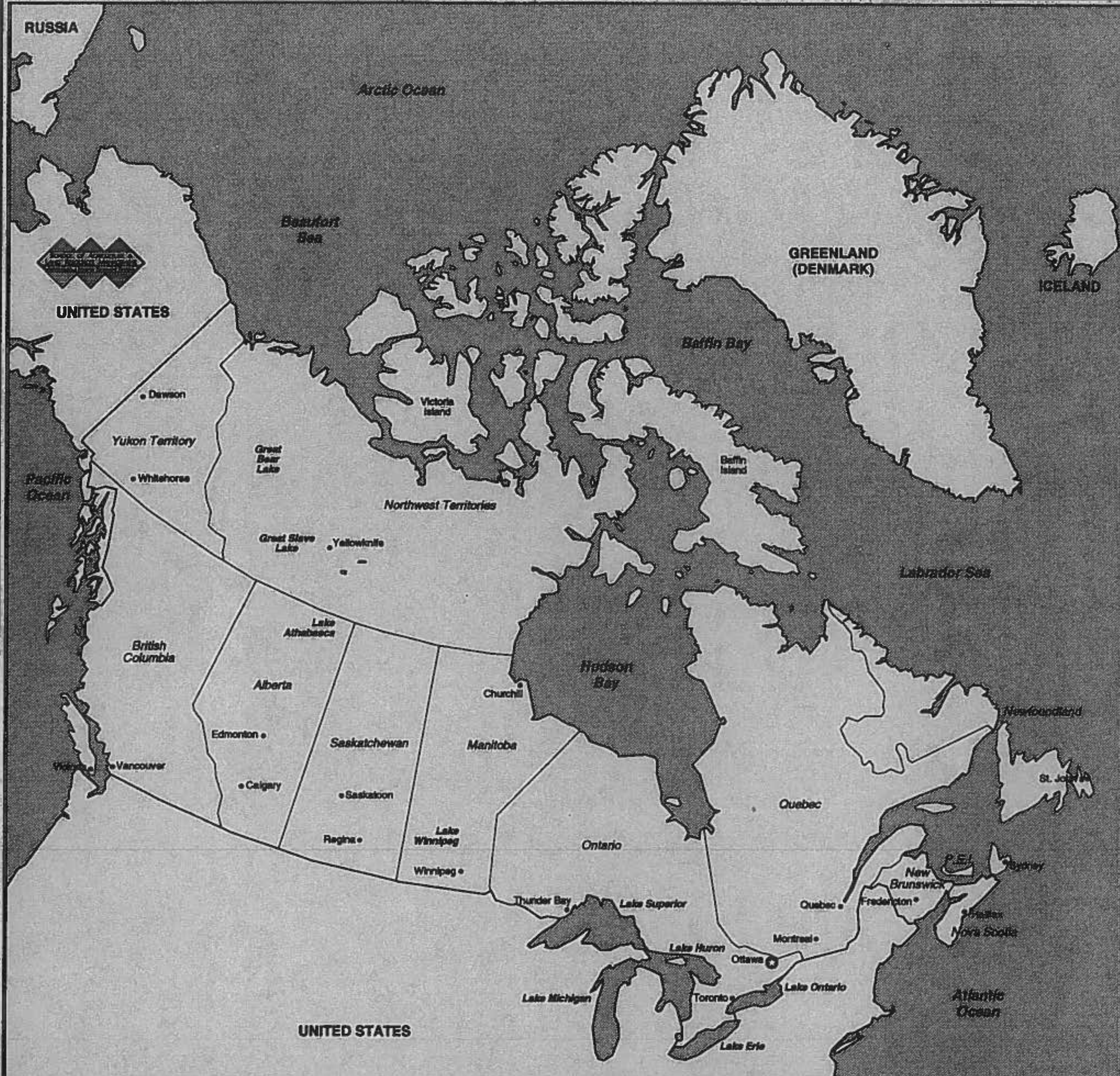

Developing Site Specific Forest Renewal Prescriptions and the Biology of Lodgepole Pine Towards its Northern Limit

School of Agriculture & Land Resources Management
Agricultural & Forestry Experiment Station

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Edmond C. Packee, Chairman IUFRO Working Party S1.05.12

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The proceedings contain papers presented at a workshop on developing site specific forest renewal prescriptions and the genetics of lodgepole pine. The papers reflect work being done in Canada, China, Finland, Sweden and the United States of America.

Keywords: forest renewal, site specific prescriptions, boreal forests, ecosystem classification, wildlife, provenance testing, lodgepole pine, mechanical site preparation, spruce forests.Opinions expressed are the authors' and do not necessarily reflect positions of the School of Agriculture and Land Resources Management, Agricultural and Forestry Experiment Station, University of Alaska Fairbanks.

Preface

This volume contains the proceedings from the Eighth Meeting of the IUFRO Working Party, S1.05-12, Northern Forest Silviculture and Management, held in Alberta and British Columbia, Canada, 22-26 August 1986.

The late summer weather of the Peace River country of western Alberta and eastern British Columbia provided a spectacular backdrop for the meeting. The Peace River country weather is unpredictable. We had, during the course of the meeting, the privilege of seeing this unpredictability: sunshine, rain, and snow; warm late summer days and brisk cool fall days. Fortunately, the weather was pleasant and mild when we were in the field. The vagaries of the weather did complement the symposium, however. Ecological processes and environmental factors were a theme running through the program, both in the symposium and in the field excursions. All too well, the weather reminded us how truly limited our capability is.

The symposium would not have been the success it was without the efforts of many individuals and organizations. Mr. Robert McMinn, Ph.D., deserves much credit! Bob was the reason why the meeting happened and was a success! He was the "Chief Push" or "Ramrod" who planned, organized, made things happen, and then edited the papers. Sponsors of the meeting included Canadian Forestry Service (Ottawa, Edmonton, and Victoria), Alberta Forest Service, British Columbia Forest Service, Proctor and Gamble Cellulose, Ltd. of Grand Prairie, and the School of Agriculture and Land Resources Management of the University of Alaska Fairbanks.

Initial funding for publication of this proceedings was thought to be secure for publishing through the University of Alaska Fairbanks in 1988. Such was not to be the case, however. The first serious budget cut with the associated loss of funds arrived and consistent budget cuts and associated losses of funding delayed printing since then. Because of the quality of the papers and the information, it was important to have the proceedings published. In April 1995, James V. Drew, Dean of the School of Agriculture and Land Resources Management of the University of Alaska Fairbanks and Director of the Alaska Agricultural and Forestry Experiment Station secured funds for a limited printing of this proceedings. I personally apologize to the many authors and supporters for the long delay.

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Contents

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Developing Site-Specific Forest Renewal Prescriptions: An Introduction to the Workshop

By: R.G. McMinn

When I was a graduate student in forest ecology nearly four decades ago, I thought that ecology and ecological classifications could be very useful for forest management. To be told by an influential forest manager that he would not know what to do with an ecological site classification of his management area even if given one, was, to say the least, deflating.

Even 15 years ago on a field trip near Prince George, I overheard a local forest officer say to another while the characteristics of a soil pit were being described "I hope that we do not have to learn that garbage."

I am pleased to say that times have changed. Ecosystem classifications and terminology have become one of the forest manager's working tools and part of his language. The forest manager of yesteryear was largely concerned with getting logs to the mill at the lowest cost. That is still important. But we now recognize that if "sustained yield" and "forest renewal" are to be more than easy terms to fool the public, we must know the ecological characteristics of our sites on a site specific basis. Hence the theme of this 8th Workshop of IUFRO Working Party S1.05.12 - "Developing Site-Specific Forest Renewal Prescriptions."

We are going to hear about the ecological classification systems developed in Alberta and British Columbia and how they are becoming a basis for site specific forest management practices. We are going to hear about site-adapted site preparation prescriptions and equipment. The era when we thought that one technique was good enough for all sites is over - or at least the search is on for site specific methods. We shall see on our Grande Prairie tour a wide range of sites and the way in which methods to obtain forest renewal are tailored to them. Near Dawson Creek, we shall see an investigation of techniques to rehabilitate the backlog - the legacy of ommissions of the past - when timber extraction not sustained yield forest management was the order of the day.

While our philosophy of forest management has changed from a careless "there is plenty more where that came from" to one at least approaching that of good stewardship - in the western world we are still not averse to the "Faustian Bargain." We may not think that we are selling our soul to the devil for present profit. But we may be nevertheless because of our philosophical approach to our landscape - to our life support system - the good earth.

Our world abounds with "Faustian Bargains." The most notorious of course is nuclear power, cheap power so that we can have anything we want. But what about the hidden - or not so hidden costs. Can we yet add up the cost of Chernobyl? The immediate cost in life was not inconsiderable but how long will affected lands be out of food production and when will we know the full cost of low level radiation in the food chain. We have not yet really experienced the cost of looking after atomic wastes for thousands of years and the cost if we cannot look after them. We have buried our chemical wastes only to find that the Love Canal and the St. Catherines River have become polluted in a relatively few years because our engineering knowledge of the good earth was inadequate.

Forestry is not without its "Faustian Bargains." Extending Norway spruce south of its native range seems to have brought about soil changes which meant that initial high profit growth rates could not be maintained. *Pinus radiata* in New Zealand seems very productive, but can the use of copper sprays to combat *Dothistroma* be maintained indefinitely - or will we have to settle for species that are more in tune with all elements of their environment. The tropical rain forests are known to be sensitive ecosystems. In the light of experience, can we expect to turn them into pine forests which will be high yielding indefintley.

I believe that our philosophical approach to forest management should embody at least two elements - firstly finding out how the natural system works and secondly being humble. Let us take as a basic precept that "a little knowledge is a dangerous thing" and that we cannot know all that there is to know. Our forests are too complex and the time element too long for us to conduct experiments which will give us all the answers. Is it not arrogant and dangerous to assume that we are going to manage our forests on the basis of hard facts alone? Experiments and trials that give us hard facts inevitably are simplified - over simplified - because even with computers we cannot conduct experiments which include all the relevant factors nor make observations over a long enough period to know the consequences of side effects or even what the main effect will be 50 years down the road. In the current political climate, 5 years is a long term experiment. But is it in the life of a forest landscape?

I recently read Masanobu Fukuoka's "One straw revolution." You would think that the traditional Japanese method of growing rice and winter grain follows sustained yield principles. Fukuoka, after careful observation, philosophical consideration and perceptive trials, concluded that it was not

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necessary to flood the field, laboriously transplant the rice seedlings, drop the water level before harvest, ridge the soil again for planting winter grain and all the time continue weeding scrupulously. His method is to sow rice, clover and winter grain in the fall and cover the seed with a heavy layer of rice straw. The rice seed remains dormant while the winter grain grows and is harvested. The grain straw is scattered on the fields. Water is then held in the field for a short time during the monsoon rains in June to weaken the clover and weeds and give the rice a chance to sprout through the ground cover. Once the field is drained, the clover recovers and spread beneath the growing rice to suppress weeds. The rice is harvested in October and after threshing, the rice straw is spread on the ground again. Rice blast is avoided because grain straw is the mulch while the rice is growing and visa versa.

Fukuoka relates an incident which is close to my heart because I too love to see things neat and tidy. The director of an experiment station came to see Mr. Fukuoka's farm with a view to emulating his methods. Later he called Mr. Fukuoka to the station because he thought that Mr. Fukuoka's method was a failure. The straw instead of being scattered in an untidy random way was neatly piled in rows and the rice seedlings had been smothered! Nature's way is not so orderly.

I bring Mr. Fukuoka's story to your attention because it is an example of observing nature's way and avoiding the heroic measures we take to reshape the forest in the way we think that it should grow. In the Peace country our treatment of aspen may not be appropriately sensitive. I am not trying to say that I have the answers. What I am suggesting is that we should continue our studies of nature's ways and retain a humble and sensitive attitude.

When we are tempted to "nuke" the weeds with herbicides or D9's, should we not remember the sorcerer's apprentice who unleashed a chain reaction that he could not control. When we think that we have the power to control northern forests to serve human needs better, it may be as well to remember that "power corrupts and absolute power corrupts absolutely."

Welcome to our workshop!

Boreal Forest Pre-harvest Silviculture Prescriptions: Problems, Issues and Solutions

By: G.F. Weetman

Abstract: An attempt is made to outline the biological, administrative and economic realities which influence the preparation of cutover regeneration prescriptions for virgin, boreal forests in Canada. Over mature public forests close to the economic margin, under a system of industrial licences, and often with unknown stand dynamics, present very difficult problems in preparation of feasible regeneration prescriptions. For rich white spruce and mixed wood types we currently lack biologically successful prescriptions except at great expense. The problems associated with these old forests will persist for several decades. Public and professional awareness of the problems has escalated recently, often triggered by reductions in allowable cuts and tightening of regulatory controls.

Introduction

During 30 years of travels to visit forests across all of Canada, much of the US and in several other countries, it became obvious to me that silvicultural decision making must be customized to local situations. However, it is often very difficult to understand why particular decisions are made. This is notably true in contrasting Canadian and Scandinavian boreal silviculture. Canadians visiting Scandinavia rationalize the impressive and stimulating intensity of Swedish silviculture, for example, on grounds of better access, higher values of stumpage, shortages of timber, a long tradition of growing timber, good foresters and long experience with the forest.

This process of mentally sorting out the measures for doing silviculture is an important one for delegates at international meetings. The reasons are often quite separate from biology. Unless it is done properly many false impressions can be left and worse, silvicultural techniques and equipment can be thoughtlessly imported, quite out of context, and often with disastrous results.

Canadian boreal forests are dominated by vast areas of old forests. Fire, insect and disease losses often make silviculture investments very risky. There has been little funding for silviculture when net stumpage returns are small near the economic margin. There is often difficult and expensive access and often youthful and inexperienced staff. Boreal silviculture often appears to be rough and ready. Many visitors regard this silviculture as a pure exploitive stage of management; with the error of our ways being more obvious to the perceptive visitor.

It should be pointed out, however, that Canadians have over 60 years of experience in cutting boreal forests and observing what happens. Some of the actions are taken very consciously with a good understanding of cutover dynamics.

Is it possible to have a good silviculture prescription while being at the economic margin? It worries our decision makers since we want the 'best' we can afford under our operating circumstances.

Since most of the boreal forests are leased, what sort of regeneration performance can the provinces expect of industry? Some administrative steps have been taken.

A distinction is made between obligatory basic silviculture, i.e. the silviculture required to regenerate cutovers with "free growing" seedlings to produce stand yields as good as the virgin forest stand and optional intensive silviculture i.e. tending practices to achieve improved stand yields. There is increasingly a requirement for approved silviculture prescriptions before cutting permits are issued. In BC, there has been the recent establishment of the Silviculture Institute of BC which provides 5 graduate level, 2-3 week teaching modules of silviculture for foresters with 5 years of experience.

It is clear that we have failed to achieve basic silviculture on large areas of boreal white spruce, and spruce/mixed wood sites. The current cry is "better prescriptions to achieve basic." We worry that we waste silviculture dollars because our inexperienced staff cannot prepare and implement successful silviculture prescriptions. How does one write and implement a feasible boreal forest silviculture prescription?

A schematic for setting stand management objectives and for preparation of silvicultural prescriptions is given in Figure 1.

A. Perspective: An examination of the circumstances and history which surround boreal forest logging give some perspective on prescriptions.

1. Early studies of boreal silviculture were characterized by a search for modified horse logging systems, which at little or no extra cost would produce adequate natural regeneration, i.e. enough to satisfy the licensee requirements for minimal regeneration performance. This search has been largely unsuccessful. We now recognize the need for extra costs and careful prescriptions for most forest types. The demands of logging mechanization and tightened regeneration regulations usually require that some silvicultural treatment be performed.

2. There has been a traditional separation of the logging and silviculture operations in the forest. The logging contractor tends to use the lowest cost system, largely without regard to silviculture problems. The silviculturist then

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has to take the cutovers as he finds them and try to meet regeneration performance regulations. We now recognize that this arrangement creates unnecessary problems. Modification of harvesting practices, which involves higher delivered wood costs, is difficult to implement.

3. There is a requirement for all operations in virgin forests to pay for the new road system. Large cut blocks are usually required. There are very few subsidies. This situation is unlikely to change.

4. Stands which are cut are Over mature, virgin, contain much dead timber, are often dying and under a 'salvage' type of logging, the edges are not wind firm, may contain non-commercial species (e.g. aspen) and a large proportion of stems too small to harvest; and many stands have advanced growth, often of marginal or questionable density, distribution or vigor. This situation will continue for several decades.

5. Only recently have the ecologists identified most of the specific forest associations in the boreal forest and characterized them by plant cover and nutrient and moisture regime. The successional trends following clear cutting on these sites are largely undocumented. It is clear that the fires, blow down\ and beetle kill as historic agencies of forest renewal are usually not the paradigm for predicting regeneration development following logging. Seedbed, seed supply, slash conditions, shade, and vegetative competition all tend to be different following logging. These circumstances put most foresters in a "discovery mode" in trying to explain and predict regeneration performance in types of forest in which we have little operating experience.

6. The forests are provincially owned and divided into very large management units, usually dominated by Over mature timber. The managerial objective is to remove old timber before it is lost to natural agencies and to do it in space and time in such a way that second growth timber will be "operable" by the time the virgin timber is removed (Baskerville 1982, Weetman 1982). The lack of successful regeneration on areas cut in the last 40 years is now undermining this managerial objective; to adjust to the new wood supply situation allowable annual cuts have been reduced.

7. The combined problems of a) protecting old stands until they can be harvested, b) lack of successful natural regeneration, and c) loss of plantations due to brush invasion, have received much recent attention and discussion. A big "push" is on for more herbicide use, better fire and insect protection, more planting, and putting failed cutover lands (backlog) into production. Pre-harvest silviculture prescriptions are now seen as a logical way to improve regeneration performance. They are now required in some provinces, e.g. B.C. Advanced silviculture education modules are being set up for experienced foresters.

8. Cutover regeneration performance standards have been tightened and cutovers now must have an acceptable number and distribution of "free growing" seedlings of commercial species before the cutover area is put back into inventory, assigned a probable yield performance rating and starts to contribute to allowable cut.

Licensees who accumulate backlog can thus suffer allowable cut reductions, while Licensees who can demonstrate cutover yield performance in excess of historic natural yields are in a position to request increases in allowable cuts. Regulatory provisions allow for both conditions.

9. Most provinces are cutting in management units at close to, or over, allowable cut levels (except in Alberta). The areas involved are very large; close to 750,000 ha are cut each year in Canada. The problems are great, e.g. the Prince George Timber Supply Area is about the size of France and is being cut at the rate of 40,000 ha per year and has over 600,000 ha of backlog; current regeneration and plantation performance has a lot of problems.

10. Some northern boreal forest areas, usually in black spruce, are at the economic margin. The decision required is whether to cut the forest at all or let it be destroyed by natural agencies. Consciously or inadvertently the decision to cut has been followed by the decision to allow only natural regeneration, largely unassisted by man. The long natural regeneration periods and probable poorer yields of cutover stands are adjusted for by lower allowable cuts. With rotations in the 100 to 120 year range, we still have only 1/4 to 1/3 rotation operational feedback in these situations; second growth yields are uncertain. Under these circumstances it is considered by some economists to be more cost effective to spend limited silviculture funds further south. Further expansion of industrial forestry in far northern Canadian forests seems unlikely; the trend is to spend money to grow wood in more productive southern locations by silviculture.

11. Some of the forest types have been relatively easy to deal with, others are very intractable. The easier types are jack and lodge pole pine, balsam fir, lowland black spruce and the pure birch and poplar types. We have a lot of experience with them and had symposia and have good documentation on them. Much more difficult are some of the upland black spruce types. The most frustrating are the rich sites with white spruce mixed woods (i.e. apsen/white spruce/white birch) and the pure white spruce types in western Canada. These latter two types represent a very large portion of our failed cutovers, or cutovers converted from conifers to poplar, birch or even willow and grass. At high elevation in the western mountains the extensive and valuable Engelmann spruce/subalpine fir (ESSF) type is also proving to be very 'intractable,' although our operating experience is only about 25 years old.

12. There has rarely been enough money to pay for the required regeneration work. The stumpage or royalty revenue from boreal forests is usually relatively low, $200,800/ha, while regeneration costs are often this much. The silviculture is often quite "risky" and protection costs

for mature timber are often high. Until recently there have been few national subsidies for boreal silviculture. The areas are often remote and with rapid turnover of youthful staff; "feedback" from mistakes and successes has been patchy. Attempts are being made to rectify the situation. Much more attention is being given to cutover and plantation performance assessments. Local workshops and study tours to examine cutovers are a summer fixture for most workers in the field. There are still large boreal forest license areas, particularly in Quebec, which after 50 years of operation still do not have much 'on the ground' silviculture.

13. The literature tools: The ecologists are now providing site specific recommendations for choice of tree species and silviculture actions based on observation. These are largely unproven, but now provide the basis for much prescription preparation. Regional or biogeoclimatic zone handbooks and studies which allow for site recognition and silviculture recommendations are common (Gerardin and Ducrue 1982, Jones et al. 1983, Meidinger et al. 1984). The 'booklets' are combined with official government manuals of procedures for carrying out silviculture operation, administering controls, conduct of surveys. Singularly lacking are forest type or species working group silviculture guides. Ontario and Quebec do have some based on more decades of experience than is available in western Canada. The U.S. Forest Service revised silvics manual is due soon and we now have a review of the autecology of important brush species (Haeussler and Coates 1986).

14. The role of industry in developing information and guidance in prescription writing has not been strong on a national basis, but there are notable exceptions. The industry operates on the ground and often has great local expertise and shows great innovation. However, there is very little industrial forest management research and there are very few industrial manuals or guide books about operational silviculture. In Alberta the industry has full managerial and cost responsibility and has been a leader. The new forest management agreements in other Provinces are causing a change.

15. The scale of silviculture work has expanded greatly. There is now a large silviculture contracting industry with its own organization and lobby groups. Successful performance of silviculture prescriptions requires the cooperation of the contractors. 'Stewardship' and 'area' based, site preparation, planting and tending contracts are favored, i.e., the contractor is required to accept more responsibility for reaching free growing status. The trend to more contractor expertise and responsibility will continue.

16. High unemployment rates have led to the large scale use of silviculture funds for job creation. This has tended to concentrate work in accessible areas and favour silviculture prescriptions which can make use of untrained labour, e.g. pre-commercial thinnings. Funding is less readily available for prescriptions which require specialized site preparation equipment or work in remote areas. 'Job creation' by silviculture is now being 'pushed' by municipalities with high unemployment rates - a new development in the formally affluent western Canada, but an old feature of Maritime and Quebec silviculture. This trend will continue.

Prescription Preparation and Implementation

There is generally good cooperation between the licensee and the government, both parties have a convergent interest to secure adequate cut-over regeneration. The simplest approach is to allow unrestrained logging, and then site preparation and planting, this is the loggers' favored approach and has a long successful tradition on low elevation coastal forests in B.C. For many boreal forests this clearly is not feasible although it is being tried on a large scale in white spruce stands in northern B.C. Scheduling of work, availability of site preparation equipment, modification of cut layout and extra logging costs are all clearly more difficult when there are different agencies or contractors doing logging and silviculture. The Alberta experience suggests that full industrial licensee responsibility for both functions works well.

The B.C. experience with a stumpage appraisal system that omits silviculture followed by a credit to stumpage payment system, which requires approval of applications and inspections before payments, has been proven to be very bureaucratic and difficult to operate.

There is a high level of frustration over our 'intractable' rich boreal forest types - white spruce and mixed wood. Feasible biological solutions for site preparation, natural regeneration and planting are difficult to develop. There have been some unrealistic expectations regarding growth rates and speed of natural regeneration in our northern forest types.

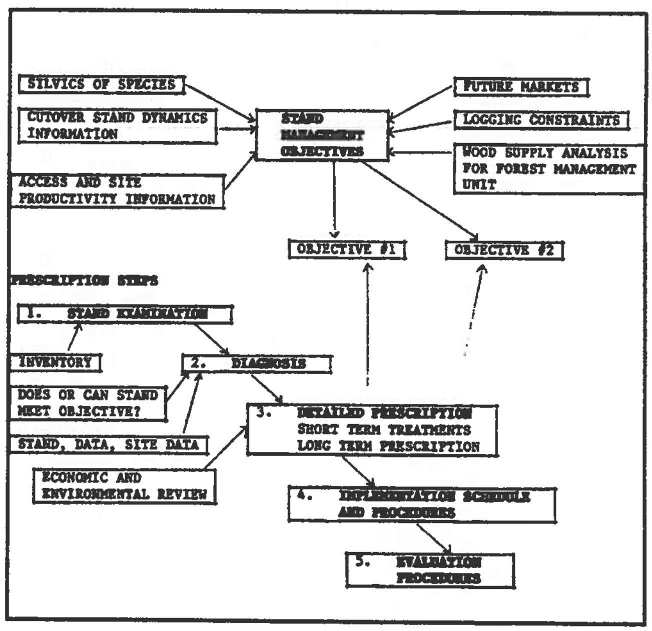

Figure 1.—Schematic for setting management objectives and for the preparation of silvicultural prescriptions to meet objectives.

We may be forced to accept long regeneration periods and rotations and be resigned to growing and using aspen. 'Forcing' white spruce plantations onto rich boreal sites at great cost and with the use of herbicides may not be the most economic option. In a tight economic environment with pressure for job creation close to towns, the pressure is on the silviculturist to modify his biological prescriptions with some economic and social realities.

Prescriptions which call for very expensive silvicultural regeneration treatments or subsequent density control operations are unlikely to be implemented. The emphasis is on identifying the minimal silviculture prescription which ensures a cutover yield as good as the original stand. In some cases this is quite feasible; in others little or no intervention is necessary provided the management objectives for second growth stands are not very demanding.

With so much unknown about the stand management objectives, successional trends, stand dynamics and stand yields, the task of the boreal forest cutover prescription preparation will continue to be very difficult. Our progress in recent years has been to create workable site classifications into which we can organize our findings and prescriptions.

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Wildlife Goals and Opportunities in Prescription Development

By: Terje Vold and Fred Harper

Abstract: Wildlife must be considered a desired forest product, not just a constraint on forest renewal prescriptions. Wildlife management objectives, consequently, must be integrated with fiber production objectives. Ways in which forest renewal activities can be compatible with wildlife management needs are discussed.

Introduction

First of all, we would like to thank the workshop chairman for providing an opportunity to explain why wildlife should be a major consideration in forest renewal prescriptions. Since so much of habitat for wildlife is found in British Columbia on crown forest land, what foresters and silviculturists do has an immediate and direct effect on wildlife, for better or for worse. Consequently, wildlife managers have a keen interest and stake in forest renewal prescriptions.

We should point out that forestry and wildlife management have much in common. We both manage renewable resources using basic ecological principles. Although we have our differences of opinion, we speak a common language as the forest ecosystems that you manage represent the habitats for wildlife that we manage.

Importance of wildlife

It is important to stress that wildlife is a one billion dollar industry in British Columbia, generating more than 123 million dollars to the government treasury through taxes and other revenue sources. A total of about 19,000 person-years of employment are supported each year from wildlife-related activities. These jobs and the resulting income are distributed throughout the province, and are particularly important to the local economy of many northern B.C. communities.

British Columbia has the greatest number and diversity of wildlife species in Canada, residents of B.C. Have the highest rates of participation in wildlife-related activities of all of the provinces. Almost 1.5 million residents, or 75% of the adult population, participate each year in wildlife-related activities.

The mandate of the wildlife program is to ensure that under the provision of the wildlife act, British Columbia's wildlife resource and its habitat are provided in sufficient abundance for both the immediate and future benefits of the people of this province. As wildlife is a crown resource, the wildlife program must allocate its use among different sectors of the public, whether the use is hunting, viewing, or simply knowing that wildlife exists.

Integration of wildlife and forestry

Section 4(c) of the ministry of forests act requires that the objectives of all forest resources, including wildlife, be integrated and coordinated. To accomplish this, wildlife resources must be considered as a desired product of forest management, including forest renewal prescriptions and not as a constraint. Wildlife objectives or concerns are too often either thought of as a constraint to stand regeneration or not considered at all. Each forest management decision has a set of consequences for wildlife and wildlife should be an intentional product of any well-managed forest.

It is essential that silviculturists view the integration of efforts to improve wood fibre with efforts to improve wildlife as a major and important responsibility.

Forest renewal in perspective

There are many options open to silviculturists to maximize wood fibre and other forest resources, including wildlife. For example, limited funds can be directed to backlog reforestation or to stand tending activities. The current $300 million five–year Canada-British Columbia forest resource development agreement (FRDA) allocates nearly $200 million for backlog reforestation and less than $80 million to stand tending activities such as spacing, thinning and fertilization.

Major funding agreements like FRDA set the initial direction for what is done on particular sites. From our perspective, we would prefer to see more emphasis on stand tending activities such as spacing and fertilization which can also increase forage for wildlife, than on backlog reforestation activities, such as site rehabilitation or brushing and weeding, that may reduce wildlife forage.

It is interesting to note a recent benefit/cost analysis (Fraser 1985) for forestry investments (looking only at wood fibre production) concluded that spacing/fertilization is the superior investment with net benefits consistently exceeding backlog reforestation activities.

Forest renewal activities

There are a number of activities associated with forest renewal that we would like to specifically address, including

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surveys and prescriptions, site preparation, planting, vegetation management including brushing and weeding, and monitoring.

Surveys and Prescriptions

Surveys provide basic site-specific information that enables a silviculturist to prepare prescriptions for specific forest renewal activities. These surveys should collect relevant related information of importance to wildlife so that wildlife can be considered when preparing prescriptions. Surveys should include information on the main wildlife forage species present, their abundance, and, if possible, the extent to which they are used by wildlife. This information is vital to wildlife managers when commenting on forest renewal projects, particularly brushing and weeding activities.

In most cases, there is simply not the manpower to cover the same ground twice. Therefore surveys must collect sufficient related information for wildlife.

SITE PREPARATION. Site preparation techniques can include the cutting of all standing vegetation, the removal of vegetation and exposure of mineral soil through the use of heavy machinery, the burning of residual vegetation and slash, and the application of herbicides. The long-term effects on developing plant communities will differ substantially depending on what technique or combination of techniques are employed. For example, the use of herbicides tends to reduce the sprouting species in favor of herb-dominant communities. Fire variously stimulates seed germination. The desired mix of crop tree species and wildlife forage species will be strongly influenced by site preparation techniques. The desired state of the wildlife forage resource should be a conscious consideration when deciding on the techniques to be used. With a little luck, or a lot of management skill, wildlife can be encouraged in some instances to forage on competing vegetation thereby promoting the growth and survival of the crop species.

Planting

One of the major goals of the wildlife program is to provide for habitat diversity. The planting of a single crop species may not provide for this goal, particularly if done over large areas. From a wildlife habitat diversity perspective, it would be better if a mix of species were planted.

Vegetation Management

Forest vegetation management has been defined as the implementation of techniques to redirect site resources to favor the survival, growth and development of desired vegetation species, while meeting environmental concerns. Vegetation management is used in site preparation, brushing and weeding and conifer release.

One of the major tools used in brushing and weeding activities is forest herbicides. Although herbicides can be useful in controlling competing vegetation, of great concern to a wildlife manager, is the effect on important forage species. There are a number of ways forest herbicide use can be modified to accommodate wildlife concerns.

First, if the site considered for treatment has important wildlife forage values, does it have to be treated at all. This may be a concern on ungulate winter ranges, particularly since our knowledge of the effect of herbicides on wildlife habitat has not been documented in B.C. Since funding for vegetation management is limited, given the number of areas that foresters feel would benefit from this activity, there should be alternative areas to treat under these circumstances.

Second, the dosage of active ingredient used in treating a site can be reduced to accommodate some forage impact concerns. Too often the tendency is to use the maximum dosage or rate registered for use, in order to maximize impacts on competing vegetation, when in fact, a lower dosage will do the job and reduce impacts on wildlife forage species.

White spruce seedlings may photosynthesis to 80% capacity under 50% shade (draper pers. comm.). Greater reduction of competing vegetation to provide higher light intensities, consequently, may provide only marginal gains in seedling growth. Too much light can in fact reduce white spruce seedling performance.

Third, if possible, apply herbicides by spot application to target species only, leaving key wildlife forage species.

Fourth, allowance for an untreated buffer that surrounds a broadcast herbicide treated area and is adjacent to forest cover can provide for most wildlife needs in many circumstances. Forest edges that provide both cover and forage are important to wildlife. Ungulates prefer forage areas that are a certain distance to cover; beyond that distance, forage use tends to decline. Thus, the provision of an untreated buffer which allows for most forage needs adjacent to cover will generally be beneficial to wildlife while still allowing for a treated core area that provides for improved seedling growth.

There are, no doubt, many other techniques that can be considered when applying forest herbicides that minimizes impacts on wildlife. Obviously the type of herbicide used, and the time of spray will both have pronounced affects on wildlife forage. These techniques all need to be explored more fully so that forage needs are intentionally considered and prescribed for in important wildlife areas.

MONITORING. Monitoring of forest renewal activities is needed to determine their effectiveness, and both the immediate and longer-term impacts on wildlife. There is concern that the impacts of herbicides in boreal and subboreal forests, for example, may be more long-term than in coastal forests. Forest vegetation may simply not recover as quickly in colder climates and thus the duration can be longer. Silviculturists need to monitor their forest renewal projects, assess impacts on the forage resource base, and provide this information to wildlife managers so that future decisions and prescriptions are more intelligently made.

Conclusion

The reason there is more concern about the integration of wildlife with forest renewal activities is in large part because of the dramatic increase in these activities in B.C. According to the recent ministry of forests (1986), forest and range resource program, the silviculture program will be receiving $700 million over the next five years. In addition to this, through FRDA and the new forest stand management fund, an additional $500 million could be available for silvicultural activities such as forest renewal. In total this represents $1.2 billion for silviculture in the next five years.

As mentioned, wildlife is currently a one billion dollar industry, and by all accounts, growing rapidly. In light of these two trends, rapid growth in forest renewal activities and in the value of wildlife, it is more important than ever for wildlife to be considered a desired goal or product of forest renewal programs.

To accomplish this, silviculturists need to consider wildlife at the outset when preparing forest renewal prescriptions. Those treatments that benefit wildlife should be encouraged, whenever possible, over those treatments that reduce wildlife forage resources. Silviculturists and wildlife managers need to work together to develop projects in areas where either mutual benefits can be gained, or where impacts on wildlife are considered minimal.

There is a lot we do not know about the effects of forest renewal activities, such as the use of herbicides, on wildlife forage species. The increased funding for silviculture must allow for research and monitoring of wildlife habitat effects, particularly longer-term effects, of various treatments on particular ecosystems. We must learn from our present endeavors to do a better job in the future for both wildlife and forestry.

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Biogeoclimatic Classification and its Application in the Boreal Forest Regions of British Columbia

By: D. Meidinger, J. Pojar, C. DeLong and A.J. McLeod

Abstract: The British Columbia Forest Service ecological classification system, developed over the past 10 years, is described. The classification is used as a framework for developing management interpretations. Increased ecological awareness among practicing foresters and improved forest management practices have resulted.

Introduction

The Forest Service of the British Columbia Ministry of Forests and Lands has been developing and applying an ecosystem classification system for the past 10 years and has been using the classification as a framework for developing management interpretations. The classification system, termed Biogeoclimatic Ecosystem Classification (BEC), was originally developed by V.J. Krajina and his students at the University of British Columbia (see Krajina 1959 et al.) but has since been modified and applied province-wide by the Forest Service.

Ecosystem studies have been carried out in most operational areas of the province and ecosystem classification and interpretation guides are available in draft or published form for almost all of these areas. The boreal forest region of B.C. is no exception, and the application of the BEC system in the boreal will be outlined after a brief description of the classification system.

Biogeoclimatic ecosystem classification

Approach

The Biogeoclimatic Ecosystem Classification (BEC) System has recently been described by Pojar et al. (1986) and this summary is based on their review. BEC is a unique system with roots in the Russian (e.g., Sukachev) and southern European (e.g. Braun-Blanquet) traditions of phytosociology (see Whittaker [1980] and Jahn [1982]); it has also been influenced by northern European (e.g. Cajander), British, and American (e.g. Daubenmire) traditions.

The key premises underlying the BEC are:

(1) ecosystems are recognizable in nature;

(2) ecosystems are fundamental units in ecology and resource management;

(3) ecosystems undergo succession, which may culminate in climax;

(4) vegetation is the best expression of the combined influence of the physical environment (site), biotic community (organisms), and past events (time);

(5) ecosystems are best organized by a multifactorial and hierarchical classification; and,

(6) ecosystem classification involves a combination of mathematical objectivity and subjective, professional judgement.

A terrestrial ecosystem is composed of vegetation, animal populations, micro-organisms, and their physical environment. For practical purposes, an ecosystem is characterized as a 'plant community' (a volume of relatively uniform vegetation) and the 'soil polypedon' (a volume of relatively uniform soil) upon which the plant community occurs.

Climate is one of the most important determinants of the nature of terrestrial ecosystems. By this, we mean regional climate. A delineation of regional climates is useful for understanding the relationships between ecosystems and for presenting the classification of ecosystems. However, you cannot usually delineate areas of uniform regional climate by the use of climate data alone due to a lack of data and a lack of knowledge of how to integrate climatic factors to form ecologically or naturally meaningful classes. Therefore, we use the concept of the zonal ecosystem.

Zonal ecosystems are those ecosystems that best reflect the regional climate of an area. Zonal ecosystems are equivalent to climatic climax ecosystems, i.e., climax ecosystems on zonal sites. A zonal site neither sheds nor receives an excess of water or nutrients; and, it is neither too nutrient rich or poor. The predominant input of energy and materials is from the atmosphere, with insignificant input from other ecosystems. Morphologically, zonal sites *usually* have the following characteristics:

(1) middle slope position on the meso-slope in mountainous terrain (meso-slope is the slope segment that directly affects site water movement); upper slope position in subdued terrain;

(2) slope position, gradient, aspect, and location that does not result in a strong modification of climate (e.g., frost

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pocket, snow drift area, steep north or south aspect);

(3) gentle to moderate (5 to 30 percent) slope; in dry or cold climates, on slopes to less than 5 percent; in wet climates, on slopes up to 50 percent;

(4) soils that have (a) a moderately deep to deep (50-100+ cm) rooting zone, (b) no restricting horizon within the rooting zone, (c) loamy texture with coarse fragment content less than 50 percent by volume, and (d) free drainage.

Zonal sites are the reference sites used to delineate regional climates. This is explained further in the next section describing the structure of the BEC system.

Zonal ecosystems are intermediate in moisture and nutrient regimes. On an edatopic grid (Figure 1), they are considered mesic in moisture regime and medium in nutrient regime (4-C). All other sites within a regional climate are considered to be dryer or wetter or nutrient richer or poorer. Soil moisture regime is a scale of soil water annually available for evapotranspiration by vascular plants over an extended period of time. It is usually applied qualitatively within a particular regional climate and is then termed potential soil moisture regime (Pojar et al. 1986).

Soil nutrient regime is the amount of essential soil nutrients that are available to vascular plants over a period of several years. A subjective synthesis of various site and soil properties (see Walmsley et al., 1980) is used to determine the soil moisture and nutrient regime classes shown on the edatopic grid.

Structure

The structure of BEC is shown in Figure 2. Three classifications are integrated in the BEC system to show relationships among ecosystems in form, space, and time, or in three levels of integration+the local, regional, and chronological levels. A local level of integration results in the organization of ecosystems according to similarities in composition and structure of their vegetation and sites by using vegetation and site classifications to produce vegetation and site units. A regional level of integration results in the organization of ecosystems according to similarities in their distribution in a vegetation-inferred, climatic space. This is done by a zonal (climatic) classification producing biogeoclimatic units. The purpose of a chronological level is to organize ecosystems into site-specific chronosequences by arranging the vegetation units recognized for a given site unit according to disturbance, treatment, and successional status.

The vegetation classification follows the Braun-for the Prince George Forest Region (McLeod and Meidinger 1985). The site or ecosystem units are presented for each biogeoclimatic unit in a field guide format (Lewis et al. 1986) using a variety of techniques.

If, for example, the site in question was in the BWBSd or Moist Cold Southern Boreal White and Black Spruce biogeoclimatic subzone, the site units are presented (Jang et al. 1985) using an edatopic grid (Figure 3), a toposequence diagram (Figure 4), and an ecosystem key (Figure 5). After determining the unit, the user can scan the site descriptions (Figure 6) to check the classification and then decide on a prescription using the management interpretation table (Fig-

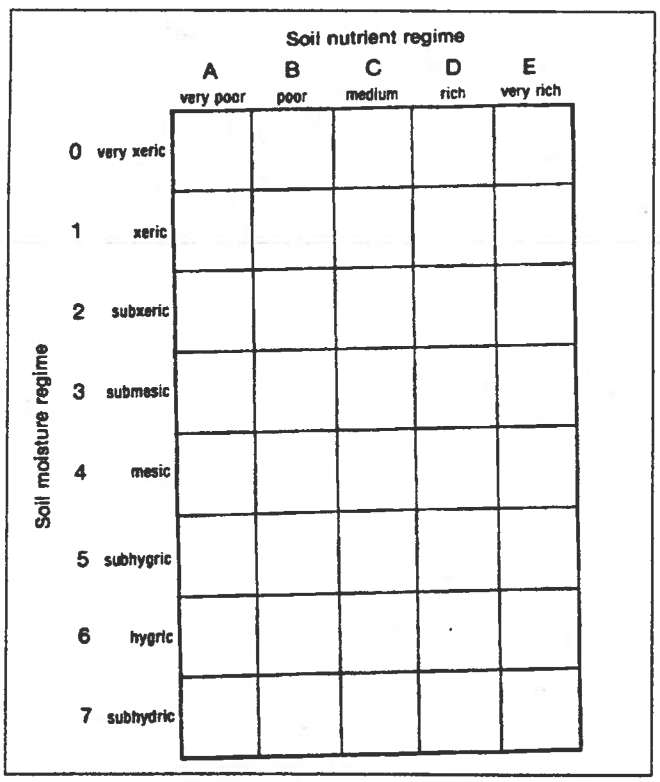

Figure 1.—Edatopic grid.

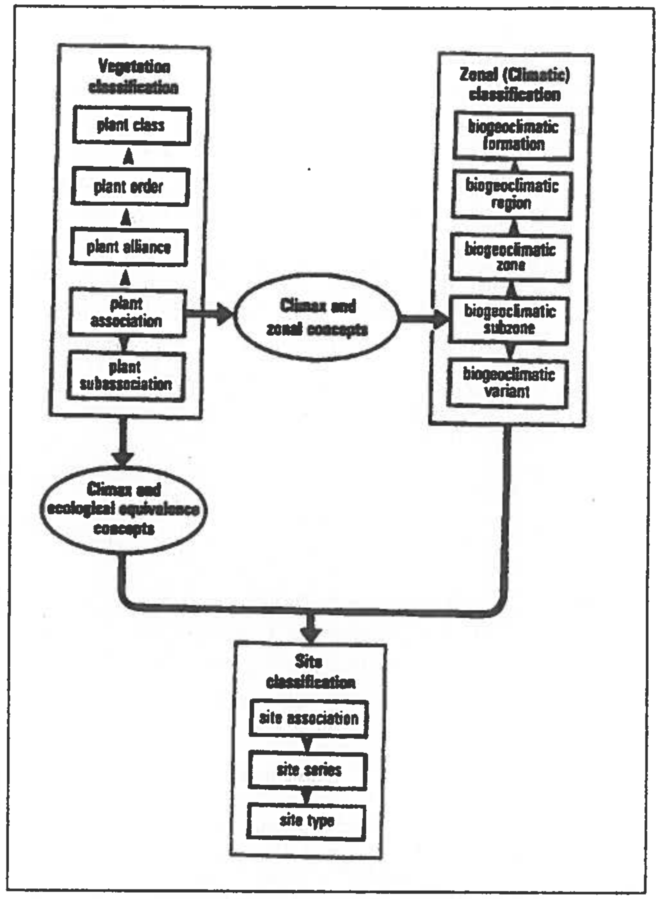

Figure 2.—Categories and relationships of the three classifications integrated in the biogeoclimatic ecosystem classification.

ure 7). Management interpretations are presented on an ecosystem unit-specific basis.

The boreal region of British Columbia (Canadian Boreal Forest Biogeoclimatic Region) includes two biogeoclimatic zones+the Sub-Boreal Spruce Zone (Meidinger and Pojar 1983) and the Boreal White and Black Spruce Zone (Annas 1983). Field guides are presently available for three-quarters of the biogeoclimatic subzones in the boreal region and are in preparation for the others. The field guides and maps are widely used by government, industry and consulting foresters as aids in the development of management prescriptions. The biogeoclimatic units have been used as a framework for developing tree species and tree cover specific flowcharts for development after wildfires in the north, (Parminter 1983a, b, 1984) and for developing seed orchard and seed zone boundaries throughout the province.

The development and application of the ecosystem classification program over the past 10 years has resulted in an increased ecological awareness among practicing foresters and in improved forest management practices. Recognition of the site or ecosystem units as the fundamental units of forest management is an important step in ensuring that "good" forestry is practiced in B.C.

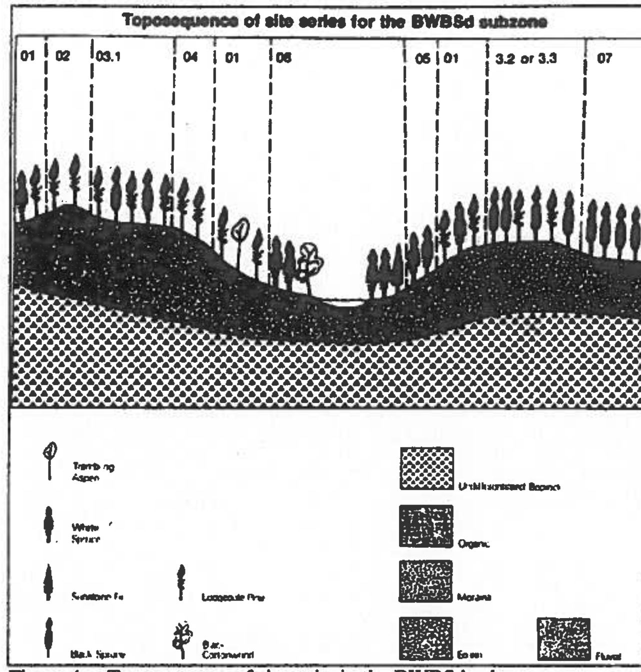

Figure 4.—Toposequence of site units in the BWBSd subzone.

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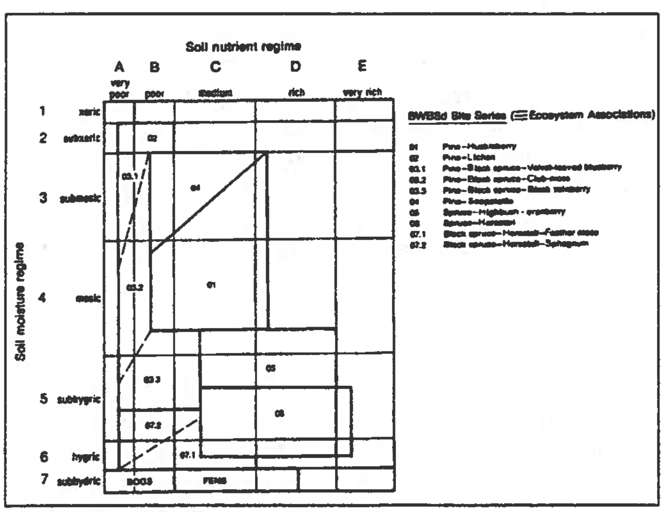

Figure 3.—Edatopic grid of soil moisture and nutrient regimes for site units in the BWBSd subzone.

SIMPLIFIED KEY TO ECOSYSTEM UNITS OF BWBSd

1a. Canopy dominated by black spruce alone: toe of slope or depression
- 2a. Usually organic soils: moss layer dominated by *Sphagnum* spp. — BWBSd/07.2
- 2b. Usually mineral soils; moss layer dominated by feather mosses — BWBSd/07.1

1b. Black spruce, if present in canopy, with lodgepole pine: upper to lower slope or depression
- 3a. White spruce in canopy
  - 4a. Mid to upper slope: *Lonicera involucrata* and *Ribes lacustre* rare or absent — BWBSd/01
  - 4b. Mid to lower slope or depression: *Lonicera involucrata* and *Ribes lacustre* common and often abundant
    - 5a. *Viburnum edule* and *Pleurozium schreberi* abundant, *Equisetum* spp. low cover (<5%) or absent — BWBSd/05
    - 5b. *Viburnum edule* and *Pleurozium schreberi* rare or absent, *Equisetum* spp. high cover (>20%) — BWBSd/06
- 3b. White spruce absent from canopy, canopy dominated by lodgepole pine or lodgepole pine - black spruce
  - 6a. Tree canopy sparse (<20% cover); lichens main ground cover — BWBSd/02
  - 6b. Tree canopy well-developed (>30% cover); lichens low cover

Figure 5.—Portion of key to site units in the BWBSd subzone.

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SITE DESCRIPTION

BWBSd | 01

PINE - HUCKLEBERRY

DESCRIPTION

VEGETATION

Forest Cover Types:
P1S, P1(S), S(P1)

Tree Layer: 50% cover
Lodgepole pine, white spruce

Shrub Layer: 60% cover
Alnus viridis ssp. *sinuata, Vaccinium membranaceum, Rosa acicularis, Spiraea betulifolia*, subalpine fir

Herb Layer: 35% cover
Cornus canadensis, Epilobium angustifolium, Linnaea borealis, Arnica cordifolia, Rubus pubescens, Pyrola asarifolia, Petasites palmatus, Lycopodium annotinum, Calamagrostis canadensis, Orthilia secunda

Moss Layer: 60% cover
Pleurozium schreberi, (Ptilium crista-castrensis)

SOIL AND SITE
Moisture Regime: submesic - mesic
Nutrient Regime: poor - medium
Slope Gradient (%): 0-67, usually less than 20
Slope Position: upper - mid
Parent Material: morainal, (glacio) fluvial
Soil Texture: variable
Coarse Fragments (%): 0-35

DISTRIBUTION: common

Figure 6.—Site description for BWBSd site series.

BWBSd/01

SILVICULTURE INTERPRETATIONS

								Regeneration Options							Stand Tending	
								Natural		Artificial						
Logging Method	Brush Hazard	Other Constraints	Site Preparation	Species Select.	Regen. Delay	Time to Free Growing	% Canopy Removed	Species	Seeding /ha	Species	Shoot/ Root Ratio	Caliper (mm)	Height (cm)	Seedling /ha	Time of Thinning	Stems/ha after Thinning
clear-cut	mod.	- possible alder problem - moderate grass competition	- drag scarify	Pl Sw	6 5	9 7	Pl	Pl	1200	Pl Sw	.9/1 2/1	3 5.5	10 18	1200 1100		

TIMBER INTERPRETATIONS

Logging Method	% Slope	Seasonal Constraints	Recommended Harvesting System
clearcut	0-30	S or W	conventional

COMMENTS

I. Management Objectives:
- manage for Sw & Pl sawlogs on a 70-80 year rotation.

II. Silviculture Applications:
- conduct a Pl cone survey to determine if enough seed is present to establish a natural Pl stand. If so, mechanically treat the site.
- if cones are insufficient, plant Pl stock without site preparation.
- thinning of over-dense Pl will need to be done only if a site inspection indicated the need for this treatment.
- harvest fine-textured moraines during the dry part of summer or in winter.
- plant as soon as the frost is out of the ground.

III. Silviculture Problems:
- trafficability may be a problem if long durations of heavy rainfall occurs.
- moderate brush competition will likely occur within three years of harvesting; sites should be inspected at three years to determine if any further treatment is required.

Figure 7.—Management interpretations for BWBSd/O1 sites.

Predicting Vegetation Management Problems

By: Craig DeLong

Abstract: There is a negative correlation between seedling growth and increasing competition. With increased knowledge of the changes in vegetation structure and competitiveness following treatments, of the autecology of competing vegetation species and of the measures of vegetation competition correlated with seedling performance, we can begin to have the capability of predicting the effect of different site preparation strategies.

Management of early seral vegetation is generally an important consideration when preparing sites for planting. Competing vegetation can be detrimental to a seedlings survival and growth. It can intercept light and thus reduce the photosynthetic activity of the seedling; it can reduce the amount of solar energy getting to the soil around the seedling resulting in reduced root activity; and. it can remove soil moisture to a point where the seedling will undergo moisture stress. However this same vegetation can provide benefits to the seedling in the form of shade from intense solar radiation, protection from winter exposure through the enhancement of snow cover protection. or increased nutrient availability from the turnover of nutrient rich vegetative matter.

Since early seral vegetation plays such an important role in the survival and growth of seedlings as well as survival and growth of wildlife. It is important for forest managers to be able to predict the nature of the vegetation that will occupy a site once it has been logged and site prepared.

There are basically five general types of silviculture treatments based on how the treatment alters the composition and structure of the existing vegetation:

1) Mechanical treatments where larger vegetation is pushed aside or sheared off, but lower vegetation and humus is left relatively undisturbed (e.g., piling or winter shearing). In this case there is little change to the floristic composition of the vegetation but the height and cover is reduced.

2) Mechanical treatments where small areas of mineral soil are exposed but much of the vegetation is left relatively undisturbed (e.g., spot scarification or mounding). In this case the composition and structure of vegetation outside of the mineral soil patch is unchanged and there will be no vegetation on the mineral soil until plants seed in or sprout up in this area. Vegetation developing on the patch of mineral soil is often of a different composition (e.g., grasses or members of the aster family).

3) Mechanical treatments where large areas of mineral soil are exposed (e.g., plowing or deep blading). This treatment type drastically changes the composition and structure of the vegetation. The areas of mineral soil are soon occupied by pioneer species adept at colonizing mineral soil usually by seeding in (e.g., grasses, or members of the aster family).

4) Broadcast burning where most or all of the vegetation is removed but, generally a portion of the humus remains. These sites are generally (depending on severity of burn) quickly occupied by species which are stimulated by the burning process like thimbleberry (*Rubus parviflorus*) or fireweed (*Epilobium anqustifolium*).

5) Herbicide treatments where one or more target species are removed or significantly reduced. In this case the composition and structure of the vegetation is changed drastically. Vegetation that can take advantage of the space left open due to the reduction of the target species will generally occupy the site. This vegetation is generally composed of species that seed-in or species that are not affected by the herbicide.

To be able to predict the vegetation that may compete with the seedlings on a site, we need to know the ecosystem unit that existed prior to disturbance and how vegetation of this unit will respond to the aforementioned treatment types. For example, Table 1 shows the changes that occured to the vegetation of a site belonging to the Black-twinberry - Lady fern ecosystem unit in the SBSf subzone (SBSf/05) after the site was logged with no subsequent treatment, logged and treated with a Bracke mounder and logged and treated with the herbicide glyphosate. The most dramatic changes were evident on the area that was treated with glyphosate. Figure 1 shows the species that underwent the greatest changes on

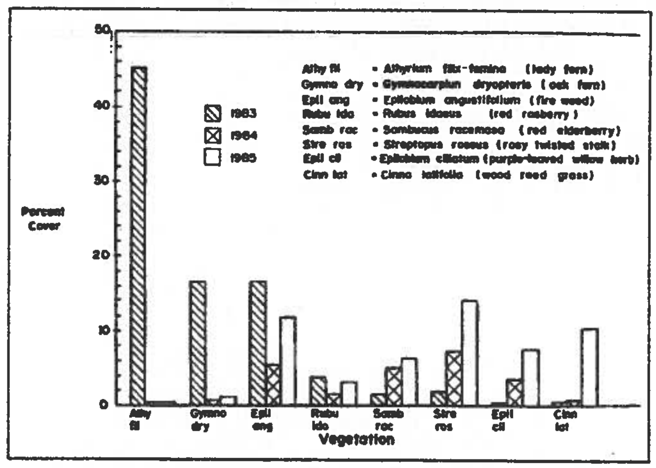

Figure 1. Changes in percentage cover of selected species over time in response to treatment with glyphosphate.

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Table 1. Changes in species composition due to different types of site treatment on a site within the SBSf/05 ecosystem unit.

		Treatment Type		
		Logged		
Vegetation	Undisturbed[b]	No treatment[c]	Mounded[d]	Herbicide[e]
Tree layer:				
Picea glauca x engelmannii	+ (12)[a]	-	-	-
Abies lasiocarpa	+	-	-	-
Shrub layer:				
Oplopanax horridus	+	x	x	-
Ribes lacustre	+	+	x	-
Rubus parviflorus	+	+	x	x
Ribes laxiflorum	+	+ (6)	+	x
Rubus idaeus	+	+ (12)	+ (8)	+
Sambucus racemosa	+	+ (13)	+	+ (6)
Herb layer:				
Athyrium filix-femina	+ (23)	+ (31)	+ (24)	x
Gymnocarpium dryopteris	+ (14)	+ (23)	+	+
Dryopteris assimilis	+ (24)	+ (7)	-	x
Rubus pedatus	+ (6)	x	-	x
Tiarella trifoliata	+ (5)	+ (10)	+	+
Streptopus amplexifolius	+	+	x	+
Cornus canadensis				
Veratrum viride	+	+	+	+
Calamaqrostis canadesis	x	x	+ (5)	x
Streptopus roseus	+ (6)	+ (6)	+	+ (14)
Epilobium anqustifolium	x	~ (11)	+	+ (12)
Cinna latifolia	x		+ (6)	+ (10)
Epilobium ciliatum	-	x	+	+ (8)

[a]+ high constancy (cover if over 5% indicated in parenthesis). x low constancy and cover. - absent.
[b]Average on sites classified during ecological classification of the SBSf.
[c]Logged 1980, no treatment since.
[d]Logged 1980, mounded with, Bracke mounder in 1983.
[e]Logged 1980, treated with glyphosate in 1983.

this site. Studying sites like these after treatment allows us to predict what vegetation may become a problem on another site which is in the same ecosystem unit and is site prepared in the same manner.

We also need to know the nature of the vegetation making up the vegetation complex developing after treatment. To do this we must study various aspects of the autecology of the main competing species making up the vegetation complex. Some of the aspects we need to study for each species are: a) leaf area; the more leaf area a species has the more light it will stop from getting through to the seedlings; b) rooting location; if a species roots in the same profile as the young seedlings it will be more of a problem; c) water use; the more water a competing species uses the less that is available for the seedling; d) cover increase; the more rapidly the competing species can increase in cover, the more problems it will cause; e) height increase; the larger the plant, the more shade it will cast and the greater the distance it can be from the seedling and still shade it; f) maximum height: the maximum height the species will attain, determines if it will be a problem for a few years or will continue to be a problem for many years. Table 2 shows some of these characteristics for three species growing on a broadcast burned site in the SBSf subzone of the Prince George region.

The final knowledge we must gain for accurate prediction is how a given amount of a particular vegetation complex will affect seedling performance. In effect we must attempt to find measures of the amount of a vegetation complex (i.e., competition indices) which are correlated with measures of the seedlings growth. Figure 2 is a graph showing this type of relationship between the growth of white x engelmann spruce (*Picea qlauca* x *enqelmanii*) and a competition in-

Table 2. Some autecological aspects of thimbleberry (*Rubus parviflorus*), red raspberry (*Rubus idaeus*), and fireweed (*Epilobium anqustifolium*) growing on a broadcast burned cutblock in the SBSf subzone of the Prince George Forest Region.

Species	Relative leaf area	Mean yearly % cover increase*	Mean yearly height increase*	Maximum height*
Rubus Parviflorus	high	8	25 cm	80 cm
Rubus idaeus	moderate	5	17 cm	60 cm
Epilobium anqustifolium	moderate	4	35 cm	120 cm

*represents data collected for 3 years following burning dex, for the same site discussed in the previous paragraph. The competition index (CI) used in this example is: $CI = \Sigma [VHj * PCj/Avj]$ where; VHj is the mean vegetation height for species j, PC; is the percentage cover of species j and Avj is the average distance from the center of a seedling to the inner edge of foliage of species j. This competition index is esentially a measure of the volume of vegetation and it's proximity to the center of the seedling. The seedling growth measure used in Figure 2 is diameter increment because it is felt to be one of the better measures of a seedlings' relative performance. If one examines the graph it is apparent that there is a negative relationship between seedling growth and increasing competition as measured by the competition index. The correlation between these measures was found to be highly significant (f= -0.749 where n=17, d.f.=15, p(.05)=0.482. p(.01)=0.606). Upon further examination of the graph in Figure 2 it is apparent that the best correlation between competition index and diameter increment is at high levels of the competition index. This would suggest that there may be a certain level of vegetation competition below which other factors begin to have as much effect on seedling performance as vegetation competition. This level may be one which forest managers will choose to use as the level of vegetation control they wish to achieve on a particular site.

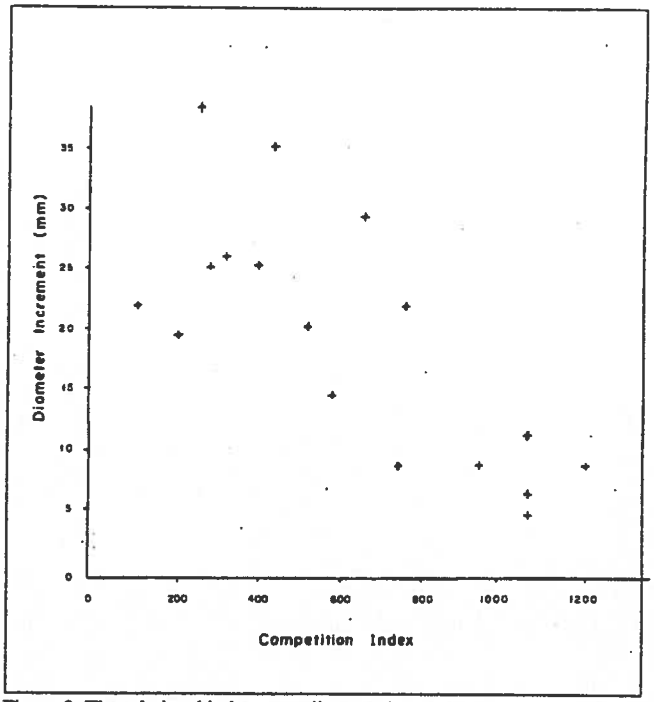

Figure 2. The relationship between diameter increment and the competition index Σ [VH * PC/Av].

As we proceed into an era where there is an increasing number of site preparation stategies for vegetation control to choose from, it becomes increasingly important to be able to predict what effect each of the different stategies will have on this vegetation. Through increased knowledge of changes in vegetation composition and structure after treatment, autecology of key competing vegetation species, and measures of vegetation competition which will correlate with seedling performance we can begin to have this predictive capability.

Historic Background to the Natural Distribution of Tree Species in Scandinavia

By: Owe Martinsson

Abstract: Scandinavia is probably poorer in tree species than corresponding boreal areas in Siberia and Canada because repeated glaciations annihilated some species and the return of others was blocked by natural east-west barriers. Experimental plots have shown that some east and south European and North American tree species, in addition to Pinus contorta, *can be superior to native Scandinavian species in hardiness and growth capacity.*

Forestry in northern Scandinavia is based upon only two tree species. The introduction of *Pinus contorta* into Swedish forestry during the last two decades has so far been successful and will probably generate considerable amounts of timber harvested within the next 50 years. This introduction has raised the question: Why is *Pinus contorta* growing faster than our native pine?" and "Is *Pinus contorta* the only introduced tree species that could be successfully utilized in Scandinavian forestry?"

Comparing Scandinavia to other parts of the boreal coniferous zone the tree species flora is poorer here than the corresponding areas within this zone in Siberia and Canada (Walter 1973). We do not need to go very far east to meet *Larix* and *Abies* and a species representing the 5-needle pines in addition to *Pinus sylvestris* and *Picea abies* (Rubner 1960) (Figure 1). In the same zone in Canada we also find species of *Thuja*, *Tsuga*, *Pseudotsuga* and *Chamaecyparis*. Evolutionary research has indicated that the present poverty in the tree species flora of Scandinavia probably arose in recent times.

First, I would like to raise the question, what is a native tree species of Scandinavia? All tree species have immigrated into Scandinavia just a few thousand years ago. Birch and pine formed the first forests after the last glaciation in central and northern Scandinavia only 9,000 years ago. Spruce did not appear until 3,000-4,000 years before present (Fries 1965).

The tree species of the boreal zone developed long before the Quaternary period and probably these species with their specific characteristics were present in northern Europe before the Pleistocene glaciations (Frenzel 1968). Scandinavia has been the center of at least 17 different glaciations and the same number of interglacial periods during the last two million years (Kukla 1977). Each cycle has lasted for about 100,000 years of which the interglacial periods have been the shorter parts. If we consider the minimum time during which conifers of the present species have existed in the north, 70 million years, the Pleistocene period represents 3.5% of that period and the period represented by the presence of the so-called native tree species in Scandinavia is less than 0.1%.

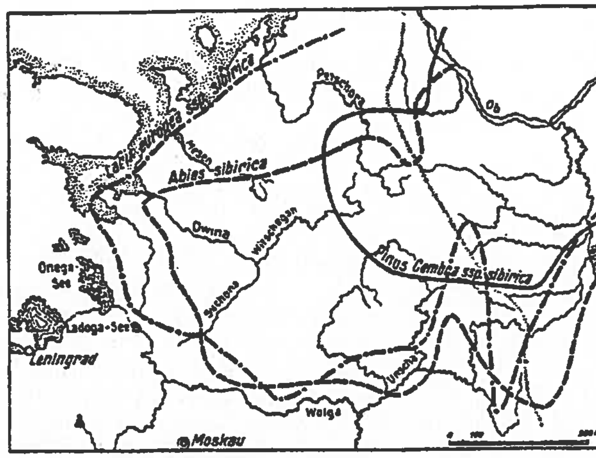

Figure 1. Western boundaries for the natural distribution of some tree species in the USSR (After Rubner 1960).

According to several authors the forests occupying northern Europe at the end of Pleistocene, 2 to 2.5 million years ago, were a lot richer in species than these forests are today (Frenzel 1968, Kurtèn 1969). The same was true for the interglacial periods of this area (Figures 2 and 3).

Based on pollen analysis in loess deposits outside the maximum extension of the ice cover and pollen analysis of deep sea sediments, it has been possible to map the northern European vegetation during interglacial periods (Frenzel 1968). According to these maps *Larix* was a north Scandinavian tree species during the last interglacial period (Eem) and during the second last interglacial (Holstein) species of *Abies* existed in the southern and *Larix* in the northern part of Scandinavia in addition to our present coniferous species. Climatic conditions during these interglacials may have been variable but during some periods probably some degrees warmer than ever since then (Dansgaard 1984).

Evidently the variety of species today is greater in Siberia and in Canada than in Scandinavia (Hultèn 1937) because of repeated glaciations which gradually impoverished our flora. Some parts of our flora have been completely annihilated and others have been unable to reoccupy the area after the glacial retreat due to natural barriers oriented in an east-west direction (The Alps, the Pyrenees, the Carpathian and Caucasian Mountains, the Mediterranean Sea, the Baltic Sea and the strait that isolated Scandinavia from eastern Europe for several thousand years).

Experimental plots in Scandinavia of east-European and south-European species, as well as North American species have demonstrated that some are superior to our native species in hardiness as well as growing capacity. *Pinus contorta* is not the only introduced species that could be utilized in practical forestry. This species was chosen in part because

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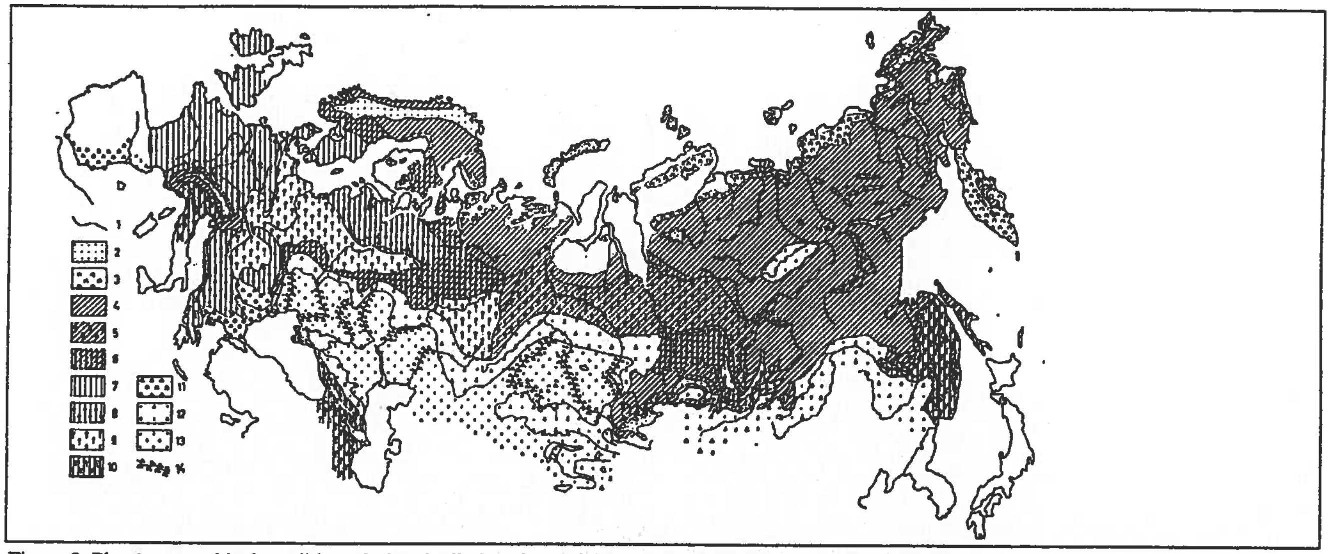

Figure 2. Plant-geographical conditions during the linden phase of the Eemian interglacial. (1) Coastlines; (2) alpine vegetation; (3) forest tundra and open birch forests of Kamchatka; (4) forests of spruce, pine and larch; (5) forests of spruce and fir, in some parts with a wealth of Pinus sibirica; (6) conifer forests with a small admixture of oak, elm, and linden; (7) mixed forests of oak and forests of oak and hornbeam; (8) mixed oak forests and conifer forests; (9) linden forests, some with oak; (10) forests of hygrophilous and thermophilous deciduous broadleaf trees and conifer forests; (11) Mediterranean oak and pine forests; (12) forest-steppe; (13) steppe and desert; (14) riverine forests (From Frenzel 1968).

of certain properties: ease of handling in the seed and seedling stage; its fast juvenile growth; and wood properties which allow *Pinus contorta* to be mixed with native spruce and pine in the pulp wood industry.

If biological and silvicultural needs alone are considered, we may find introduced species which are better adapted to some of the Scandinavian site conditions than *Pinus contorta*. Species which under different site conditions may be superior to Pinus contorta in the northernmost part of Scandinavia as well as in high altitude areas are *Larix sukaczewii*, *Abies lasiocarpa*, *Abies sibirica* and *Picea mariana*.

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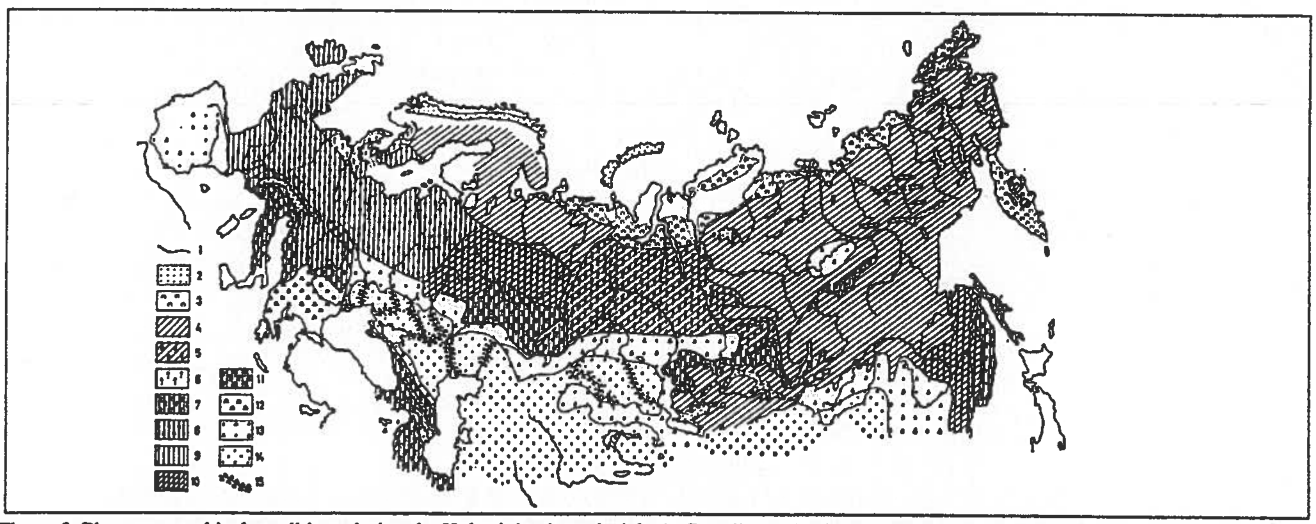

Figure 3. Plant-geographical conditions during the Holsteinian interglacial. (1) Coastlines; (2) alpine vegetation; (3) forest tundra and birch forests of Kamchatka; (4) taiga vegetation, chiefly composed of pine, spruce, and larch; (5) forests of spruce, fir, and *Pinus sibirica*; (6) oceanic pine forests; (7) conifer forests, characterized by spruce and fir, with an admixture of thermophilous broadleaf elements; (8) mixed forests of *Abies*, *Carpinus*, oak, and elm; (9) mixed forests of oak, fir, and linden, with beech; (10) forests of pine and spruce with oak, elm, and linden; (11) chiefly forests of broadleaf thermophilous and hygrophilous trees, with Juglandaceae; (12) Mediterranean deciduous and evergreen forests; (13) forest-steppe; (14) steppe and desert; (15) riverine forests (From Frenzel 1968).

Wind Firmness of Lodgepole Pine vs Scots Pine

By: Owe Martinsson

Summary

The crown, stem and root properties of lodgepole pine and Scots pine were investigated in relation to wind stability in artificially regenerated stands in Sweden. The experimental material comprised young seedlings as well as 57 year old trees.

The lodgepole pine usually develops a root system with sinker roots, but, typical tap roots may occur.

The root/shoot ratio of lodgepole pine seedlings is lower than that of Scots pine seedlings. In older trees there is no significant difference in root/shoot ratio between the two species.

In relation to the weight of the stem and the root, the branches of a lodgepole pine are heavier than those of a Scots pine. Moreover, the lodgepole pine is taller than the Scots pine with similar total weight.

In relation to the weight of the crown and stem the turning moment required to break down the tree artificially is lower for lodgepole pine than for Scots pine.

The correlation between the wind speed and the wind force on the tree indicate a higher wind force for lodgepole pine than for Scots pine at the same wind speed. The lodgepole pine stem is more elastic, however.

The percentage weight increase due to snow and ice crust during the cold season is higher for lodgepole pine than for Scots pine.

Therefore there is a greater risk of blow-down of lodgepole pine than of Scots pine.

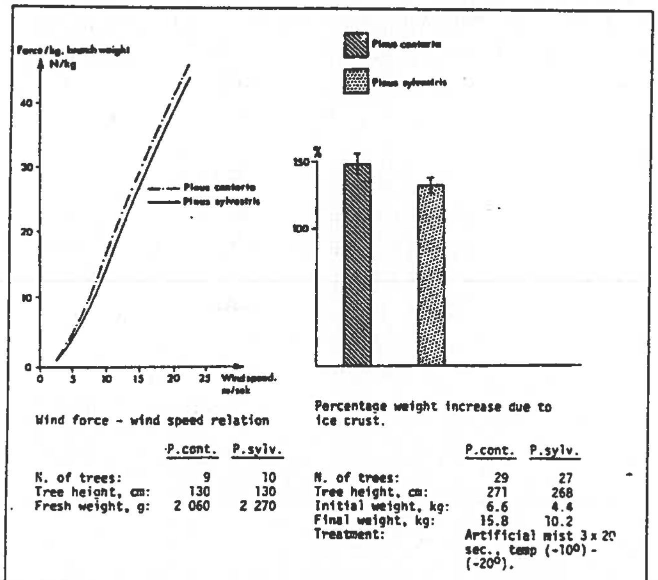

Figure 1. Affect of wind and snow.

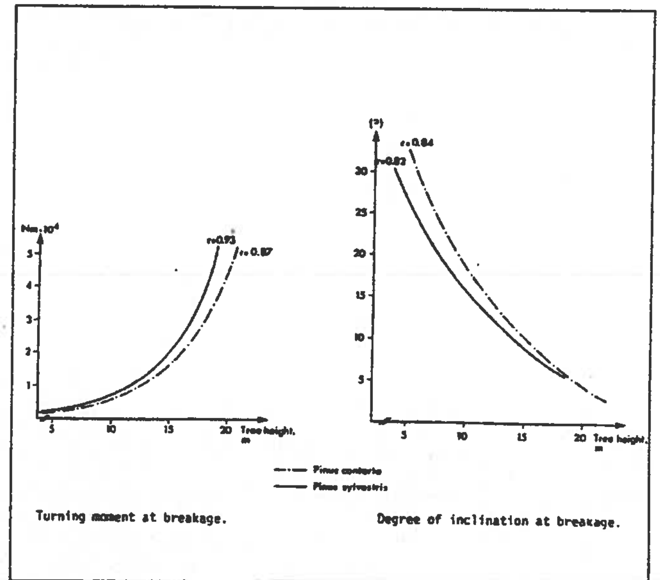

Figure 2. Tree pulling.

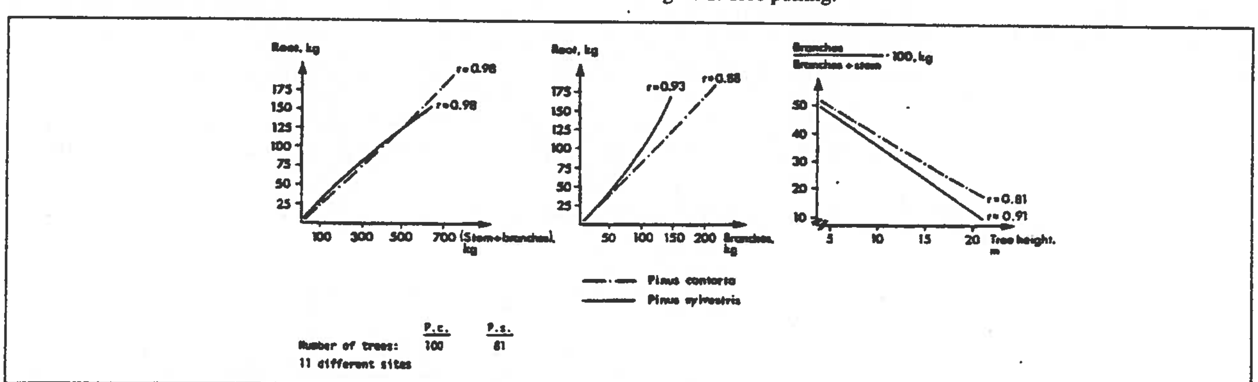

Figure 3. Root, stem and branch properties.

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Can We Utilize Provenance Test Results from Other Countries of Choice of Lodgepole Pine Provenances in Sweden?

By: Katarina Lindgren

Abstract: The results obtained from the 10-year-old IUFRO lodgepole pine provenance series in British Columbia were compared with results obtained from the IUFRO series from one site in Sweden.

The best performing provenance areas are the same in both countries. For individual provenances, there is a positive correlation between height growth in both countries, and the more important deviations seem to be mainly explained by differences in latitude between the Swedish and the British Columbia sites.

The delineation of the geographic areas in British Columbia of provenance origins with similar performance, based on earlier Swedish results, was supported.

The provenances originating from low altitudes give higher height growth than those originating from high altitudes (within the latitude range 600-1800 m).

Introduction

The evaluation of results of the international IUFRO 1970/71 lodgepole pine provenance series in Sweden (Lindgen 1983 and 1985) indicated that:

•Provenances originating from inland British Columbia (B.C.) and the Yukon territory are of practical interest for Sweden.

•The survival of the provenances increases with increasing latitude and altitude of provenance origin, especially on sites with severe (harsh) growing conditions.

•The damage caused by voles and moose decreases with increasing latitude of provenance origin.

•Provenances originating from local low altitudes should be used in reforestation work. High altitude origin causes considerable reduction in height growth, and only a rather limited improvement in survival.

•Trees from seed collected from some provenances and geographic areas have better height growth than trees from seed collected from other provenances or areas at similar latitudes.

The last statement is illustrated in Figure 1, which shows the relative height growth of individual provenances after 8 years in field, on 10 sites in Sweden (north of latitude 60). The large black part of the square, (e.g., provenance 2015 and 2030) indicates good growth on many of the sites and small or no black part (e.g., provenance 2051) indicates poor growth on most of the test sites. Thus, there may be recognizable geographic areas and provenances which give good height growth on many sites, or poor growth on most of the sites. If there is similar ranking of provenances—if a given provenance performs well on different sites with wide range of growing conditions and, if another provenance performs poorly on most of those sites—this would indicate that there is a low genotype x environment interaction.

The purpose of this work was to investigate if the ranking of performance of provenances is similar in IUFRO experiments close to their origin. Thus, similar ranking indicating low genotype environmental interaction would indicate that:

•It is likely, that the plus tree selection made in Canada will give a genetic gain in Sweden.

•B.C. and Sweden could both benefit on an exchange of advanced breeding material.

•It may be possible to confirm and improve the delineation of areas of provenances of similar performance (see below and Figure 2 and Lindgren et al. 1985).

In this investigation the last point is of particular interest. Can we confirm the delineation of the areas of provenance origins in British Columbia recommended for use in Sweden, as shown in Figure 2?

The delineation is based on consideration of several aspects, such as:

•The results from IUFRO series shown in Figure 1;

•The results from SCA (Svenska Cellulosa Aktiebolaget) provenance trials;

•Results from Institute for Forest Improvement provenance trials;

•Relief map of B.C. and the Yukon;

•Precipitation map;

•Biogeoclimatic map;

•Stream flows map;

•Forest tree seed zones of British Columbia.

The following comparison of Swedish and B.C. IUFRO lodgepole pine provenance series results would not be possible without data from British Columbia series, kindly provided by Ch. Ying, K. Illingworth and M. Carlson. Their analyses and results of the B.C. series are published by Ch. Ying *et al.* (1985).

Material and Methods

The B.C. series is described by Ying *et al.* (1985) and the Swedish series by Lindgren *et al.* (1980) and Lindgren (1983).

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In this paper, only the provenances which are of potential interest for B.C. and Sweden were considered. The height growth and the survival rate data from 10 years old trees were used.

The data consisting of 45 B.C. and the Yukon provenances on one site in Sweden (Horndal lat. 60°16'N, long. 16°34'E, alt. 150 m) were compared with data consisting of the same 45 provenances, plus an additional 25 provenances, tested on 55 sites (in latitudinal range 49°-56° W) in British Columbia, subdivided into 11 regions. In B.C. all provenances are not tested on all sites. On each site within a given region a subset of 60 provenances (of a total of 140) were tested. Nine (standard) provenances were tested across all 11 regions.

There is only one Swedish site which is suitable for this comparison—the mildest test site shown in Figure 1 (no. 8). The other sites have either too high mortality, too much damage or are situated too far north and require more northern provenances than those from B.C. sites.

Actually, the data from still milder and more southerly sites would be justified to use in the present comparison. There are some sites in southern Sweden (belonging to the same experimental series) which would be more relevant for this comparison because of their better correspondence in latitude. But high damage and mortality caused mainly by moose and deer, makes them unsuitable.

In Sweden it was found that there is a negative relationship between high altitudes of seed origin and height growth.

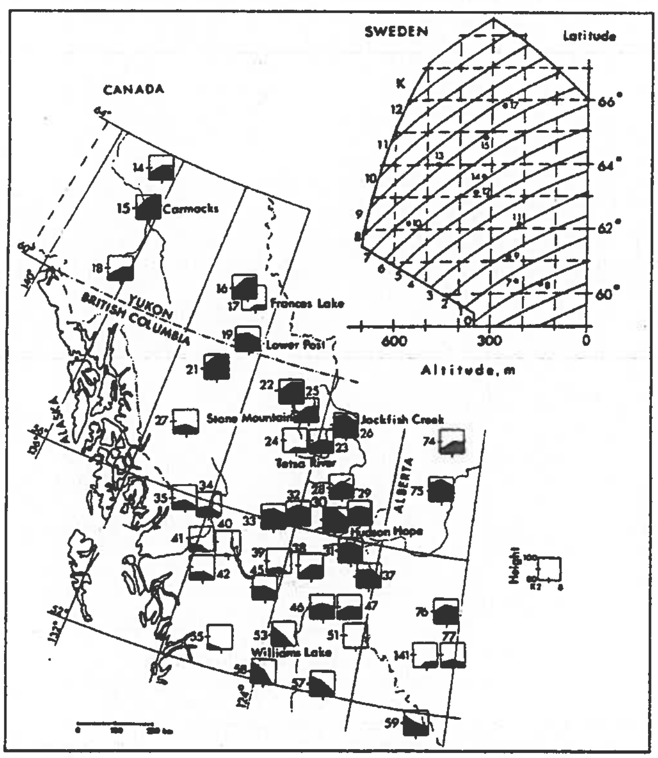

Figure 1. The expected relative height of individual provenances (related to the best provenance = 100) for the sites of K-value 2, 5 and 8 (left, middle and right part of each square). The low K-value indicates relatively mild while high K-value indicates sites with severe climatic conditions. On K-values where the relative height is near 100, the provenance belongs to the best ones. The relative height is based on ten sites (no. 8-17) ranging from latitude 60-66° in the northern part of Sweden. The numbers indicates the IUFRO provenance numbers 20—; 2—.

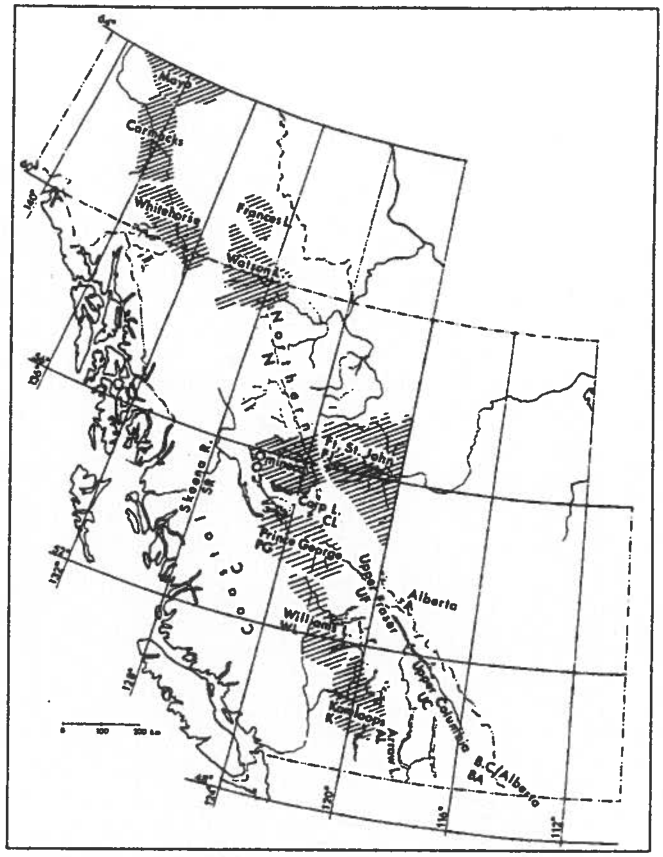

Figure 2. The areas of provenance origins recommended for use in Sweden (dashed areas).

We do not recommend to use seed collected on altitudes higher than about 1000 m. Therefore, when provenances were pooled into the groups, the provenances originating from altitudes higher than 1000 m north of latitude ± 530° and from altitudes higher than 1200 m on latitudes 49°-53° (except for three Rocky Mountains provenances from altitude of 1280-1385 m on the southernmost border of B.C. and the Alberta) were omitted from the calculations.

In this paper overall relative height growth and height sum across 11 regions in B.C. will be used. Furthermore, the results obtained when only regions 5-11 were included in calculations will be considered. The reasons for omitting regions 1-4 are, that several of the provenances of interest were not tested on many of the test sites in region 1-4; the biogeoclimatic conditions vary considerably in those regions; and the provenances originating from those southernmost regions are not recommended for use in Sweden. Approximate areas of locations of test sites subdivided into regions 1-4 and 5-11 are indicated in Figure 3a.

To facilitate comparison between sites, the data were standardized. For calculation of relative height in the B.C. series the mean heights were used, while in the Swedish series the average heights of 10 provenances originating from latitudinal range 54°40'-60° in B.C. were used.

Results and Discussion

Height and height sum

The relative height of 9 B.C. standard provenances (those

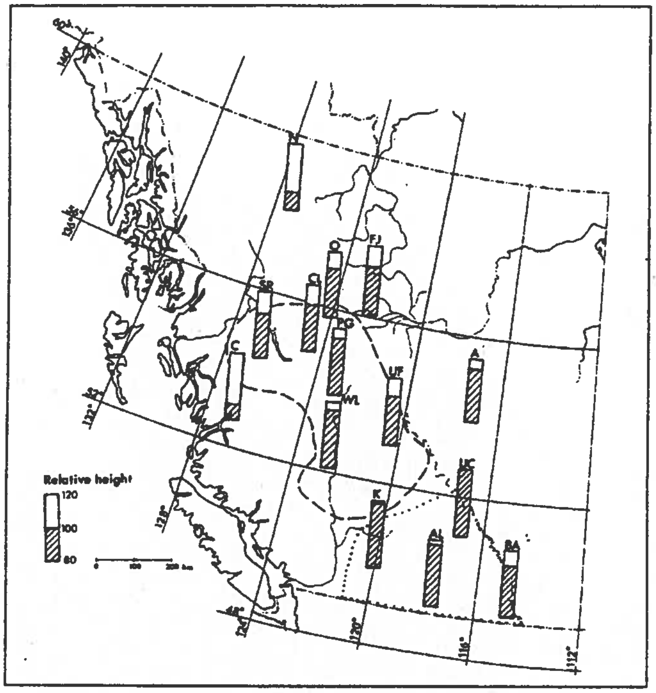

Figure 3.Area of experimental sites and origin and height of different provenance groups.
a. Approximate delineation of the area of location of test sites subdivided into the regions 1-4 (...) and 5-11 (—) in B.C.
b. Mean relative height across all 11 regions in B.C. of the provenances pooled into the groups of resembling provenances (cf. Figure 2).
The group of provenances from Arrow Lake (A L) will not be included in calculation of relationship between the B.C. and Swedish results as there is no provenance represented in this area in Sweden.

present in all regions) was examined by analyses of variance. Highly significant differences were obtained among provenances.

The average relative height per provenance across all regions was calculated. Furthermore, provenances were pooled into groups of similar provenances with respect to performance and geographic neighborhood. The grouping was mainly based on experiences obtained from several Swedish provenance experiments (cf. Figure 1 and 2). The reasons for pooling of provenances are:

•The original provenances from which we have obtained our results are often not available anymore e.g., they were felled when seeds were collected. If we pool provenances to the areas and thus know the performance of the areas, we may be able to predict how other provenances available within those areas (but not available yet in Sweden) may perform. This is important information for seed import and provenance transfer practice.

•The number of provenances tested in the B.C. series is greater than in the Swedish series. When the provenances are pooled to the area of origin, then the information obtained from all B.C. provenances may be utilized, compared to analyses based on individual provenance levels. Thus, a given group in the B.C. series may be represented with a greater number of provenances than that group in the Swedish series, hence the results may be expected to be more accurate.

The overall relative height of provenances pooled into different groups/areas across all 11 regions in B.C. is shown in Figure 3b. The group of provenances from the coastal area, Skeena River, and the area north of around 56° latitude showed low height growth. This corresponds rather well with the general Swedish experience (cf Figure 1, site 8, extrapolate for K_0). Provenances with highest overall height growth originated from latitude 49°-53° in the interior B.C.

Since the three areas of provenance origin mentioned above give lower height growth than other areas, they are not of practical interest, and therefore they will not be considered in the remainder of this paper. Only the interior B.C., and the Alberta provenances up to 57° latitude will be evaluated.

It is likely that correlations between Sweden and B.C. would become considerably higher if poorly adapted provenances were included (a common practice by scientists to get nice looking diagrams). As such comparisons do not have many practical applications, it was not done here.

In Figure 4, the mean relative height of individual provenances obtained from all 11 regions in B.C. is plotted against the relative height obtained from Swedish site Horndal (no. 8, Figure 1).

There is a positive significant, ($P < 0.01$) relationship between relative height growth in both series across all 11 regions pooled. Provenances which are fast growing in B.C. are also fast growing in Horndal and poor growing provenances in B.C. are also poor growing in Horndal (Figure 4). The deviations seem to be mainly explained by differences in latitude between Swedish and B.C. sites. The slightly significant ($P < 0.05$) relationship for region 5-11 is also shown in Figure 4.

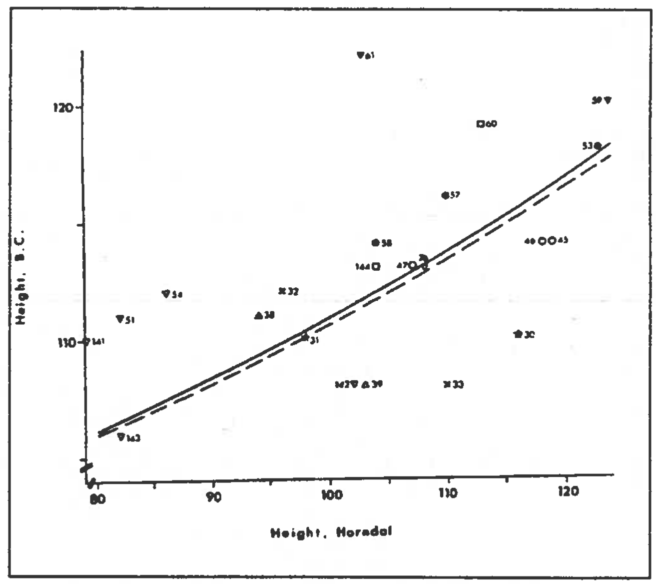

Figure 4. The relationship between relative height of individual provenances averaged over region 1-11 in B.C. and at Swedish site Horndal. ——indicates regression line for region 1-11, and — for region 5-11. The numbers within the diagram indicates the IUFRO provenance numbers 20— or 2—.
Observe, that in Figure 4-6 the regression lines for test sites subdivided in region 5-11 are only added to the figure and are not suppose to fit to the individual points, which are averages over region 1-11.
The different symbols indicate the different areas of provenance origin:
= Ft. St. John= Williams Lake
= Omineca= Kamloops
= Carp Lake= Upper Columbia
= Prince George= Upper Fraser; B.C./Alberta and Alberta

As the points at Horndal are based on a sample size of 11 to 23 trees, the statistical error is rather large. Thus, the scattering due to statistical reasons is considerable.

The corresponding relationship for provenances pooled into the groups (similar to those in Figure 2) is shown in Figure 5. There is slightly significant indication, that the groups of provenances which grow well in B.C. also give good growth at Horndal, but the poorly growing provenances in B.C. may be poorly or relatively good growing in Sweden. The four best growing groups of provenances (Figure 5) are identical at Horndal and B.C.

There are often problems with survival in Sweden. Therefore besides evaluation of height growth, also the height sum is investigated. The height sum is the survival rate multiplied by height of survivors. Height sum gives a good prediction of ranking for mature volume yield in Scots pine provenances (Marklund 1981).

Relationship between the relative height sum in B.C. on one hand and the relative height sum in Horndal on the other hand, is significant on sites in region 5-11 and slightly significant across all regions 1-11 pooled (Figure 6). The five best performing groups of provenances are the same at Horndal and B.C.

Altitude

The influence of altitude of seed origin on relative height growth of individual provenances in B.C. is illustrated in Figure 7. A second degree polynomial based on all provenances indicates that provenances originating from altitudes of around 900 m give the tallest trees. The regression is highly significant ($P < 0.0001$). However, if the provenances originating north of latitude 54°30' (Fort St. John; Omineca

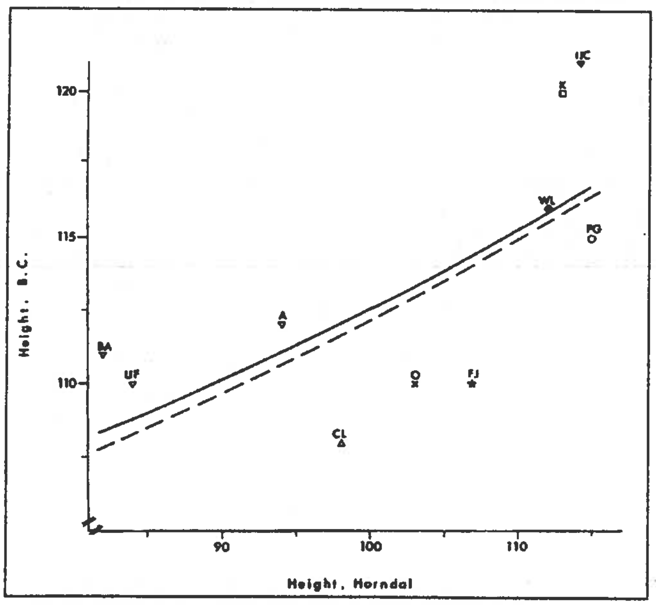

Figure 5. The relationship between relative height growth of provenances pooled into the groups on sites in region 1-11 B.C., and at Swedish site Horndal. —— indicates regression line for region 1-11 B.C. and — for region 5-11. This Figure as well as Figure 6, is based on 30 provenances in the B.C. series and on 20 provenances in the Swedish series.
The different symbols indicate the different areas of provenance origin:
= Ft. St. John (FJ)= Williams Lake (WL)
= Omineca (O)= Kamloops (K)
= Carp Lake (CL)= Upper Columbia (UC)
= Prince George (PG)= Upper Fraser (UF) B.C./Alberta (BA) and Alberta (A

Table 1.

IUFRO nr:	Name	Lat. N	Long. W	Alt. m
2053	Udy Creek	53°01'	123°14'	982
2057	Oie Lake	52°00'	121°12'	990
2059	Marl Creek	51°31'	117°11'	945

and Carp Lake area give poor growing provenances in south B.C.) are omitted from calculations, then a highly significant relationship for decreasing height growth with increasing altitude was obtained (in the altitudinal range of 580-1815 m). A second degree polynomial was omitting the northern provenances, indicates an optimal altitude of 790 m.

For provenances originating from Ft. St. John and Omineca area a slightly significant relationship for height growth and altitude was obtained (Figure 7) with a slope similar to the southern group.

The relationship for sites subdivided in regions 5-11 was so similar to the pattern shown in Figure 7, for pooled regions 1-11, that it was not worthwhile to show it in the figure.

No significant relationship between height growth and altitude of provenance origin at the site Horndal, at altitudinal range 670-1525 m was found.

A contributing reason is probably the low number of provenances originating from high altitudes. Only 3 provenances out of 23 were originating from altitudes higher than 1205 m.

Conclusion

This investigation indicates that there is a fair agreement between results obtained from comparison of the IUFRO B.C. lodgepole pine provenance series with the IUFRO-series on one site in Sweden:

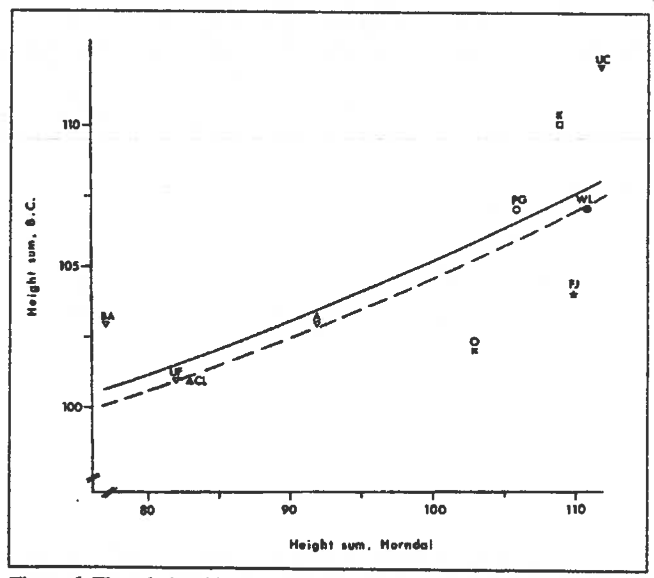

Figure 6. The relationship between relative height sum of provenances pooled into groups in region 1-11 in B.C. and at site Horndal. —— indicates regression line for region 1-11, and — for region 5-11 in B.C. For explanation of different symbols and abbreviations, see Figures 5 and 2.

•Only provenances originating from B.C. are of practical interest.

•Provenances north of latitude 56°, from the coastal area and provenances from Skeena River area give lower height growth than provenances from southcentral B.C.

•Provenances originating from central B.C. from areas: Upper Columbia Kamloops, Arrow Lake (not represented in Sweden) and Williams Lake were provenances of highest average performance.

•Provenances originating from areas: Upper Fraser; west, east and northeast of Carp Lake; southernmost border B.C./ Alberta (high altitude provenances 1280-1385 m); and southern Alberta were provenances of poor average performance.

•Provenances originating from Prince George area performed relatively well in both materials.

•Provenances from Ft. St. John and from the Omineca area performed better on the Swedish site than expected from their performance on B.C. sites. This is probably an effect of latitude, as this is a northernmost group of provenances not suitable for use on sites in southern B.C.

•Provenances which were classified as superior both in the Swedish as well as the B.C. series are shown in Table 1.

•The delineation of the areas of provenance origins in British Columbia recommended for use in Sweden shown in Figure 2 was supported by this investigation.

•Differences between "Sweden" and "B.C." can at least partly be understood by discrepancy in latitude. Comparisons including more northerly sites in B.C. and perhaps also more southerly sites in Sweden would give more and more relevant information, but such data were not available.

•There is a negative relationship between height growth in B.C. and altitude of provenance origin (in the altitudinal range 600-1800 m).

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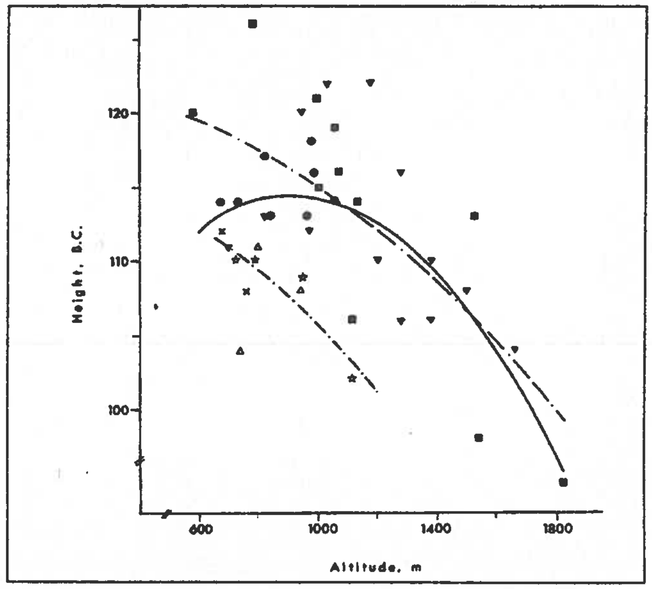

Figure 7. The relative height of individual provenance in region 1-11 in B.C. as a function of altitude of provenance origin. ——indicates relationship for all provenances shown in figure; — · — · provenances originating north of latitude 54°30' (areas: FJ and O) and — · — — · indicates provenances originated south of 54°30' filled symbols; areas: PG, WL K, AL, UC, UF, B/A and A (cf Figure 2).

Factors Affecting Plantation Performance in Boreal Forests in Ontario

By: Bijan Payandeh

Abstract: Data from 18 experimental plantations in northern Ontario were analyzed by stepwise regression analysis to evaluate their performance. The results generally indicate that total height and height increment were affected by fewer site and stock factors but more strongly than survival. This type of analysis and proper interpretation of results can be used as a basis to identify and/or quantify factors affecting plantation performance.

In general, results indicate that total height and height increment are affected by fewer factors but more strongly than the survival. Of the three species, jack pine survival and height increment may be predicted more precisely than spruces and its total height better than black spruce. Black spruce survival was the most heterogeneous response variable where six predictor variables (factors) accounted for about 56 of its variability.

The results indicate that one to five of the qualitative site factors accounted for less than 23% of the variability in survival rate and less than 30% of variability in total height. Stock type, planting season, weed control and chemical site preparation were among the factors showing low but significant correlations with the response variables. Of the planting stock characteristics, quality index was significant in every case while shoot-root-ratio, root collar diameter and dry weight were significant in one or two cases. The most single significant variable, however, was the number of growing season since planting which accounted for up to 30% of the variability in survival rate 63% of the variability in total height.

This type of analysis and proper interpretation of the results can be used as a basis to identify and/or quantify factors affecting plantation performance. Variables identified as significant factors will then be used to develop nonlinear regression models expressing plantation growth and survival as functions of time, site factors and planting stock characteristics. It should be noted, however, that variables selected in the stepwise regression procedures because of high partial correlations with the response variables do not necessarily represent cause and effect type relationships.

Introduction

Forest renewal is the most pressing problem currently facing forest managers in Canada [see Fellows (1986) for a historical review]. Because of the impending wood supply problems and the backlog of cutover areas, federal and provincial agencies and the forest industry are to invest increasingly large sums of money annually in forest regeneration.

Recent symposia on forest regeneration (Anon. 1981, Morz and Berner 1983, Scarratt et al. 1981) effectively illustrate the need for synthesis of information on forest renewal for each region. In Ontario, artificial forest regeneration practices have been studied for many years. Investigations have ranged from biological factors to economic considerations. Much is known about the individual factors affecting seedling survival, growth, and production costs. However, researchers have not completely addressed the interrelationship of the important identified factors. Therefore, there is a strong need to synthesize the knowledge currently available in order to understand the regeneration process as a whole. Such an understanding would be facilitated by the development of a management-oriented computer simulation model.

A research study to develop a model for artificial regeneration systems in Ontario began at the Great Lakes Forestry Centre in 1985. The intention of the study is to fully integrate the biological factors with economic component of the regeneration systems. The preliminary stage of model development requires the identification of critical factors (both biological and managerial) significantly affecting the performance of the candidate species during the regeneration phase. The objective of this paper is to describe the procedures employed to screen out factors affecting plantation performance in northern Ontario. It should be noted that the results obtained here maybe data specific and thus may not be generalized.

Materials and Methods

The data used are from a cooperative research study between the Great Lakes Forestry Center and the Ontario Ministry of Natural Resources to compare the outplanting performance of bare root and paperpot stock and time of planting, i.e., spring and summer, on a variety of site conditions in northern Ontario. Recently, Wood and Dominy (1985) reported the results of this study by species in 18 separate outplanting experiments located across northern Ontario. Approximately 22,000 crop trees were planted and assessed for survival, growth, and condition.

Detailed description of the experiments and results thereafter are given by Wood and Dominy (1985). However, a very brief description of the main characteristics of the information utilized is provided here. Species used were black spruce (*Picea mariana* [Mill] B.S.P.), white spruce (*Picea glauca* [Moench] Voss), and jack pine [*Pinus banksiana* Lamb.), the three most important commercial species in

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Table 1. Summary of the final categorical variables and their associated dummy variables used in evaluating factors affecting growth and survival of black spruce, white spruce, and jack pine outplantings in Ontario.

		Dummy variables		
		2	3	
Variable name	Classes	D	D1	D2
Site type	Upland	1	-	-
	Lowland	0	-	-
Site preparation	Mechanical	-	1	0
	Chemical	-	0	1
	Burn -	0	0	
Weed control	Chemical	1	-	-
	None 0	-	-	
Planting season	Spring1	-	-	
	Summer	0	-	-
Stock type	Bareroot	1	-	-
	Container	0	-	-
Bare root type	Transplant	1	-	-
	No transplant (seedling)	0	-	-
Container size	FH 408 paperpot	1	-	-
	FH 308 paperpot			

Ontario. Experimental sites are located within operational planting sites, therefore the results should be compatible with the provincial forestry practices. Sites were harvested, site prepared, and tended according to operational standards.

The experimental plantations are located (Figure l) near the cities of Timmins, Kirkland Lake, Kapuskasing, Hearst, and Thunder Bay in north and northwestern Ontario. Experimental designs used included completely randomized, blocked and paired designs. Wood and Dominy (1985) provide tabular descriptions of each experiment for the three species in terms of: a) boreal forest region section, b) site district and region, c) surficial geology, d) local relief and aspect, e) soil texture and moisture regime, and f) organic horizon description. They also give summary tables on recent forestry practices for each experiment and species outplanted. These include: a) previous forest stand characteristics, b) harvesting dates and method, c) site preparation history, and d) post-planting treatments. In addition, they provide tabular information on outplant experiments by planting stock types and time of planting for each of the three species. Other details on planting stock, planting season and methods, stock handling, stock characterization, and field assessment may be found in Wood and Dominy (1985).

In the study reported here stepwide multiple linear regression analysis is used to screen out factors influencing plantation performance. Both continuous and categorical type variables were used as predictor variables. For each categorical variable, to distinguish k classes, (k-l) dummy variables are used (see Draper and Smith 1966, Chatterjee and Price 1977, Sokal and Rohlf 1981). For example, as shown in Table 1, a two category variable, such as weed control, planting season, and stock type, is represented by a single dummy variable D, which takes the value of 1 if the case belongs to the first category and zero, otherwise. The three site preparation methods (mechanical, chemical, and prescribed burn) are assigned the two dummy variables of D_1 and D_2, where: 1.0 represented mechanical, 0.1 represented chemical and 0.0 represented prescribed burn as site preparation methods, respectively. In this case, the third category or prescribed burn is used as the reference point, i.e., the other two categories are compared against it. Either of the other two categories could have been used as the reference.

Some of the soil and site variables were originally described by multi-category variables. For example, soil texture was described as: very fine sand, sandy loam to medium sand, silty to sandy clay, clay loam to silty clay, sandy clay-loam to silty clay, silt-loam, loam, fine sand, silt loam, loam, and silty-clay loam. Since only two of the eleven descriptive classes in soil texture were the same, it was first treated as a 10 class categorical variable, however, due to low frequency and extremely poor correlations with either survival or height it was reduced to a four class categorical variable of: a) sandy, b) silty, c) loam and d) clay. Similarly soil moisture was reduced to a three class categorical variable of: a) fresh, b) moist, and c) very moist. However, since none of the soil variables showed significant correlation with any of the response variables, they are further reduced into a two category site variable of upland and lowland. This is represented by a single dummy variable for site type which takes the value of 1 if it is upland and zero otherwise (see Table 1).

Stepwise multiple linear regression is employed to express survival, total height or height increment of each species as a function of: a) categorical variables (soil type, stock type, site preparation methods and weed control), B) categorical variables and planting stock measurable characteristics, and C) categorical variables, planting stock measurable characteristics and plantation age (see Tables 3-9).

It is well recognized that plantation survival and total height may be best expressed as an exponential decay and sigmoidal functions of time or plantation age, respectively. However, they are expressed as linear functions of the above mentioned variables to demonstrate the relative effects of various factors on plantation performance. Once variables with significant effects on plantation performance are identified, appropriate nonlinear models will be used to express survival rate and total height as functions of plantation age and other significant factors.

Analysis and Results

The statistical summary of the data used in this analysis is given in Table 2. This table indicates that of the three response variables, survival rate was the most homogeneous one followed by total height and height increment. Of the three species black spruce was the most homogeneous data set followed by white spruce and jack pine.

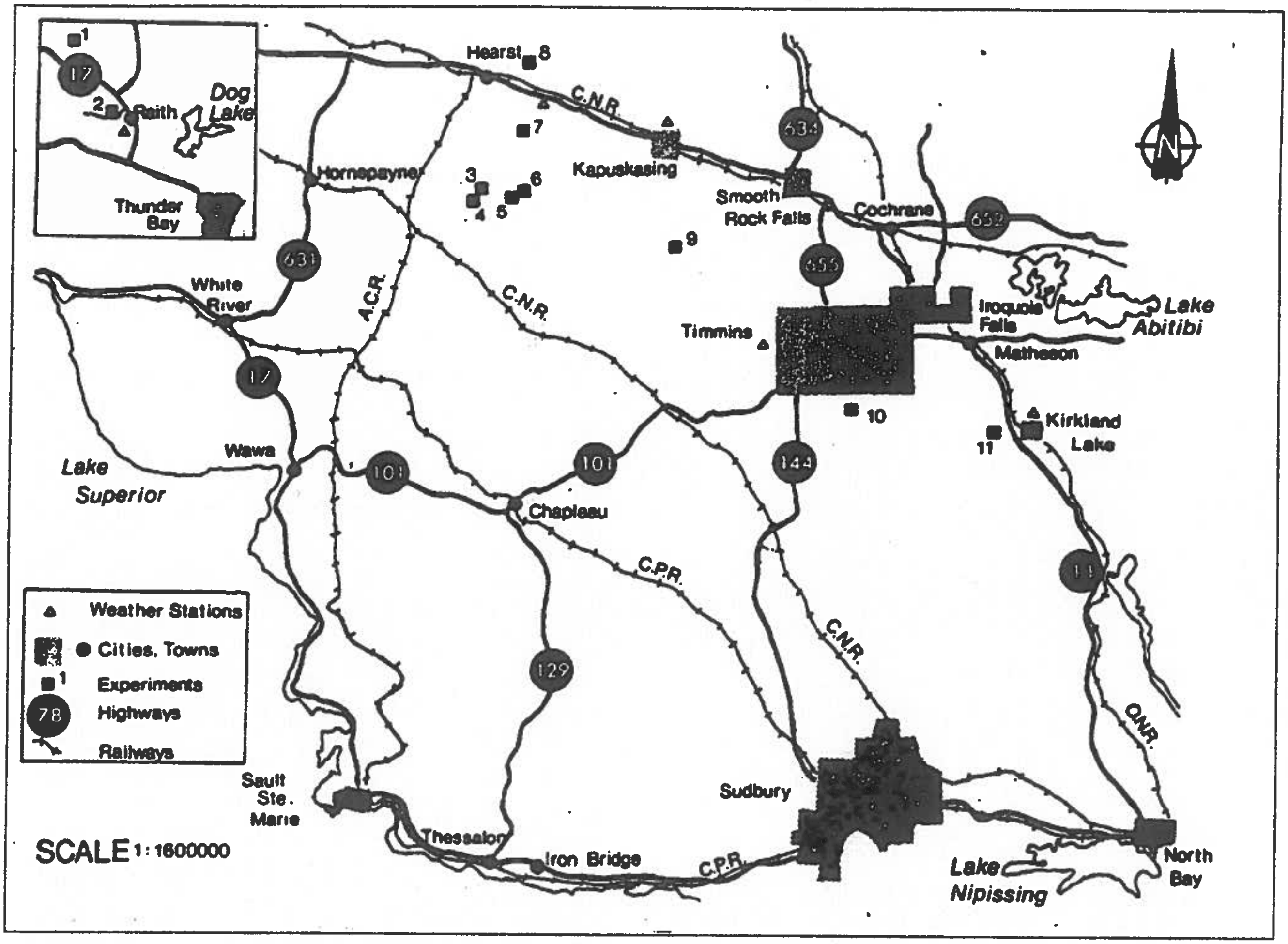

Figure 1. Location of experimental plantings and weather stations used to collect weather data, in relation to Northern Ontario cities, towns, and transportation routes.

The resulting stepwise multiple linear regression analyses are summarized in Tables 3 to 9. Categorical variables included in the regression equations are shown by [ ] to emphasize that they are represented by dummy variables. Each dummy variable takes the value of one if the case belongs to that class and thus it increases or decreases (depending on the sign) the estimated value of the response variable by its coefficient. If the case does not belong to that class, the dummy variable takes the value of zero, and thus the term drops out of the equation.

The regression equations for black spruce outplanting survival show that stock type [ST] is the first categorical variable entering the regression equation (Table 3, A). The value of R^2 (i.e., adjusted R^2) indicates that this variable, although statistically significant, accounts for only 9.7% of the variability in black spruce survival. The regression equation, S = 0.908 - 0.889 [ST], means that based on this single variable alone, the estimated survival would be = 0.908 - 0.089 [1] = 0.819 (i.e., 81.9%) for bare root stock and S = 0.908 - 0.089 [0] = 0.908 (i.e., 90.8%) for the container stock. It also indicates that black spruce container stock averaged 8.9% higher survival than the bare root stock.

The second equation of Table 3 indicates that transplanting [TP] of bare root stock was the second most significant variable entering the regression equation. It accounted for an additional 14.8% of the variability. It indicates that, for the data set used here, on the average black spruce survival for bare root transplants was about 15% higher than the nontransplants. The third variable entering the regression equation is chemical site preparation [SPC] which accounts for an additional 1.4% of the variability. This equation indicates that on the average, black spruce survival on chemically prepared sites was 5.3% less than the prescribed burn sites (prescribed burn was used as reference point as defined by two dummy variables D_1 and D_2, see Table 1). Planting season [PS] was the next significant variable entering the regression equation accounting for an additional 1.3% of the variability. This equation indicates that, for the data set in question, the survival of spring planted black spruce stock averaged 3.5% lower than that in summer plantings. The last categorical variable entering the regression equation is the container size [CS] which accounts for an additional 1% of the total variability. This equation indicates that on the average survival of the FH 408 paperpot was 3.7% greater than those of the FH 308 paperpot.

Section B of Table 3 provides equations expressing black spruce survival as a function of categorical variables and planting stock measurable characteristics. The first two equations of this section are the same as in section A. The next equation indicates that height increment was the third sig-

Table 2. Summary statistics of the continuous variables for the three species black spruce, white spruce and jack pine from 18 experimental outplantings in northern Ontario.

Variable name	Black spruce Mean	Black spruce Coefficient of variation %	White spruce Mean	White spruce Coefficient of variation %	Jack pine Mean	Jack pine Coefficient of variation %
Total height (cm)[a]	29.36	57.3	21.61	57.7	42.76	103.7
Height increment[a] (cm)	7.59	122.3	4.68	136.8	22.41	102.9
Initial height[b] (cm)	17.11	44.6	14.32	55.0	14.75	50.4
Dry weight[c] (g)	2.66	90.8	3.37	97.3	2.54	102.3
Root collar[c] (mm)	2.87	46.2	3.22	52.6	2.55	78.1
Root area index[c] (cm^2)	20.17	87.4	21.72	85.6	20.76	95.4
Shoot-root-ratio[c]	4.31	67.2	3.59	35.7	3.22	71.0
Quality index[c]	0.26	102.2	0.40	108.1	0.30	110.4
Growing seasons	2.16	78.7	2.10	80.8	2.15	77.0
Survival[d]	0.86	16.3	0.88	14.2	0.86	23.5

[a]Total height and height increment, i.e., previous growing season's height growth, measured over all growing seasons.
[b]Shoot height at the time of planting.
[c]Initial measurement made at the time of planting (see Wood and Dominy 1986 for details).
[d]Average survival rate over all growing seasons.

Table 3. Summary of stepwise linear regression analysis expressing survival[a] of black spruce as a function of site factors, planting stock characteristics, and plantation age in northern Ontario.

Variable in equation	R^2	F	Regression equation
	A) Categorical variables (site and stock factors)		
Stock type [ST]	0.097	34.8	S = 0.908-0.089 [ST]
Transplant [TP]	0.245	50.7	S = 0.909-0.161[ST]+0.150[TP]
Site preparation [SPC]	0.259	36.3	S = 0.916-0.168[ST]+0.163[TP]-0.053[SPC]
Planting season [PS]	0.272	29.1	S = 0.933-0.175[ST]+0.169[TP]-0.071[SPC]-0.035[PS]
Container size [CS]	0.282	24.4	S = 0.915-0.180[ST]+0.195[TP]-0.062[SPC]-0.044[PS]+0.037[CS]
	B) Categorical variables and planting stock characteristics		
Stock type [ST]	0.074	34.8	S = 0.908-0.098[ST]
Transplant [TP]	0.245	50.7	S = 0.909-0.160[ST]+0.150[TP]
Higher increment [HI]	0.345	54.8	S = 0.947-0.167[ST]+0.156[TP]-0.005HI
Quality index [QI]	0.384	48.7	S = 0.935-0.202[ST]+0.095[TP]-0.005HI+0.178QI
Site preparation [SPC]	0.405	42.3	S = 0.940-0.216[ST]+0.095[TP]-0.005HI+0.209QI-0.077[SPC]
	C) Categorical variables, planting stock characteristics and plantation age		
Growing season (X)	0.234	96.26	S = 0.950-0.040X
Stock type [ST]	0.332	77.73	S = 0.995-0.040X-0.080[ST]
Transplant [TP]	0.478	95.26	S = 0.994=0.040X-0.159[ST]+0.150[TP]
Quality index [QI]	0.508	80.38	S = 0.982-0.039X-0.189[ST]+0.097[TP]+0.154QI
Site preparation [SPC]	0.530	69.96	S = 0.988-0.039X-0.205[ST]+0.201[TP]+0.186QI-0.67[SPC]
Height increment [HI]	0.555	64.15	S = 1.000-0.060X-0.195[ST]+0.104[TP]+0.165QI-0.073[SPC]-0.005HI

[a]Survival may be best expressed as an exponential decay function over time (growing season). Here, it has been expressed as a linear function of planting stock, site characteristics and other variables to demonstrate the relative contribution (or effect) of such variables on black spruce survival.

nificant variable entering the equation accounting for an additional 10% of the variability. The negative sign of its coefficient indicates that the faster growing seedlings had a lower survival rate[3]. Seedling quality index (QI)[4] was the next significant variable entering the regression equation which accounted for an additional 3.9% of the variability. The higher the quality index, the better the rate of survival. Chemical site preparation is the last variable entering the regression equation accounting for an additional 2.1% of the variability. Again the sign of this coefficient is negative indicating that, for the present data set, survival rate on chemically prepared sites was lower than on prescribed burned. The last equation of section B indicates that three of the categorical variables plus two planting stock characteristics account for 40.5% of the total variability in black spruce survival.

The first equation of section C of Table 3 indicates that number of growing seasons or time since planting is the most significant single predictor variable, accounting for 23.4% of the variability in black spruce survival. The next two variables entering the regression model were stock type and transplanting, accounting for 9.8% and 14.6%, respectively of the variability in black spruce survival. The next three variables entering the regression equations are quality index, chemical site preparation, and height increment. Although statistically

Table 4. Summary of stepwise linear regression analysis expressing total height[a] as a function of site factors, planting stock characteristics, and black spruce plantation age in northern Ontario.

Variable in equation	R^{-2}	F	Regression equation
	A) Categorical variables (site and stock factors)		
Stock type [ST]	0.106	37.1	H = 23.73+10.92[ST]
Site preparation [SPC]	0.124	20.9	H = 23.01+10.96[ST]+5.56[SPC]
	B) Categorical variables and planting stock characteristics		
Initial height [IH]	0.137	49.6	H = 15.43+0.81[IH]
Quality index [QI]	0.155	28.6	H = 16.85+0.56[IH]+11.01[QI]
	C) Categorical variables, planting stock characteristics and plantation age		
Growing season [X]	0.634	544.5	H = 12.35+7.86X
Root collar dia. [RCD]	0.771	525.5	H = -1.12+7.87X+4.69[ORCD]
Initial height [IH]	0.780	367.9	H = -2.26+7.86X+2.540[RCD]+0.674[IH]+15.25[QI]
Quality index [QI]	0.791	294.8	H = 0.80+7.87X-1.403RCD+0.674IH+15.25QI
Site preparation [SPC]	0.796	303.9	H = -1.18+7.86X+0.623IH+8.869QI+4.286[SPC]
Weed control [SPC]	0.807	259.3	H = 4.69+7.83X+0.625IH+9.690QI+7.440[SPC]+4.382[WC]

[a]Total height may be best expressed as a sigmoidal function of time (growing season). Here, it has been expressed as a linear function of planting stock, site characteristics, and time to demonstrate the relative contribution (or effect) of such variables on total height.

Table 5. Summary of stepwise linear regression analysis expressing total height[a] as a function of site factors, planting stock characteristics, and black spruce plantation age in northern Ontario.

Variable in equation	R^{-2}	F	Regression equation
	A) Categorical variables (site and stock factors)		
Weed control [WC]	0.121	36.9	S = 0.824+0.091[WC]
Container size [CS]	0.160	25.4	S = 0.802+0.087[WC]+0.050[CS]
Site preparation [SPC]	0.182	19.9	S = 0.811+0.081[WC]+0.046[CS]-0.162[SPC]
	B) Categorical variables and planting stock characteristics		
Weed control [WC]	0.121	36.9	s = 0.824+0.091[WC]
Height increment [HI]	0.222	39.7	S = 0.852+0.100[WC]-0.007[HI]
Container size [CS]	0.261	32.8	S = 0.830+0.094[WC]-0.006[HI]+0.05[CS]
*Dry weight [DW]	0.370	20.0	S = 0.769+0.107[WC]-0.007[HI]+0.062[CS]+0.307[QI]-0.054[ST]+0.023[SRR]+0.049[SOI]-0.028[DW]
	C) Categorical variables, planting stock characteristics and plantation age		
Growing season [X]	0.301	120.54	S = 0.969-0.041X
Weed control [WC]	0.416	99.19	S = 0.914-0.041X+0.088[WC]
Container size [CS]	0.459	78.54	S = 0.893-0.041X+0.082[WC]+0.052[CS]
Height increment [HI]	0.499	68.96	S = 0.910-0.060X+0.069[WC]+0.055[CS]+0.007[HI]
Quality index [QI]	0.530	62.34	S = 0.878-0.060X+0.074[WC]+0.070[CS]+0.006[HI]+0.074[QI]
Stock type [ST]	0.544	54.60	S = 0.887-0.059X+0.076[WC]+0.073[CS]+0.006[HI]+0.083[QI]-0.037[ST]
Shoot-root ratio [SRR]	0.559	49.56	S = 0.840-0.059X+0.071[WC]+0.080[CS]+0.006[HI]+0.104[QI]-
0.057[ST]+0.014[SRR]			

[a]Survival may be best expressed as an exponential decay function over time (growing season). Here, it has been expressed as a linear function of planting stock, site characteristics and other variables to demonstrate the relative contribution (or effect) of such variables on black spruce survival.
*Steps 4-7 were omitted to condense the table.

significant the last three variables account for only 3.0%, 2.2% and 2.5% of the total variability, respectively. The last equation containing six predictor variables (three quantitative and three categorical variables) explains 55.5% of the total variability in black spruce outplanting survival.

For the plantations examined, the last predictive equation may be interpreted as follows: Black spruce survival is a decreasing function of time; the rate of survival for bare root stock averaged 19.5% less than that of container stock while transplanting improved bare root stock survival by 10.4%; black spruce survival on chemically prepared site averaged 7.3% less than the prescribed burns (see footnote ?); survival was positively related to planting stock quality index, but negatively related to height increment.

Table 4 summarizes the stepwise linear regression equations expressing black spruce total height as a function of site factors, planting stock characteristics and plantation age. Section A of this table indicates that, as with survival, the most significant categorical variables was stock type which accounted for 10.6% of the variability. However, the posi-

Table 6. Summary of stepwise linear regression analysis expressing white spruce total height[a] as a function of site factors, planting stock characteristics, and plantation age in northern Ontario.

Variable in equation	R^2	F	Regression equation
A) Categorical variables (site and stock factors)			
Stock type [ST]	0.242	89.2	H = 14.18+12.47[ST]
Planting season [PS]	0.270	51.5	H = 15.98+12.77[ST]+4.19[PS]
Weed control [WC]	0.288	37.5	H = 14.08+12.87[ST]+5.00[PS]+3.57[WC]
Container size [CS]	0.307	30.7	H = 15.64+12.35[ST]+4.32[PS]+3.78[WC]-3.55[CS]
B) Categorical variables and planting stock characteristics			
Initial height [IH]	0.392	180.7	H = 7.40+0.992[IH]
Quality index [QI]	0.401	93.4	H = 8.86+0.742IH+5.37QI
Weed control [WC]	0.410	64.4	H = 7.76+0.700IH+6.82QI+2.51[WC]
C) Categorical variables, planting stock characteristics and plantation age			
Growing season [X]	0.464	242.4	H = 11.100+4.99X
Initial height [HI]	0.844	778.5	H = 2.870+4.947X+0.982IH
Weed control [WC]	0.852	534.9	H = 3.878+4.947X+0.979IH+1.689[WC]
Quality index [QI]	0.858	419.8	H = 2.892+4.914X+0.765IH+2.231[WC]+4.564QI
Dry weight [DW]	0.861	341.6	H = 3.726+4.928X+0.905IH+2.386[WC]+9.108QI-0.917DW

[a]Total height may be best expressed as a sigmoidal function of time (growing season). Here, it has been expressed as a linear function of planting stock, site characteristics, and time to demonstrate the relative contribution (or effect) of such variables on total height.

tive coefficient for stock type indicates that, after five growing seasons, total height of bare root stock averaged 10.92 cm greater than those of the containers. The second categorical variable entering the equation was chemical site preparation which indicates that total height averaged about 5.56 cm greater on chemically prepared sites than on prescribed burns. The latter variable accounted for only 1.8% of the variability. None of the other categorical variables had any significant effect on total height.

Section B of Table 4 indicates that initial height (seedling height when planted) and planting stock quality index were the two significant variables accounting for 15.5% of the variability. It should be noted that stock type and chemical site preparation did not prove to be significant in the presence of initial height and quality index. Total height was higher on the average for seedlings with higher quality index and initial height.

Section C of Table 4 shows that time since planting (plantation age) is the most significant single variable affecting total height of black spruce accounting for 63.4% of the variability. The first equation of Section C indicates that on the average total height increased by 7.86 cm per growing season. The second significant variable affecting total height was root collar diameter (at the time of planting) which accounted for an additional 13.7% of the variability. The larger the initial root collar diameter, the higher the total height. The next four variables entering the equations were initial height, planting stock quality index, chemical site preparation and weed control, each accounting for only about 1% of the total variability. The last equation containing three continuous and two categorical variables accounted for about 81% of the total variability in total height (note that the variable root collar diameter was removed from the equation due to interaction with other variables entering the equation in later steps). The last equation indicates that mean total height of black spruce outplantings increased as time, initial height, and quality index increased. It was on the average 7.44 cm higher on chemically prepared sites than those on prescribed burns. Total height on sites sprayed for weed control averaged 4.38 cm higher than the untreated sites.

Tables 5 to 8 summarize the resulting regression equations for white spruce and jack pine survival and total height, respectively. Detail description and interpretation of the results are similar to those for black spruce, given elsewhere (Payandeh and Wood 1986), and thus omitted here. Table 9 provides the summary of stepwise regression analysis expressing height increment as a function of site factors, planting stock characteristics and plantation age for the three candidate species, respectively.

The last equation for black spruce indicates that height growth was positively affected by time since planting, chemical site preparation and weed control, but decreased as shoot-root-ratio increased. For white spruce, time since planting was the most important factor affecting height growth while weed control had a positive and minor effect. No other variables affected white spruce height growth significantly. Finally jack pine height increment was strongly and positively correlated with plantation age and quality index, but was negatively influenced by the root-collar diameter.

Summary and Discussion

Results showed considerable differences among factors influencing plantation survival and growth among the three species studied. In general, survival is more hetero geneous and influenced by more factors than growth and therefore may not be predicted as precisely as height growth. Considering all factors, plantation survival may be predicted with very good precision (R^2 ranged from 0.56 to 0.76) based on up to seven predictor variables and plantation height may be predicted with even greater precision with the same or fewer variables (R^2 ranged from 0.81 to 0.86).

From two to five of the qualitative factors considered had statistically significant but minor effects on the survival and growth. For example, although black spruce survival was correlated with planting stock type (i.e, bare root or containers, transplant or not, and container size), planting season, and chemical site preparation, all these factors combined explained less than 23% of the variability in the survival rate for black spruce. In case of white spruce, weed control, container size and chemical site preparation combined accounted for only 18% of the variability, while planting season and stock type were responsible for 18% of the variability in jack pine survival.

Results indicated that white spruce total height was influenced by planting stock, container size, planting season and weed control. These factors combined accounted for about 31% of the variability. Black spruce and jack pine total heights were affected by stock type and chemical site preparation or planting season. These factors accounted for only 12% of the variability in total height. Total height was significantly higher but survival lower for bare root stock as compared to containers for all three species. Larger containers resulted in higher survival but in lower total height. Spring planting resulted in lower survival rate for both black spruce and jack pine than summer planting height for the white spruce. Black spruce survival was also higher for transplants than seedlings.

Of the three site preparation methods (i.e., mechanical, chemical and prescribed burning) chemical site preparation affected survival and height of black spruce and the survival of white spruce. Results indicated that mechanical site preparation had significant but minor effect on jack pine survival accounting only for 1.4% of the variability. Its effect seems to disappear due to time, however. Since mechanical site preparation is one of the more costly aspects of plantation establishment, these results may have far reaching economic and practical implications.

Of the planting stock measurable characteristics examined, quality index was chosen as a significant predictor in every case, although it did not account for a large proportion of the variability. Other variables included initial planting height for all species, total height and height increment for all species survival. Shoot-root-ratio and root area index were also significant in the case of jack pine survival.

Plantation age or the number of growing seasons since planting was the most significant concomitant variable for black and white spruce survival and total height of all species+accounting for up to 30% of the variability in survival and up to 63% of the variability in total height. In the case of jack pine survival, shoot-root-ratio and initial height were the two most significant predictor variables.

Results indicated that plantation height increment may be predicted with a good degree of precision (R2 from 0.65 to 0.74) for the three species based on two to four predictor variables. Plantation age or number of growing seasons since planting is the most significant predictor of height increment for all species. Other variables include: chemical site preparation, weed control and shoot-root-ratio for black spruce;

Table 7. Summary of stepwise linear regression analysis expressing jack pine survival[a] as a function of site factors, planting stock characteristics, and plantation age in northern Ontario.

Variable in equation	R^{-2}	F	Regression equation
A) Categorical variables (site and stock factors)			
Planting season [PS]	0.067	7.3	S = 0.896-0.117[PS]
Stock type [ST]	0.178	10.9	S = 0.965-0.155[PS]-0.142[ST]
B) Categorical variables and planting stock characteristicsa			
Shoot-root-ratio [SRR]	0.315	46.9	S = 1.024-0.05SRR
Initial height [IH]	0.517	54.0	S = 0.886-0.069SRR+0.014IH
Stock type [ST]	0.578	45.6	S = 0.817-0.056SRR+0.020IH-0.168[ST]
Root area index [RAI]	0.622	40.7	S = 0.789-0.036SRR+0.012IH-0.319[ST]+0.005RAI
Height increment [HI]	0.640	34.8	S = 0.817-0.037SRR+0.014IH-0.309[ST]+0.005RAI-0.012HI
Site preparation [SPM]	0.654	30.6	S = 0.736-0.037SRR+0.014IH-0.321[ST]+0.006RAI-0.012HI+0.087[SPM]
C) Categorical variables, planting stock characteristics and plantation age			
Shoot-root-ratio [SRR]	0.315	46.89	H = 1.025-0.050SRR
Initial height (IH)	0.517	54.04	H = 0.886-0.069SRR+0.014IH
Growing season (X)	0.626	55.67	H = 0.978-0.067SRR+0.013IH-0.041IX
Height increment (HI)	0.669	50.00	H = 1.007-0.062SRR+0.010IH-0.079X+0.003HI
Stock type [ST]	0.725	51.70	H = 0.935-0.048SRR+0.016IH-0.082X+0.004HI-0.166[ST]
Weed control [WC]	0.748	47.93	H = 0.911-0.051SRR+0.017IH-0.091X+0.005HI-0.167[ST]+0.074[WC]
Quality index (QI)	0.775	47.24	H = 0.866-0.029SRR+0.013IH-0.082X+0.004HI-0.341[ST]+0.091[WC]+0.293QI

[a]Survival may be best expressed as an exponential decay function over time (growing season). Here, it has been expressed as a linear function of planting stock, site characteristics and other variables to demonstrate the relative contribution (or effect) of such variables on black spruce survival.

Table 8. Summary of stepwise linear regression analysis expressing jack pine total height[a] as a function of site factors, planting stock characteristics, and plantation age in northern Ontario.

Variable in equation	R^2	F	Regression equation
	A) Categorical variables (site and stock factors) only		
Stock type [ST]	0.056	6.0	H = 34.17+21.27[ST]
	B) Categorical variables and planting stock characteristics		
Quality index (QI)	0.093	10.5	H = 30.51+40.61QI
	C) Categorical variables, planting stock characteristics and time		
Growing season (X)	0.742	293.7	H = -6.85+23.03X
Quality index (QI)	0.828	242.7	H = 18.34+22.92X+38.911QI
Root collar diameter (RCD)	0.845	182.2	H = 12.69+22.99X+69.14QI-5.86RCD
Initial height (IH)	0.852	142.7	H = -19.42+23.25X+65.20QI-7.62RCD+0.802IH

[a] Total height may be best expressed as a sigmoidal function of time (growing season). Here, it has been expressed as a linear function of planting stock, site characteristics, and time to demonstrate the relative contribution (or effect) of such variables on total height.

weed control for white spruce; and quality index and root collar diameter for jack pine.

Analyses and results presented here should clearly indicate that both qualitative and quantitative factors affecting plantation growth and survival may be identified and their relative effects or contributions assessed using standard statistical techniques such as correlation and regression analysis. Once the relative effect and significance of various factors are determined, they should be evaluated on the basis of cost and practical consideration. For example, if the analyses indicate that spring planting on the average results in 10% lower survival than summer planting. The desirability of opting for early summer planting should be obvious if there is no difference in planting cost of the two seasons. Again, if mechanical site preparation on the average would improve survival by 5% as compared with prescribed burning, but if it would cost disproportionately more, mechanical site preparation would not be economical.

Careful examination of results presented here may reveal much more useful information on the various factors examined. It should be remembered, however, that stepwise regression analysis is a mechanical method of choosing, i.e, entering and removing the variables in the model, because of the apparent high partial correlation with the response variable. That is, the variables or factors chosen in the model do not necessarily have a cause and effect or biological relationship. They are simply concomitant variables which may directly or indirectly represent a multi-way interaction among variables causing the outcome.

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Table 9. Summary of stepwise linear regression analysis expressing annual height increment as a function of site factors, planting stock characteristics and time since planting for black spruce, white spruce and jack pine outplantings in Ontario.

Variable in equation	R^2	F	Regression equation
			Black spruce
Growing season (X)	0.714	784.3	H = -2.37+4.6X
Site preparation [SPC]	0.722	405.4	H = 2.66+4.56X+2.40[SPC]
Weed control [WC]	0.738	293.0	H = -4.87+4.58X4.64[SPC]_+2.97[WC]
Shoot-root-ratio (SRR)	0.742	224.5	H = -3.85+4.58X+4.11[SPC]+3.06[WC]-0.23SRR
			White spruce
Growing season (X)	0.635	486.8	H = -1.63+3.00X
Weed control [WC]	0.654	264.1	H = -2.80+3.00X+1.85[WC]
			Jack pine
Growing season (X)	0.653	192.1	H = -1.80+11.24X
Quality index (QI)	0.722	131.4	H = 7.18+11.9X+18.2QI
Root collar diameter (RCD)	0.747	98.5	H = -3.69+11.23X+36.87QI-3.62RCD

[1]Site factors, site preparation methods and post planting treatments applied were not intended as design variables in the original experiment. Had such factors been built into a sound experimental design, their effects on plantation performance could have been evaluated better. Nevertheless such factors are treated as random variables in the present analysis to demonstrate how factors affecting plantation performance can be evaluated.

[2]Combining classes of categorical variables because of similarities and/or low frequency is necessary for regression analysis. Since each class is represented by a dummy variable which carries one degree of freedom regardless of its frequency, classes with low frequencies should be avoided, otherwise they would influence the resulting regression relationship disproportionately.

[3]Variables selected in stepwise linear analysis because of high partial correlations with the response variable do not necessarily represent cause and effect relationship. More importantly, often curvilinear relationships exists between a response variable and two or more predictor variables. In such cases one or more of the predictor variables takes the opposite sign to compensate for the curvilinearity relationship. This may appear as contradictory biological relationship, but it usually is not.

[4]Quality index at the time of planting was calculated according to the formula developed by Dixon et al. (1960) as follows: mean seedling total dry weight (g) QI = shoot weight (g) + shoot length (cm) root weight (g) root collar diameter (mm)

Afforestation of Heathlands in Eastern Newfoundland

By: J. Peter Hall and A. Boyde Case

Abstract: The attempts at afforestation of the heathlands of eastern Newfoundland from 1937 to 1970 are described. It is concluded that commercial forests can be established under conditions of sheltered sites, modified by plowing and planting large vigorous seedlings at close spacing. Recommended species include Japanese, European and eastern larch; Scots and jack pine and Sitka spruce. The expected end product will likely be firewood, a product in considerable demand in the area.

Introduction

The barren heathlands of eastern Newfoundland are perhaps the most distinctive feature of the landscape. Vegetation on these barrens consists largely of ericaceous dwarf shrubs and coniferous krummholz growing on thin podzols. Most of these heathlands were created by and are maintained by fire, and Meades (1983, p. 305) considers the "landscape as permanent under prevailing climatic conditions."

The similarities of the Newfoundland heathlands to those of Scotland and Scandinavia have stimulated many proposals during the last fifty years for the afforestation of these areas. Serious attempts were begun about 1937 and continued sporadically until about 1950. Many of the plantings were unsuccessful and in the 1960s various experiments were conducted to see if site modifications and substitution of other tree species would achieve greater success. To date no comprehensive assessment has been made of the plantation trials. This paper integrates the data which have accumulated and makes recommendations on the potential for afforestation of these heathlands.

Description of the area

The areas studied comprise the Avalon and Bonavista peninsulas of eastern Newfoundland between 46°-49°N lat. and 52°-54°W long. The topography is a rolling plateau underlain by a variety of sedimentary and volcanic rocks and drained by many small rivers (Rowe 1972). Soils are thin and composed primarily of nutrient poor humo-ferric and ferric-humo podzols. The climate is strongly influenced by the sea, precipitation is abundant (870-1400 mm) and well distributed throughout the year. Mean temperature in July is 16°C and -5°C in February. Fog is common throughout the year especially in the spring (Wilton 1956; Wilton and Lewis 1956). A further constraint on forest growth is that of wind, this being one of the windiest parts of Canada. Average annual wind speed measured at St. John's Airport is 24.6 kph which is 3.2 kph higher than that permitting production of commercial forests (cf. Nickerson 1968).

Slightly more than one-third of the land mass of the two peninsulas is forested; these forests being dominated by balsam fir (*Abies balsamea* (L.) Mill.) with lesser amounts of white spruce (*Picea glauca* (Moench.) Voss); black spruce (P. mariana [Mill.] B.S.P.) and tamarack (*Larix laricina* Du Roi K. Koch.). Hardwoods occur sporadically in the deeper and more sheltered valleys and consist of white birch (*Betula papyrifera* Marsh.) and the occasional yellow birch (*B. allaghaniensis* Britt.) (Rowe 1972). These forests have been exploited for firewood, lumber and boat building since these areas were first settled in the seventeenth century. Cutting has been unrestricted in quality or quantity and as a result the forest has been degraded to a large extent. Harvesting of firewood occurs among small trees many of which have not produced seeds, and this further reduces the amount of forested land.

The most destructive agent is wildfire. A history of wildfire in eastern Newfoundland has listed a total of 566 fires covering 0.4 ha or more between 1619 and 1960 (Wilton and Evans 1974). Fire in fir forests destroys both seed source and advance growth of fir and burned sites remain unstocked; repeated burning of the forests creates barren lands which are ecologically stable and thus unlikely to revert to forest (Meades 1986). It is estimated that 720,000 ha of barren heathlands occur in eastern Newfoundland, most of which is capable of supporting merchantable forest (Meades 1986).

Heathlands are a common feature in boreal climates and in some areas, Scotland and Scandinavia for instance, heathlands support productive forests. In the coastal areas of Newfoundland wood is in high demand for construction, boat building and increasingly for firewood. The combinations of demand for wood and examples of successful afforestation elsewhere led to the attempts at afforestation of the heathlands in eastern Newfoundland. The afforestation program is described in two parts: plantings from 1937 to 1951 and from 1966 to 1970.

Planting Methods

Except for a few experimental seeding trials (all unsuccessful) attempts at afforestation have involved hand planting of bareroot stock. Planting stock was primarily 2 + 2 for

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spruces; and 2 + 1 or 2 + O for pines (Lewis 1954).

Spacing in the earlier plantations varied from 1. 5-2.1 m (Lewis 1954). In the later series of plantations spacing was 1.8 m; actual spacing was variable because of the rocky nature of the terrain.

For the later plantings the sites were ploughed in order to improve the microsite for planting and early growth (Wilton 1970). A Parkgate Tine Plow pulled by a D-4 caterpillar tractor was used. Furrows were spaced at 1.8 m and trees were planted on the side of the furrow. The trees were fertilized with approximately 60g of ground mineral phosphate applied around the base of each tree.

Species Planted

A wide variety of species has been planted (Table 1). The species mix has varied over the period. Before 1942, plantings used mostly balsam fir and white spruce (Lewis 1954). Because of failures using these species emphasis then switched to jack pine, Scots pine and Norway spruce. By 1944 Norway spruce was the most commonly planted species. In the late 1940s pines became the predominant species. The hardwoods listed in Table 1 were planted in 1946 and 1947 but none were successful and were not used in any later plantings. A test of exotics by the Canadian Forestry Service had shown some promise for Sitka spruce and this was widely used in the second series of plantings (Nickerson et al. 1964). The later plantings also used native black and white spruce and both native and exotic larches.

Seedlings for all trials were grown in Newfoundland. The seed used in the first series was purchased from commercial seed dealers and little or no information is available as to seed source. Most seed sources are known from the second series of plantings (Appendix I). A variety of species was planted in the different plantations, but not all were replicated at each site.

Table 1. Species planted in afforestation trials.

Scientific Name	Common Name
Pinus resinosa (Ait.)	Red Pine
P. strobus (L.)	White Pine
P. banksiana (Lamb.)	Jack Pine
P. contorta (Dougl.)	Lodgepole Pine
P. ponderosa Laws.	Ponderosa Pine
P. sylvestris L.	Scots Pine
P. nigra Arn. *v. austriaca* (Huess) Aschers	Austrian Pine
P. nigra Arn. *v. corsicana* (Loud.)	Corsican Pine
Picea mariana (Mill.) B.S.P.	Black Spruce
P. glauca (Moench.) Voss	White Spruce
P. rubens (Sarg.)	Red Spruce
P. sitchensis (Bong.) Carr.	Sitka Spruce
P. englemannii (Parry)	Englemann Spruce
P. abies (L.)	Norway Spruce
P. jezoensis (S. & Z.) Carr.	Hondo Spruce
Larix laricina (Du Roi) K. Koch	Tamarack (Eastern Larch)
L. decidua (Mill.)	European Larch
L. kaempferi (Lam.) Carr.	Japanese Larch
Abies balsamea (L.) Mill.	Balsam Fir
Betula papyrifera (Marsh.)	White Birch
B. japonica (Winkl.)	Japanese White Birch
Quercus rubra (L.)	Red Oak
Ulmus americana (L.)	American Elm
Acer saccharinum (L.)	Silver Maple
Fraxinus (L.) spp.	Ash

Plantation Assessments

The various plantations were assessed for survival and height growth at various stages during their development. Survival counts were commonly done within one to two years and reasons for mortality assessed. Since then there have been sporadic measurements of height. In 1985-86 remeasurements were made in four plantations on the Avalon Peninsula when the planted trees were 20 years from seed.

Results and Discussion

Plantations Established Between 1937 – 1951

Several plantations were established by the Newfoundland Government between 1937 and 1951 and covered an estimated 800 ha (Lewis 1954).

Assessments of the planted areas in 1952 indicated a total of 12.6 ha to be successful, i.e., likely to form a merchantable stand. Nearly all of this successfully afforested area was in the Colliers plantation. Measurements were taken at the Colliers plantations when the trees were 38 years old (Table 2). Most trees however, were crooked and poorly formed and suitable only for firewood. Tree form in the other plantations was also poor. Trees in the plantation have been cut for firewood during the last few years.

The account given by Lewis 1954 (p. 6) describes the plantations rated as failures. He states:

"In 1942, a part of the area was planted with local balsam fir and white spruce. In the ensuing eight years nearly all these trees died and the majority of the few alive are badly stunted.

"The next planting was made in 1947 when a small number of Scots pine, silver maple, white spruce, American elm, and white birch were set out. The examination revealed that none of the hardwoods and few of the pine and spruce were still living. Again it was found that the surviving trees were in small sheltered pockets, but were too scattered for measurement. A further planting was made in 1948 with 25,000 Scots pine and 20,000 jack pine. Only a few of these trees can be found scattered over the area. The final planting was made in 1951 with 31,000 Scots pine of which few are expected to survive.

"An examination of the soil at various places on the plantation indicated the usual red sandy loam, but very compact and rocky. Further planting on this location appears useless, at least for those species already tried."

Eight other plantations were also examined by Lewis (1954); these were planted between 1949 and 1951 and covered about 700 ha. All were failures with none likely to form a merchantable stand. By the 1980s almost no traces of these plantations remain. The conclusions reached by Lewis (1954) concisely sum up the results of early afforestation attempts (pp. 13-14).

Table 2. Height growth of species planted in three plantations.

	Total Height (m) in Each Plantation at Age[1]					
	Species	Age	Colliers (12)	Colliers (38)	Bonavista (9&11)	Catalina (9&11)
Jack pine	1.27	5.87	.79	(9)	.48	(9)
Scots pine	1.35	8.46[2]	.56	(9)	.38	(9)
White pine	—	—	.25	(11)	.25	(11)
Red pine	—	—	—	—	.28	(11)
Norway spruce	—	—	.61	(11)	.38	(11)

[1]Age from seed in (years) - planting stock assumed to be 2 + 2.
[2]This species planted on a sheltered forested site on the Avalon Peninsula averaged 12.0 m at age 45

It was concluded that:

1. Exposure rather than soil conditions plays the major role in plantation failure;
2. Fencing of plantations to prevent browsing by livestock is a necessity except in remote areas;
3. Plantations of hardwood species have been complete failures;
4. The successful afforestation of large expanses of open barren land such as are found on the Avalon and Burin peninsulas and elsewhere in Newfoundland cannot be accomplished by ordinary planting methods with any species tried to date. Instead, highly specialized techniques are required, and much research would be required to determine which of these methods would be most applicable to Newfoundland conditions;
5. The afforestation of sheltered slopes and hollows in unsheltered windswept barren country is possible by planting Scots pine and jack pine;
6. Red pine and Norway spruce are suitable for planting in southeastern Newfoundland in openings in existing stands or in otherwise well sheltered locations.

As a direct result of the examinations of these early afforestation attempts an experiment was established by the Canadian Forestry Service to test the exposure effects. A variety of exotic species was planted in four exposed sites on the Avalon Peninsula (Nickerson et al. 1964). At each site planting was done in a microsite of maximum, minimum and average exposure. Survival and growth were best where exposure was least. A combination of suitable species and seed source and adequate planting site showed that successful establishment and subsequent tree growth were possible. Both Scots pine and Sitka spruce were found suitable. The experiment showed that there was a marked affinity between success of the shrub, mountain alder (*Alnus crispa* (Ait.) Pursh) and the success of Sitka spruce.

These early studies showed many of the limitations in afforesting heathlands and also indicated directions for future research. Conclusions and recommendations from these studies are:

(i) Exposure is a major reason for plantation failure; it cannot be modified but it can be avoided. Sheltered topography can be selected for planting and some potential for mutual shelter in plantations might be achieved.

(ii) A variety of species proved successful on exposed sites - jack pine, Scots pine, Sitka spruce, red pine and Norway spruce.

(iii) A fortuitous combination of site (moist, sheltered), ground cover (mountain alder) and reforestation species (Sitka spruce) proved to be quite successful.

(iv) The nearly uniform failure of plantations on the Bonavista Peninsula resulted in abandonment of attempts at afforestation there. The heaths of the area, dominated by *Empetrum nigrum* and/or *E. eamseii* were on exposed headlands and were more severely exposed than the Kalmia heaths of the Avalon Peninsula.

Plantations Established between 1966 – 1970

The second series of plantations, established on heathlands between 1966 and 1970 were on sites treated by ploughing (Evans and Salter 1969). The plowing treatment was in response to an earlier recommendation for specialized site treatments needed to enhance tree establishment. The ploughing treatment broke up the organic layer which ranged in depth from 10 to about 50 cm. The trees were then planted in the area of mixed organic matter and mineral soil. Most of the sites were quite rocky and had varying degrees of exposure. Four areas on the Avalon Peninsula were ploughed and subsequently planted to a variety of species. Species planted included red, jack and Scots pine; eastern larch, white birch and the following spruces, black, white, red, Englemann, Norway and Sitka.

Seedlings were frost-heaved as a result of a mild winter with little or no snow cover in 1967-68. Seedlings were replanted in May-June, 1968. Richardson (1968) studied the problem in the Come-by-Chance plantation where frost upheaval was most widespread and concluded that the problem might be alleviated by several approaches including the

Table 3. Percentage survival over two periods in four plantations on plowed heathlands (1966-70 series).

Percentage Survival[1], Each Plantation, Each Measurement								
Species/	Avondale		Come-by-Chance		Chapel Arm		Mobile	
Seedling Age	15	20	8	20	8	20	8	20
Jack Pine	90	90	—	—	0	0	—	—
Scots Pine	53	50	60	56	41	40	—	—
Black spruce	46	42	54	40	63	30	70	40
White spruce	31	28	—	—	—	—	—	—
Norway spruce	—	—	—	—	—	—	78	60
Sitka spruce	21	16	56	38	21	15	76	60
Eastern larch	81	78	72	70	37	32	—	—

[1]Survival is estimated; based on number of live trees in a plot of 0.04 ha.

use of larger planting stock (i.e. 2 + 2 or older) or deeper planting. Avoidance of the problem might be accomplished by using shelterbelts or by delaying establishment until there is a cover of natural vegetation including grasses. This was observed at Avondale where the natural vegetation reduced frost upheaval during the same period.

The plantations were measured in 1972, six years after establishment (Case 1977). Survival was again measured when the trees were 20 years old from seed (17 years from planting). Most mortality apparently took place during the first few years of establishment and has not increased by much since. Best survival was at Avondale where as noted there was some considerable ground vegetation which afforded protection (Table 3). Lowest survival was at Chapel Arm, considered to be the most exposed of the four (Case 1977).

Among the various species jack pine and eastern larch had excellent survival at Avondale but not at all plantations. Black spruce probably had the best overall survival. The data indicate that, except in the most exposed locations, it is possible to establish trees on these heathlands. The more sheltered sites at Mobile and Avondale had the best survival. At Mobile, which had much of its shelter provided by alder, survival of two exotic spruces, Sitka and Norway, was superior to black spruce. Data from an unrelated experiment, a provenance trial of Sitka spruce which included local black and white spruce, also showed the Sitka spruce to have superior survival (Sitka spruce 64-84%, black spruce 39%, white spruce 37%.) The affinity for Sitka spruce and alder has been noted previously (Nickerson et al. 1964).

Height growth has been greatest at Avondale where better site conditions have permitted development of a closed stand (Table 4). While many trees have been deformed by the wind, in most cases a reasonably straight stem exists and the afforestation attempt is considered to have been successful

At Come-by-Chance, which is intermediate in exposure between Chapel Arm and Mobile, trees grew only on microsites where some shelter was provided by shrubs and small trees. Erosion had occurred in the furrows and a number of small trees had been washed away. However the depressions and hollows provided protection for others.

Growth was poorest at the most exposed site at Chapel Arm. The organic layer was shallow, 10 cm or less, and it was much broken up by plowing. While erosion resulted in significant mortality, it again created some microsites where nutrient sinks and shelter allowed for the development of healthy foliage. All species have been affected to some degree by wind and exposure but only spruce has developed the distinctive krummholz characteristic of alpine tundra areas (Arno and Hammerly 1984). This has occurred at all plantations except Avondale. Characteristically all shoots above snow line were killed by winter desiccation leaving a mat of healthy foliage which may be a meter or more in diameter but about 15-30 cm tall.

At Mobile the plowing was quite beneficial and broke up the deep (50 cm) organic layer. Natural vegetation was more abundant on this site than on the others and consisted of alders, ericaceous dwarf shrubs, sphagnum moss and sedges.

A comparison of species, shows eastern larch to be by far the best, followed by jack and/or Scots pine. Unlike the spruces, larch and pines seem hardy enough to survive above the snow line. Sitka spruce survives well but does not grow on exposed sites (Table 4). At 20 years from seed it is not yet a meter tall on any of the four sites. By contrast, measurement of some 20 year old Sitka spruce of the same provenance when planted on a good forested inland site on the Avalon Peninsula reached an average height of 4.49 m. (Hall, J.P. unpub. data.)

The data on the four plantations has indicated wide species to species variation in survival and growth. One of the objectives of the afforestation trials was to determine which species to plant. A species trial was established at Avondale approximately 2 km from the one already described (Salter and Evans 1976). A total of 3,476 trees of several species was planted in June 1970. No remeasurements were made until the trees were 20 years from seed (Table 5).

Data show survival to be low except for Japanese larch and red spruce. Larches have by far the best growth; spruces the poorest. Japanese larch, a species shown to have proven the best of the exotics on several sites in Newfoundland, has outgrown all others (Hall 1982).

Conclusions

Afforestation of the heathlands of eastern Newfoundland is a difficult process limited by conditions such as wet stony soils and high winds which are beyond our ability to control. Within these parameters, however, there are possibilities and opportunities which can be exploited to produce commercial forests.

1. Planting sites must be chosen carefully. Lower slopes where shelter is provided by topography and established vegetation (alders) should be selected. A method of measuring exposure where tatter flags were used to integrate exposure effects was developed by Nickerson (1968). Potential afforestation sites were monitored with these flags. Sites where the tatter rate exceeded one square inch (6.45 cm^2) per day, he considered to be marginal for forest production.

Table 4. Average total height of planted trees over two periods in four plantations (1966-70 series).

Average Total Height (cm), Each Plantation, Each Measurement								
Species	**Avondale**		**Come-by-Chance**		**Chapel Arm**		**Mobile**	
Seedling Age	**15**	**20**	**8**	**20**	**8**	**20**	**8**	**20**
Jack pine	328	480	—	—	—	—	—	—
Scots pine	273	412	54	156	46	102	—	—
Black spruce	120	173	38	72	34	57	34	66
White spruce	121	233	—	—	—	—	—	—
Norway spruce	—	—	—	—	—	—	31	154
Sitka spruce	62	72	34	30	25	49	35	53
Eastern larch	412	569	71	328	68	179	—	—

2. Site modification by mechanical preparation can be used to promote drainage and to provide an adequate soil/organic matter mix which permits seedling establishment.

3. Seedlings should be planted deeply to avoid frost upheaval and plantations monitored closely. Frost-heaved seedlings can usually be replanted successfully. Advantage should be taken of favorable microsites within the plantation area.

4. Seedlings should be fairly large, at least 2 + 2 for spruce and pine and 2 + 1 for larch with vigorous well-developed root systems.

5. Several species seem suitable for planting; the three larch species, eastern larch and Japanese and European larch are easy to establish and outgrow all other species planted on the same sites. Also, both jack and Scots pine, which are slower growing than larch, tolerate exposure well. Sitka spruce grows well when planted on sites where there is a cover of alder. A narrow range of spacing, 1.5 to 2.One m has been used in plantation establishment and no replicated spacing trials have been established on these heathlands. However, given the potential value in mutual shelter, closer rather than wider spacing should be used.

7. Consideration must be given to the final product. It is not likely that afforestation of the heathlands will result in production of timber of saw log quality; rather firewood will be the eventual product. This product, once out of favor, is now in wide demand and can be produced close to the market.

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Table 5. Species planted, survival and growth at Avondale 20 years from seed.

Species planted	Seedlot	Survival (%)	Height (cm)	Diameter (cm)
Scots pine	49	30	271	4.7
Scots pine	51	51	251	4.0
Austrian pine	92	7	261	5.2
Austrian pine	107	0	-	-
Corsican pine	56, 108[1]	4	247	4.2
Black spruce	160	27		
White spruce[2]	-	-	265	
Red spruce	26	80	146	2.0
Hondo spruce	52	44	134	
European larch	102	62	435	7.6
European larch	134	16	410	6.9
Japanese larch	129[3]	41	557	10.6
Japanese larch	129	96	557	9.9

[1]A mixture of the two seedlots was planted and it was not possible to separate the lots when measured.
[2]An unknown number of local wildlings was planted.
[3]This seedlot was planted as 4 + O seedlings, the other as 3 + 1.

Appendix I. Seed origin of species planted on ploughed heathlands, 1966-70.

	Seedlot	
Species	**No.**	**Origin**
Jack pine	23	Newcastle, North. Co., New Brunswick
Scots pine	49	Kilen, Norway
Scots pine	51	Vilppula, Kuorevesi, Finland
Scots pine	55	Speymouth Forest, Morayshire, Scotland
Austrian pine	92	Lower Austria
Austrian pine	107	Central Europe
Corsican pine	56	Sherwood Forest, Notts., U.K.
Corsican pine	108	Southern Europe
Black spruce	160	West Branch L., Badger, Nfld.
White spruce	24	Guysborough Co., Nova Scotia
Red spruce	26	Northumberland Co., New Brunswick
Englemann spruce	35	Kamloops, British Columbia
Sitka spruce	29	Terrace-Nass River, British Columbia
Norway spruce	50	Vilppula, Finland
Hondo spruce	52	Tokyo Univ. Forest, Hokkaido, Japan
Eastern larch	27	Guysborough Co., Nova Scotia
European larch	102	Central Europe
European larch	134	Germany Region VII (?)
Japanese larch	129	Germany Region VI (?)
White birch	138	Mt. Yatsugatake, Nagano, Honshu, Japan

Natural Fire and the Distribution of Spruce Forests in the Greater Khingan Mountains

By: Hongqui Wu

*Abstract: Lightning caused fires are frequent in the northern Greater Khingan Mountains. Spruce forests have limited distribution, mainly in cold and humid valleys (*Picea koraiensis*) and in hilly areas at 800-1200 m (*P. jezoensis*). The present distribution of spruce forests is discussed on the basis of adaptive strategy (especially to fire), ecological strategy, regeneration and growth of juvenile spruce and larch forests and fire distribution and cycles. These factors provide a scientific basis for the management of spruce forests in the area.*

Introduction

The forest area of the Greater Khingan Mountains is mainly in the northern part of the Mountains. In that area there are few plant species and they are mostly floral elements of East Siberia. Natural Dahurian larch (*Larix gmelinii*) forests are the dominant vegetation form and they are distributed widely. Dahurian larch forests are the prevalent climatic climax. Spruce forests occur only in cold, humid valleys and in hilly areas at elevations of 800 to 1200 m. Picea koraiensis is the principal edificator. The area of spruce forests is very small. Mongolian scots pine (*Pinus sylvestris* var mongolica) forests occur on steep slopes where the soil is dry and barren. Asian white birch (*Betula platyphylla*) forests are the pioneer forest type following fire and are mainly distributed on north-, east-, and northeast-facing slopes which are usually moist. In the south and southeast Greater Khingan Mountains, human disturbance is severe and forest fires are frequent. Dahurian larch forests are destroyed over and over again. They are replaced by broadleaved forests. Dahurian birch (*Betula dahuria*) and Mongolian oak (*Quercus mongolica*) forests become the dominant forest types.

Two dominant factors determining the distribution of plants are rainfall and temperature. Recent research results show that they are of only indirect importance, insofar as they influence the competitive power of the various species. Only at the absolute distribution limit are they of direct importance. Competition among principal trees in the area must be discussed, giving consideration to their adaption, and their adaptive and ecological strategies.

Adaption to Temperature

The principal trees in the area can be put in order according to their cold-resistance (Figure 1). Spruce and fir are very tolerant to cold. But Korean spruce (*Picea koraiensis*) and Yezo spruce (*P. jezoensis*) only occur in very small areas with isolated distributions. Korean pine (*Pinus koraiensis*) and Khingan fir (*Abies nephrolepis*) do not appear in the forests of the area. In the Lesser Khingan and Changbai Mountains, Korean pine can occur at higher elevations than Mongolian oak. Why are there no Korean pine or Khingan fir distributed here and why are spruce forests distributed only in small areas? Therefore, the adaption of trees to moisture will be discussed.

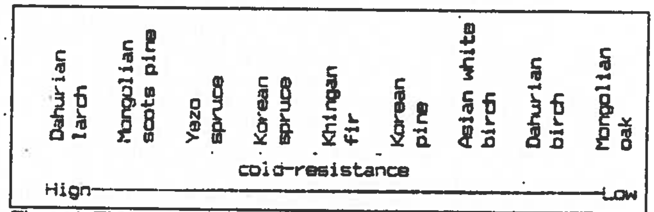

Figure 1. The order of cold-resistance of trees

Adaption to moisture

Based in our investigations and research on man-made forests of Korean spruce in the southern Lesser Khingan Mountains, we believe that the ecological amplitude of Korean spruce is eurytopic and its drought resistance is strong. The principal trees can be put in order according to their drought-resistance (Figure 2). Mongolian scots pine, Dahurian oak and Dahurian birch occupy mountain ridges, south-facing slopes and some dry sites. But why is Korean pine not distributed widely in the area? Although the requirement of Yezo spruce for water is relatively vigorous, why does it occur only in the Mengke Mountains at elevations of 800-1200 m and why is it not distributed on other hills with the same elevation in forest areas?

Adaption to Light

We can also order these trees according to their understory tolerance (Figure 3).

Adaption to Fire

Forest fire is serious in the area. In the north, that is north of the Yilehuli Branch Range, the rate of lightning-caused fire is high (Table 1). There, human disturbance is not severe and primeval forests are dominant (principal edificator is Dahurian larch). Spruce forests occur only in this area. Based on their reproductive characteristics, fire-resistance and adaption of trees after fire, we can divide each of these factors into five classes and give each class a numerical value. According to the sum of the numerical values, we can decide the fire-adaptation capacity of the trees (Table 2). The distribution of these trees and fire cycles have a close relationship (Table 3). Table 3 shows that the fire cycle is shorter, conifers infrequent and broadleaved trees are more frequent from the north to the south in the forest area in response to their order of fire-adaptation capacity. In the light of the

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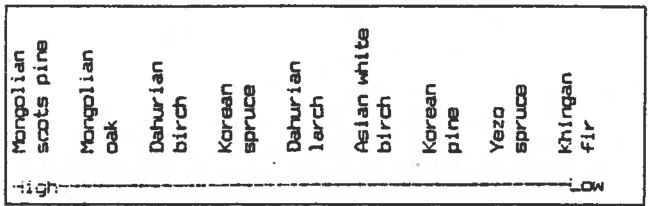

Figure 2. The order of the dry resistance of the principal trees.

above-mentioned considerations, we believe that disturbance by fire has become the limiting factor affecting the distribution of the trees in the area. Particularly, lightning-caused fire allows spruce forests to only appear in those areas where lightning-caused fire happen rarely. The fire adaptation capacity of Khingan fir is very low and there are no Khingan fir forests occurring here. Korean pine is similar to the spruces, but Korean pine cannot live in the sites where the spruce occurs because these sites are cold and humid. So Korean pine disappears here. If fire disturbance is controlled, Dahurian larch forests will be replaced by Yezo spruce forests in hilly areas at elevations of 800 to 1200 m and Korean spruce forests in other areas of the Greater Khingan Mountains. Also it is possible to plant Korean pine and Khingan fir in the area. But we must control the forest fire. The opinion that the Dahurian larch forests are a climatic climax in the area is not quite suitable. To further discussion, we will look upon fire as a disturbing factor and used ecological strategy theory to discuss it.

The Ecological Strategies of the Principal Trees

By analysis of the biological characteristics of the principal trees, and by their body size and life-span, we can order them into the r-K strategy series (Figure 4). From Figure 4, we find that Asian white birch, Dahurian birch, Mongolian oak and Dahurian larch lie at the r-end. This demonstrates that those trees have a high disturbance-resistance capacity. Korean pine, Yezo spruce and Khingan fir lie at the K-end. They have low disturbance-resisting capacity and avoid death by fire by restricting their range to the eastern mountains of Northeast China. There, environmental conditions are relatively stable and these species become the dominant trees. Mongolian scots pine and Korean spruce lie in the middle. They rely on their eurytopic amplitude to occur in some specific sites where other trees almost cannot survive in isolated distributions. The ecological amplitude of Dahurian larch is also very eurytopic. It can grow well in cold and undrained sites mixed with Korean spruce. Dahurian larch, Korean spruce and Mongolian scots pine have great intraspecific variability. Maybe their adaptive strategy is to create considerable intraspecific variability for adaption to various sites. Other conifers in the area are the opposite (have little variability).

Table 1. Frequency of lightening-caused fires in the Greater Khingal Mts.

Greater Khingal Mountains Avg. annual freq. %	Monthly freq. %					N. of Yilehuli Branch Range Avg. annual freq. %
	May	Jun	Jul	Aug	Sep	
16	11	83	2	0	4	60

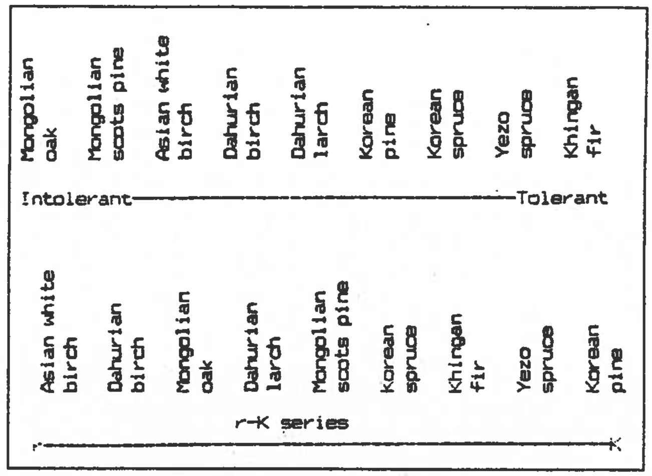

Figure 3. The order of tree tolerance.

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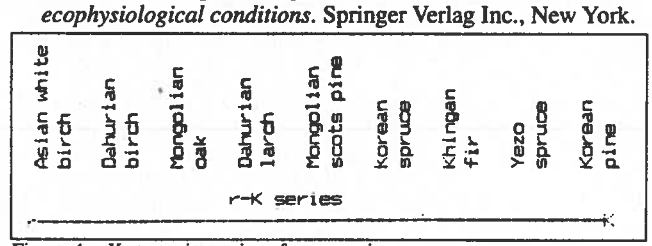

Figure 4. r-K strategies series of tree species

Table 2. Fire adaptation capacity of the principal trees.

	Sexual reproduction Class value		Asexual Reproduction Class Value		Fire resisting capacity Class Value		Adaptation Capacity to fire Class Value		Sum Value
Dahurian larch	2	4	4	2	1	5	4	2	13
Mongolian scotch pine	3	3	5	1	1	5	4	3	12
Mongolian oak	5	1	1	5	2	4	1	5	15
Dahurian birch	1	5	2	4	2	4	3	3	16
Asian white birch	1	5	2	4	3	3	4	2	14
Korean pine	5	1	5	1	2	4	4	2	8
Korean spruce	4	2	5	1	5	1	3	3	7
Yezo spruce	3	3	5	1	4	2	5	1	7
Khingan fir	4	2	5	1	5	1	5	1	5

Table 3. Fire cycle and composition of tree species.

Region	Fire cycle (year)	Conifers	Mongolian oak Dahurian birch	Other broad-leaf trees
North	110-120	89.72	0.2	10.08
East	30-40	76.80	2.27	20.93
South	15-20	42.07	24.03	33.90

The Regeneration of Spruce Forests in Northeastern China

By: Hongqui Wu

Abstract: The regeneration processes of spruce forests in the different areas of Northeastern China are discussed in terms of the biological characteristics and the understory tolerance of the principal species, the age structure and the height growth of seedlings and saplings, and the long term dynamics of spruce forests. Suggestions for the management of spruce forests are proposed.

Introduction

Northeastern China includes Liaoning, Jilna and Heilongjiang Provinces and the eastern part of the Nei Mongol Autonomous Region (Figure 1). The area of Northeastern China is 1.6 million sq. km. Spruce forests are an important component of the forests of the region. Although they are distributed widely, the area of spruce forests is small with isolated distributions, mainly in the mountains (Figure 1). In the Greater Khingan Mountains, the dominant vegetation is Dahurian larch *(Larix gmelini)* forests and in the Lesser Khingan Mountains and the Changbai Mountains it is Korean pine (*Pinus koraiennsis)*-deciduous broadleaf mixed forests. The dominant vegetation is steppe (principal edificators: *Stipa grandis, S. krylovii*, etc.) in the Nei Mongol sands, with Mongolian spruce (*Picea meyeri var. mongolica*) forests distributed mainly in hilly areas at elevations of 1300-1500 m.

Biological Characteristics of the Principal Trees in Northeastern ChinaI

The biological characteristics of tree species are determined by their genetic factors. It is essential that we study and compare the biological characteristics affecting the regeneration of the principal tree species of Northeastern China (Table 1). Table 1 shows that their biological characteristics are very different. The three broadleafed species have high asexual reproductive ability. Also Asian white birch (*Betula platyphylla)* and Dahurian birch (*Betula dahuraca*) in particular produce copious seeds which disperse great distances. These species, which are intolerant pioneers, are widely distributed in the secondary forest developing following disturbance. The tolerance of tree species, an important factor affecting regeneration in spruce forests, needs further discussion.

The Tolerance of Tree Species

The use of the term tolerance to refer to the relative capacity of a forest plant to survive and thrive in the understory is a restricted application of the general biological meaning of the term. Here understory tolerance is a more precise term. In the understory of spruce forests, light intensity is very low and lack of light is a restricting factor affecting survival and growth of forest plants in the understory. Understory tolerance here equates to the specific concept of shade tolerance. Tolerant tree species have low rates of respiration. Their light compensation point is low.

The growth of seedlings and saplings in the understory of a spruce forest shows their tolerance. We chose a typical sample plot in a spruce forest (Asian white birch-Khingan fir-Korean spruce forest). The light intensity was low in the understory of the sample plot (20 x 20 m.) which had 362 seedlings and saplings [see Figure 5 (3)]. The mean relative light intensity is 15.9% (for 60 points at a height of 40 cm). According to the distribution curves of lower limit height of seedlings and saplings of different ages (Figure 3), we find that Khingan fir is the most tolerant tree and Korean spruce is more tolerant than Korean pine. Also according to Table 1 and predecessor's work, we get the order of tolerance shown in Figure 2 for the principal trees in Northeastern China.

The Age Sturcture of Seedlings and Saplings and D.B.H. Distribution of Trees

Based on the investigation of two typical sample plots in the Greater Khingan Mountains and three typical sample plots in the Lesser Khingan Mountains, we get Figures 4, 5, 6 and 7. The area of the sample plots is 400 m (20 x 20 m).

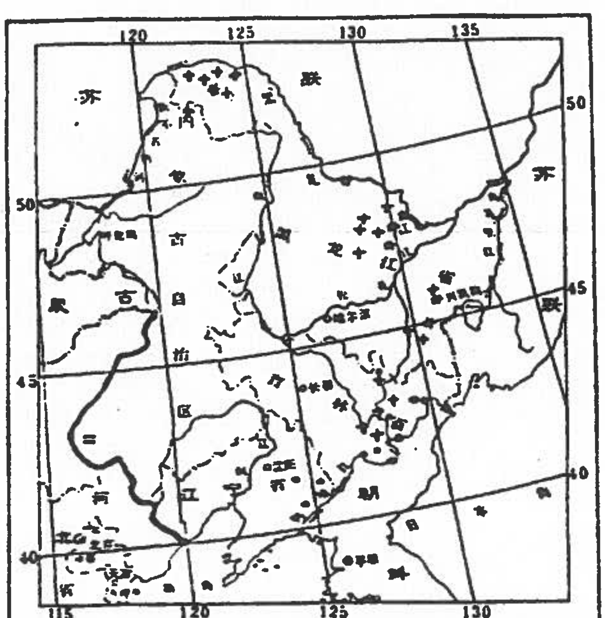

Figure 1. The distribution of spruces in Northeastern China. + *P. koraiensis* * P. jezoensis . *P. jezoensis var komarovii* = P. meyeri var mongolica

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All individuals in the plots were investigated. Figures 4 and 6 are the age structures of seedlings and saplings (D.B.H. >3 cm or height below D.B.H.) D.B.H. is 1.2 m. Figures 4 and 5 illustrate the regeneration of Korean spruce forests and Figures 6 and 7 illustrate the regeneration of Yezo spruce forests in different stages of succession.

The Regeneration Processes of Spruce Forests in Northeastern China

Both environmental conditions and tree species differ in the spruce forests of the different areas. Although Korean spruce and Yezo spruce belong to the same genus, they are not in the same section. Korean spruce belongs to the section Picea and the Yezo spruce to the section Omorica. Their biological characteristics are also different. Yezo spruce is more tolerant. There are no other tolerant tree species in the 800 - 1200 m elevation belt in the Great Khingan Mountains. From Figures 6 and 7, it is very obvious that Yezo spruce will replace the intolerant trees (including *Pinus sylvestris* var. *mongolica, Betula phatyphylla, B. ermanii* and *Larix gmellinii*). Finally, a pure Yezo spruce forest occurs in the 800 - 1200 m belt as a climax [Fig. 6 (2)]. *Betula ermanii* gradually replaces *B. platyphylla* with increasing elevation in the 800 - 1200 m belt. Also *B. ermanii* is more tolerant than Mongolian pine.

Khingan fir, distributed in the Lesser Khingan and the Chingbai Mountains, is more tolerant than Yezo spruce (including Komarov spruce). Consequently Khingan fir seedlings and saplings are sometimes more common than those of Yezo spruce. Khingan spruce, therefore, may be more frequent than Yezo spruce during a stage in the long-term dynamics of spruce forests. But the life span of Yezo spruce is longer and the distance of seed dispersal is greater than those of Khingan fir which is eventually replaced by Yezo spruce.

Korean pine forests are distributed widely in Northeastern China, but only in cold and humid valleys. In the Greater Khingan Mountains, if there is enough time, Korean spruce will replace Asian white birch, Mongolian pine and Dahurian larch to finally become a pure Korean spruce forest. But Khingan fir and Korean pine also occur in the Lesser Khingan and Changbai Mountains. Competition between these species is intense. Korean pine is a tolerant tree. Its life span is longer than that of spruce and distance of seed dispersal by animals (especially squirrels) is also greater. Additionally, mixed forests form the general cover. Korean spruce forests are restricted to cold and humid sites where Korean spruce can regenerate and grow well except where the site is too cold and wet. From Figures 4 and 5, it can be seen that Korean spruce is dominant in both the understory and the overstory. But is sometimes high and even pure Khingan fir forests occur as a stage in the long-term dynamics of spruce-fir forests. In this case, seed source is most tolerant. Khingan fir is also very tolerant. Pure fir forests can occur as conditions of Khingan fir forests so that seedlings and saplings become fewer and fewer. But there can be transitions between spruce - fir and Korean pine forests. This may be associated with animal activity, especially squirrels.

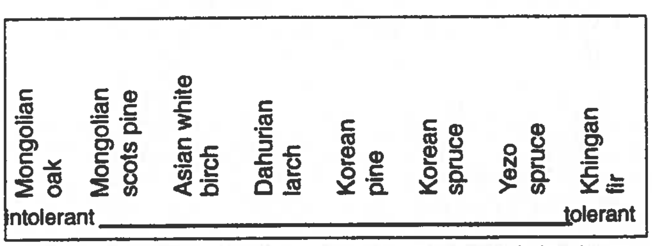

Figure 2. Understory tolerance of the principal forest trees in Northeastern China.

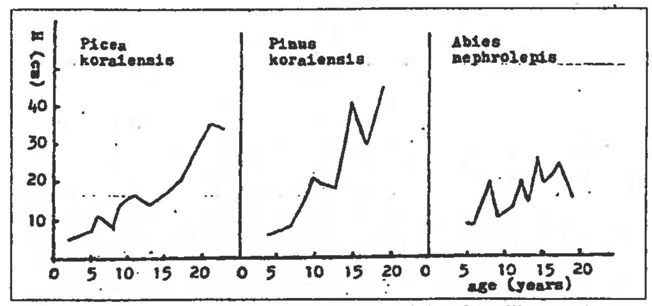

Figure 3. The distribution of the lower limit height of seedlings and saplings at different ages in the forests of Northeastern China.

Mongolian spruce forests only occur in the western part of the arid Nei Mongol sands region of Northeastern China in mountainous areas at elevations of 1300 - 1500 m. There, Mongolian spruce is a tolerant tree and regenerates easily. But it only regenerates well on the north-facing slopes of dunes and in valleys in the sands because moisture is a limiting factor.

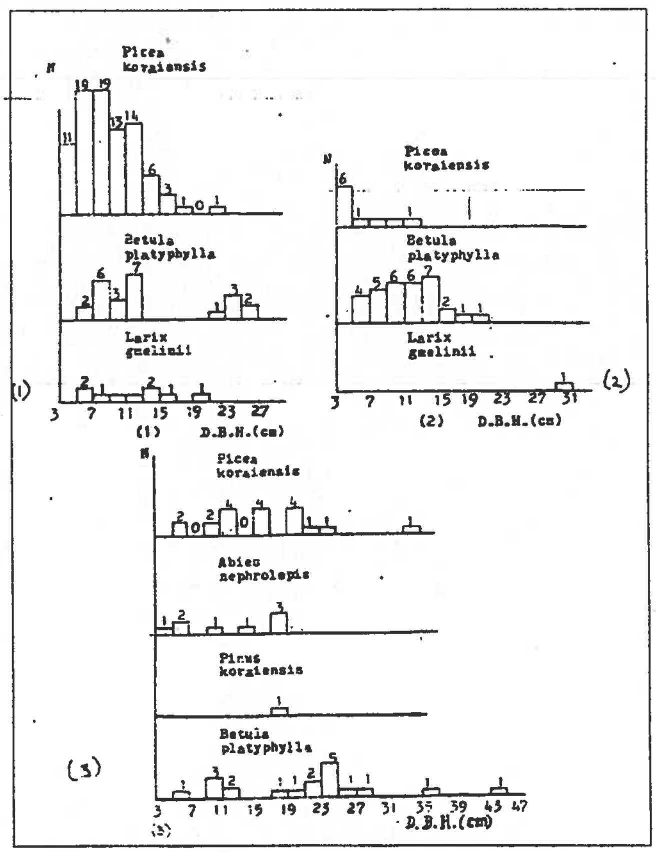

Figure 4. The diameter (D.B.H. >3cm) distribution of the tree species in: (1) Asian white birch-Korean spruce forests; (2) Asian white birch forests ; (3) Asian white birch-Khingan fir-Korean spruce forests in Northeastern China.

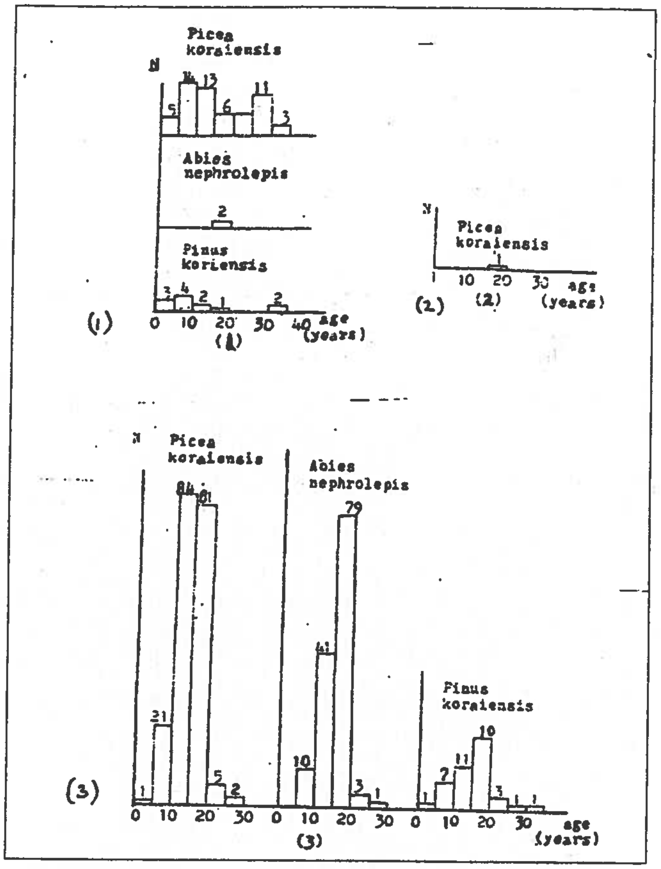

Figure 5. The age structure of seedlings and saplings in: (1) Dahurian larch-Yezo spruce forests; (2) Yezo spruce forests in Northeastern China.

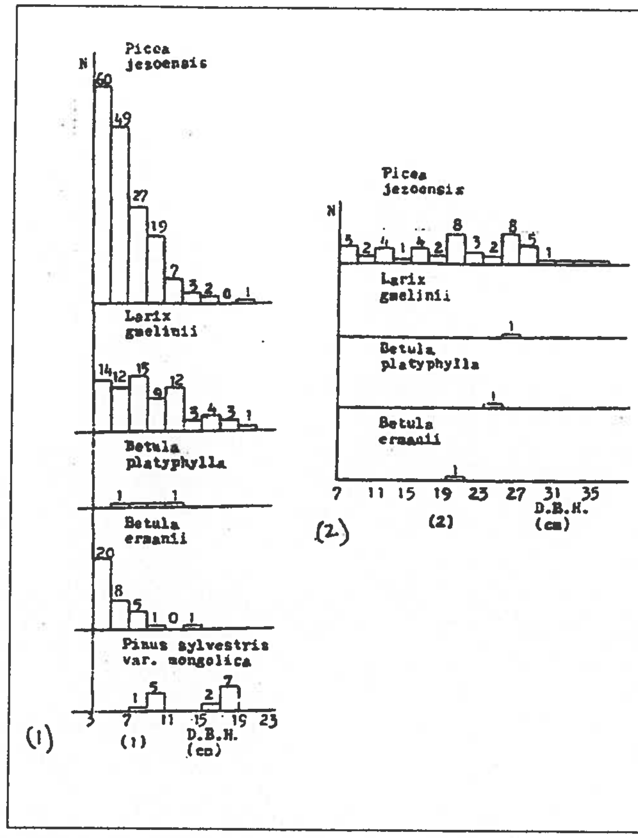

Figure 6. The diameter (D.B.H.) distribution of tree species in: (1) Dahurian larch-Yezo spruce forests; (2) Yezo spruce forests in Northeastern China.

Table 1. The biological characteristics of the principal forest trees in Northeastern China.

Species	Age of fruition (years)	Abundance of seed	Adult scale or bract	Seedwing size (length x width)	Size of seed (length x width)	Seed weight (x 1000) g	Link between seed and wing	Distance of seed dispersal m	Method of seed dispersal	Seed rot resistance	Asexual reproductive ability	Growth rate of young trees
Khingan fir (Abies nephrolepis)	80-160	high	deciduous	1.0 x 0.5	0.4-0.6 x 0.4	10.00	not easy to separate	close (30)	wind	strong	very weak	slow
Yezo spruce (Picea jezonsis)	80 160	high	persistent	0.9 x 0.35	0.3-0.4 x 0.2	2.10	easy to separate	30-50 (120)	wind	strong	very weak	slow
Korean pine (Pinus koraiensis)	140-240	7080 seeds	persistent	-	1.2-1.6 x 1.0	555.6	easy to separate	30-50 (120)	wind	strong	very weak	slow
Korean spruce (Picea koraiensis)	80-160	ca 400 cones	persistent	1.3-1.6 x 0.5	0.4 x 0.2	4.68	-	-	bird or squirrel	strong	very weak	very slow
Mongolian scots pine (Pinus sylvestris var. mongolica)	40-100	4000-5000 seeds	persistent	1.1-1.5 x 0.5	0.45-0.6 x 0.3	5.88	not easy to separate	200-250 (500)	wind	strong	weak	fast
Dahurian larch (Larix gmelinii)	60-160	4000-17000 seeds	persistent	0.92 x 0.45	0.43 x 0.3	4.00	not easy to separate	30-50 (150)	wind	strong	strong	faster
Asian white birch (Betula platyphylla)	15-20	very high	deciduous	very small	very small	very light	not easy to separate	very far (1000)	wind	strong	strong	very fast
Dahuriab birch (Betula dahurica)	15-20	very high	deciduous	very small	very small	very light	not easy to separate	very far (1000)	wind	strong	strong	very fast
Mongolian oak Quercus mongolica	15-30	low	persistent	-	2.0-2.3 x 1.3	heavy	--	around parent tree	animal or gravity	strong	very strong	very fast

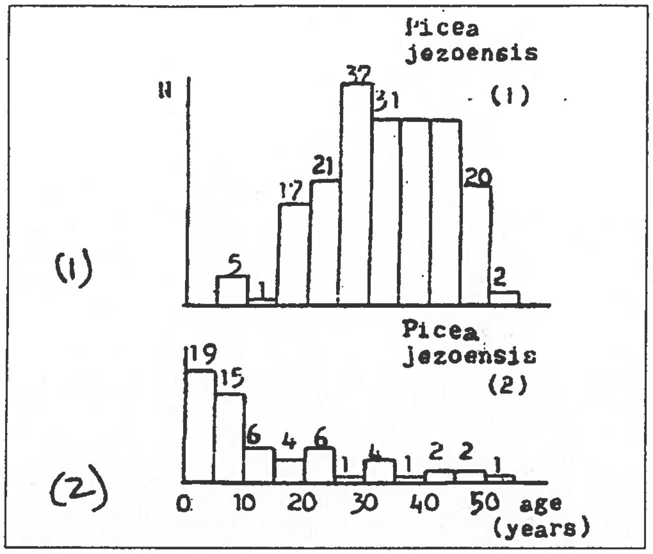

Figure 7. The age structure of seedlings and saplings in: (1) Dahurian larch-Yezo spruce forests; (2) Yezo spruce forests in Northeastern China.

mined by its biological characteristics and the size of gaps controlled mainly by disturbance (wind, fire, etc). Light intensity, which is controlled by gap size, is a very important factor affecting regeneration of spruce forests. Light intensity will select the tree species which will regenerate and control its growth. Pure spruce forests appear as the last stage in the Greater Khingan Mountains.

Spruce-fir forests occur as the last stages in the long-term dynamics of spruce forests in the Lesser Khingan and Changbai Mountains. Other community types occur as stages in the long-term dynamics of spruce forests. The duration of the different stages is determined by the degree of disturbance. Each stages is defined as a shifting-mosaic type. When environmental conditions are relatively steady, each stage is defined as a Shifting-Mosaic Steady State. The regeneration of each tree species is determined by its tolerance. Its maintenance as a dominant tree is dependent on its life span.

Suggestions and Conclusions

1. The ecological amplitude of Korean spruce is more eurytopic than Yezo spruce and Komarov spruce. According to research on man-made forests of Korean spruce in the south of the Lesser Khingan Mountains, seedlings and saplings grow much better under full sunlight than shade, and Korean spruce forests grow best on south- and west-facing slopes. The present distribution of Korean spruce forests is reduced. So there is great potential for afforestation in better sites. Also it is possible to plant Korean spruce in arid sites. The growth of the tree is fast. Diameter growth can reach 0.8 cm per year at the age of 24 years in man-made forests.

2. Yezo spruce and Koramov spruce should be planted in mountains at elevations appropriate to the location. They can only grow well in well-drained sites with high atmospheric humidity.

3. Mongolian spruce also grows very fast. According to investigations of man-made Mongolian spruce forests in the north of the Greater Khingan Mountains, diameter growth can reach nearly 1.0 cm per year at about 25 years.

4. From Figure 8, it can be seen that the stages from seeding to sapling and from sapling to free-to-grow tree are most important. The proper intermediate cuttings and exposure of trees to light are necessary.

5. The existence of the different stages in the long-term dynamics of the spruce forest is necessary because they are beneficial for the maintenance of soil fertility.

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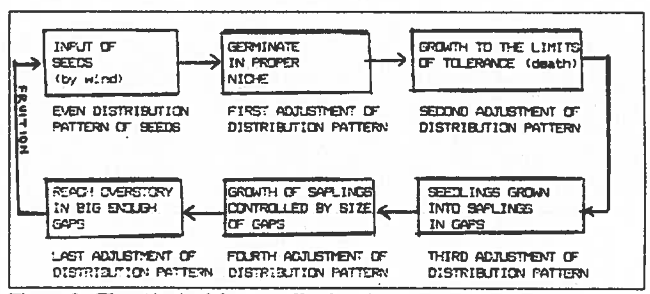

Figure 8. The principal factors affecting the regeneration process of spruce forests in Northeastern China.

Natural Regeneration, Feast or Famine

By: A.K. Hellum and Y. Norokorpi

Table 1. Reforestation in Alberta and British Columbia 1963 to 1983.

	ALBERTA (cut periods)			BRITISH COLUMBIA (cut periods)	
ACTIVITY	1963-72	1975-79	1980-83	1975-79	1980-83 (Pl + Sw only)
CUT HA/YR	16,000	21,500	30,300	176,000	115,100
Scarified + Direct Seeded (%)	31	29	18	0	0
Scarified + Planted (%)	12	30	47	39	95
Scarified Only (%)	23	18	2	35	0
Natural Regeneration (%)	34	23	33	26	5
Sum	100	100	100	100	100

Summary

Reforestation efforts in Western Canada are increasing and while major reliance was placed on natural regeneration before 1980, after this date planting and seeding dominate.

Judging by work of 15 years ago, our plantations and stands established by direct seeding do not meet provincial stocking standards in more than 20% of Alberta situations and maybe 33% in B.C. The rest of our success is due to natural seed cast or to seeds in pine slash (Tables 1, 2, 3).

The authors agree that we must learn how to use this natural seed supply. To ignore it or remove it is expensive and unecological. We already know what conditions have to be met to secure germination and rapid early growth, and we postulate that enough natural seed cast is taking place to secure the establishment of the new stands. What we need to do now is to apply this knowledge to our work on scarification to ensure that we are creating the desirable seedbeds we need.

In the future, when natural seed cast may be less, because of having removed adjacent mature and seedbearing trees, our reforestation success will change unless we acknowledge that what we do today to be successful is in large measure due to mother nature. Reforestation in the future may have to become more reliant on planting and seeding and we need to make these operations more remunerative in the future or reforestation successes will be harder to find.

Table 2. Reliance on natural regeneration (i.e., natural seed cast onto prepared and unprepared ground) in Alberta and British Columbia (B.C.)

	CUT PERIODS		
PROVINCE	1963-72	1975-79	1980-83
ALBERTA	88%	71%	35%
B.C.	N/A	61%	5%

Table 3. Success attributable to various reforestation activities in Alberta and B.C.

		CUT PERIODS		
PROVINCE	TREATMENT	1963-72	1975-79	1980-83
ALBERTA	Plant	4%	10%	16%
	Direct Seed	7%	7%	4%
	Natural	89%	83%	80%
Sum		100%	100%	100%
B.C.	Plant	N/A	14%	33%
	Direct Seed	N/A	0%	0%
	Natural	N/A	86%	67%
Sum		N/A	100%	100%

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A Review of Soil Preparation in Finland

By: Eino Mälkönen

Abstract: Use of prescribed fire declined following the increased capability of tilling (preparing) soils mechanically. About 80% of reforestation is now by planting, although due to high costs, natural regeneration following soil tilling is receiving increased attention. Soil tilling is intended to reduce labor intensive activities, promote early growth and be as long lasting as possible. About 75% of Finnish upland sites are very stony which limits the type of equipment that can be used. Soil tilling must also improve paludified soils. The small size (1.5 ha) of privately owned land requiring reforestation in Southern Finland is an important constraint. The principle soil tilling methods, disc trenching, wing plowing, use of excavators and the relevant biological factors influencing their use are discussed.

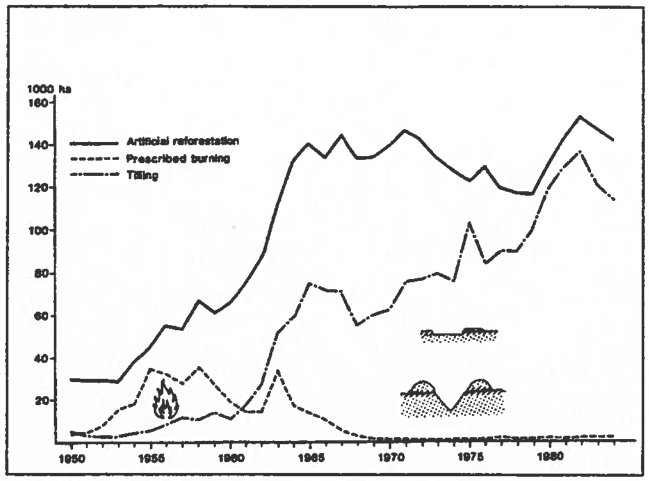

Figure 1. Soil preparation and artificial reforestation areas in Finland, 1950-1984.

Background

Artificial reforestation started to become a common practice in Finland during the 1950s. The most widely used soil preparation method at the time was prescribed burning (Viro 1969), usually followed by manual screefing to expose bare soil seeding or planting patches. Screefing was mechanized as suitable drawing equipment (prime movers) became available. However, this method did not give satisfactory results on rather impervious soils (Pohtila 1977). Prescribed burning, being a technique that is greatly dependent on the weather conditions and the availability of labor, gradually decreased as soil tilling equipment was developed. Nowadays there is a growing interest in prescribed burning owing to its natural character. Prescribed burning requires, however, also soil tilling.

Artificial reforestation reached its present level of about 130,000 ha/a, i.e., 66% of the forest land area (19.7 million ha), half way through the 1960s (Figure 1). Changes only gradually took place in the internal structure of artificial reforestation during the 1960s and 1970s. The proportion of seeding fell from the previous level of about 60% of the annually reforested area to around 20% (Yearbook of Forest Statistics 1986). At the same time, there was an increasing trend in planting away from Norway spruce to the use of Scots pine, and from barerooted transplants to various kinds of containerized seedlings.

In addition to artificial reforestation, soil tilling has also been used as a means of promoting natural regeneration, which is a practice that has received increasing attention during the last few years owing to the rise in reforestation costs. Since natural regeneration is mainly carried out on sites where reforestation is relatively easy, the soil tilling methods used for promoting natural regeneration are lighter than those required in problematic reforestation areas.

As the extent of artificial reforestation activities increased, the main purpose of soil tilling was to rationalize the reforestation work, i.e., to lighten the labor-intensive stages of planting. Another aim has been to promote the initial development of the seedlings by improving the germination conditions for the seed or immediate environment of the planted seedlings (Figure 2). As far as soil management is concerned, the soil-ameliorating effects of the site preparation methods used on reforestation areas should be as long-lasting as possible (Mälkönen 1976).

Despite the fact that the aims of soil tilling and the factors affecting these aims are rather complex, the soil tilling method actually used has mainly been determined by the terrain mobility of the different soil-tilling machines (Kaila & Päivänen 1981). About 75% of Finnish upland sites are glacial till soils where stoniness sets considerable demands on the soil-tilling machines. In addition to stoniness, another feature which typically affects soiltilling is the paludification of forest soils. In such cases there is a need for drainage, especially during the reforestation stage. In addition, planning soil tilling work is made difficult by the small size of the reforestation areasthe mean size of reforestation areas in privately owned forests in southern Finland is only 1.5 ha.

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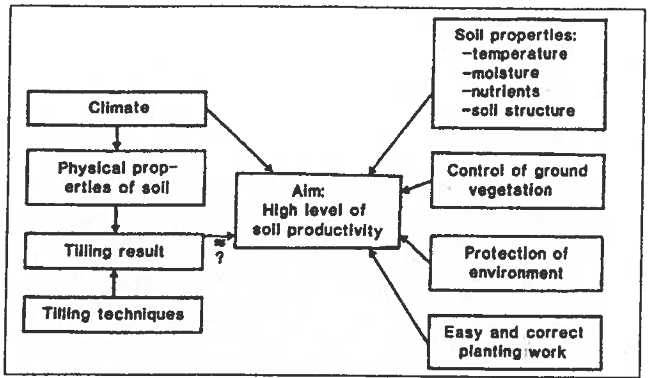

Figure 2. Different factors to be taken into account in soil tilling.

Soil Tilling Methods

Disc plows [disc trenchers] expose the mineral soil in a continuous furrow. This method produces a greater selection of suitable planting spots than screefing [patch scarification]. Disc plows have also frequently been used in conjunction with natural regeneration. During the last decade, disc plowing has been the most commonly used soil tilling method in southern Finland (Figure 3). However, it is not suitable for use on areas where excess water is a problem. Powered disc plows, in which the discs are pressed down and rotated hydraulically, improve disc penetration into the soil. They can also produce a ridge [berm], suitable for planting, next to the mineral soil furrow. Heavy forest tractors are used for pulling disc plows. The average cost of tilling by disc plowing now FIM 550/ha.

Wing plowing started in the 1960s with crawler tractors as the prime mover. The first wing plows made a furrow about 30 cm deep and exposed the mineral soil on both sides of the furrow (should plowing). Since shoulder plowing does not till the soil at the planting points very much, plows have since been developed which turn the excavated soil over into ridges [berms] along both sides of the furrow (ridge plowing). A heavy two-winged plow requires auxiliary wheels both for moving the plow and for regulating the plowing depth. In shoulder plowing the wheels usually travel along the shoulder, while in ridge plowing they can run along the ridges and compress them at the same time. The aim has been to improve the suitability of ridges for planting by compressing them. At the moment the use of wing plowing is diminishing. However, it is the most common soil tilling method used in northern Finland (Figure 3). Crawler tractors are used for pulling them, or heavy forest tractors in the case of lighter plows. Wing plowing costs about FIM 800/ha.

On the most difficult types of terrain, tractor diggers (or excavators) have been used for mounding—in this context, mounding refers to the "dollops" of soil dug from drainage ditches rather than the mounds formed by machines such as the Bräcke Mounder or the Sinkkila 2 (Laiho & Kinnunen 1985). Thus ditching work aimed at local drainage can also be carried out simultaneously on peat lands and water-logged mineral soil-sites. The excavators make about 40-cm-deep ditches at 10 - 12 m spacings, and the spoil from the ditches is placed in mounds along both sides of the ditch. Thus four rows of mounds are made per strip. The goal is to obtain 1 - 2 planting points per mounds, and a planting density of 2500/ha. Drainage mounding is especially suitable for reforestation areas including different types of terrain that form a mosaic which is usually difficult to till by the more conventional methods. This is the soil tilling method used in the worst problem areas. However, only a few thousand hectares of drainage mounding is done annually. The average cost of drainage mounding is about FIM 1000/ha. In the development of tilling equipment special attention has recently been paid to the requirements set by the varied conditions in clear-cutting area. So, for instance, mounding scarifiers (for example the Sinkkila 2) have been developed which can be changed during the operation from screefing to mounding.

Biological factors

One of the factors restricting seedling development is considered to be low soil temperature, which directly weakens the vitality of the roots and indirectly affects the availability of nutrients to the plants by lowing down the decomposition of organic matter in the soil. In northern Finland especially, improving the temperature conditions of the soil has, irre-

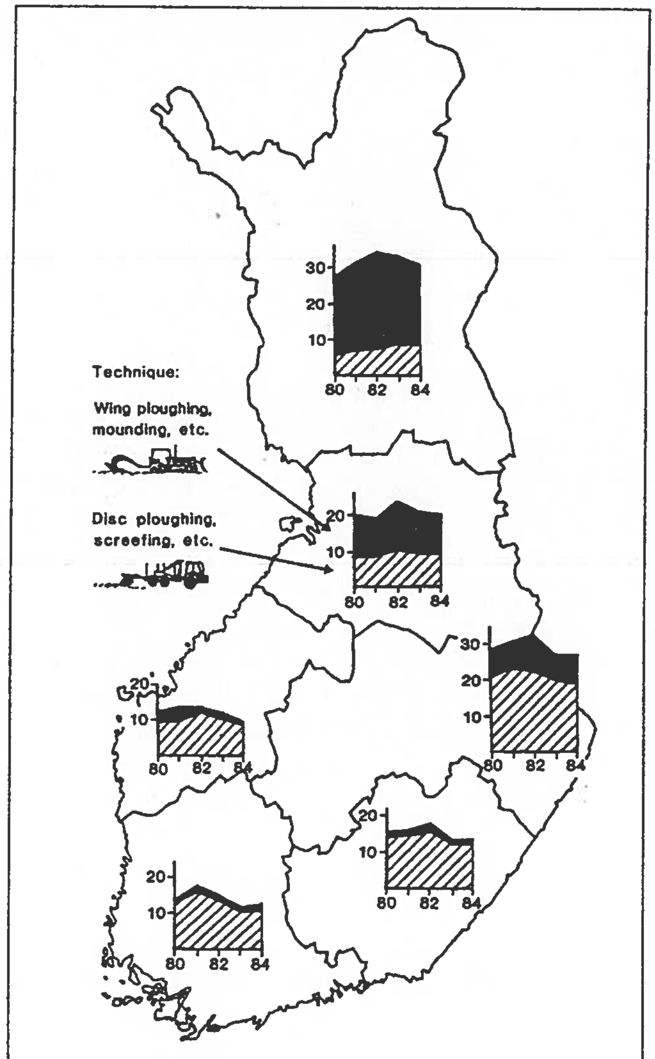

Figure 3. Development of the soil tilling area in forestry board districts, 1980-1984.

spective of the type of soil, a favorable effect on the development of the young trees.

When the insulating layer of humus is removed from the planting point in soil tilling, the temperature in the top-most layer increases considerably (Table 1). Of the different soil tilling methods, plowing brings about the greatest change in the temperature conditions of the soil (Lexical 1974, Mälkönen 1976). This is caused, for instance, by exposure of the mineral soil and changes in the microphotography of the soil surface. However, maximum temperatures in the ridge soil can reach levels that may even be harmful, and minimum temperatures remains rather low depending on the prevailing type of radiation (Pohtila 1977, Writer & Lähde 1978). Other forms of soil tilling do not increase soil temperature as much as plowing. However, their temperature conditions remain more stable than those in the ridge.

Since evapotranspiration is decisively decreased following clear-cutting, relatively impervious soils easily start to become paludified. Silty soils especially, owing to their high water-retaining capacity and poor aeration, are problematic (Lähde 1974). It is clear from biological principles that if the moisture content of the soil is so high that it will limit the future growth of the stand, then wing plowing can have a long-term beneficial effect on the soil. The aim in this case is to ensure that the excess water flows away from the reforestation area, and to produce elevated, sufficiently dry ridges where the soil structure improves the availability of nutrients to the seedlings. Under such conditions, better results are obtained with mounding than with wing plowing because suitable mounding points can be selected individually, and drainage has been done with the aims of reforestation in mind (Laiho & Kinnunen 1985). The advantage of mounding also lies in the fact that, in contrast to plowing, there are not so many furrows to restrict the regular development of the root system. At the same time, detrimental effects on the environment are minimized and the need for clearing hardwood sprouts is less than with plowing. The optimum height of mounds and ridges has been estimated to be about 20 cm.

Plowed ridges especially, have a very heterogeneous water status owing to the presence of logging residues and stumps. Attempts have been made to elucidate the moisture conditions of tilled soil from the point of view of the water uptake of the seedlings by measuring the tension of the soil water (Mälkönen 1976). It is apparent that, even in ridges in a compressed state, the moisture content of the soil may fall below the critical level during rain-free periods.

When we consider the nutrient requirements of the stand within the framework of the whole rotation period, it is obvious that there are more nutrients available for tree growth during the reforestation stage than at any other point in the life cycle of the stand. Large amounts of nutrients are returned to the soil in the logging residues left by the final cutting. These nutrients are gradually released and become available for reuse by the plants. In addition, clear cutting promotes the mineralization of nutrients bound in the humus and at the same time also increase potential leaching losses.

The increase in the soil temperature, improved aeration and intermixing of the humus and mineral soil caused by soil tilling promote the activity of soil microorganisms (Voss-Lagerlund 1976, Palmgren 1984). This results in a considerable speed-up in the mineralization of nutrients (Table 2). Thus there are abundant plant-available nutrients in ridge, mound or rototilled soil during the years immediately following soil tilling. Heavy soil tilling increases the risk of leaching. Consequently, it is important to ensure that the nutrient-rich surface soil is not removed from the planting point during soil tilling.

Soil tilling on dry mineral soil sites, where the water-retaining capacity of the soil is low and nutrients scarce, is mainly beneficial in making planting easier and in the control of the ground vegetation (Mälkönen 1983). Heavy soil tilling on sites of this type may merely reduce the nutrient status of the soil.

Table 1. Effective temperature sum (degree days) at a depth of 5 cm in soil tilled different ways.

Location of experiments	Untilled		Wing plowing: Ridge		Wing plowing: Shoulder		Disc plowing		Rotary tilling	
	Temperature sum									
	d.d.	%	d.d.	%	d.d.	%	d.d.	%	d.d.	%
Tammela (60°40'N)[1]	992	100	1341	135	1183	119	1101	111	1938	105
Kuru (61°55'N)	960	100	1284	134	1108	115	1078	112	1007	105
Kivalo[2] (66°17'N)	813	100	1144	141	1068	131	928	114	909	112
Vaalolehto[1] (67°51'N)	605	100	983	162	916	151	•	•	•	•

[1]Results from Tammela are for 1973 only; other results are averages for 1972 and 1973.
[2] According to Leikola (1974); all other results from Mälkönen (1976).

Table 2. Nutrient content of the soil solution at a depth of 15-20 cm in a fine-sand soil at Sotkamo (63∞45'N).

Sampling year	Nutrient	Forest	Clearcut area	Sampling point Patch	Ridge	Rotavated soil	F-value[1]	HSD 0.01
1977	N	1.27[1]	1.59	1.81	1.09	2.26	4.14**	0.84
	P	0.013	0.042	0.019	0.036	0.105	4.92**	0.064
	K	2.09	4.62	6.09	3.44	17.24	20.93***	4.85
	Ca	1.51	1.11	1.24	0.90	4.29	8.35***	1.75
1978	N	1.71	1.78	1.76	6.69	2.12	11.23***	2.49
	P	0.007	0.019	0.019	0.102	0.030	19.10***	0.033
	K	2.50	5.27	3.99	14.12	12.59	15.20***	5.29
	Ca	1.19	0.95	1.75	3.33	4.02	6.27***	2.13

[1] Values are averages for samples taken on three occasions during the growing season. The stand was cut in 1975 and the soil tilled in 1976.
[2] mg/l.

Conclusions

The tilling equipment developed in Finland permits different kinds of soil tilling. In practice, however, it is difficult to take into account the varied soil conditions in clear cutting areas. This would presuppose that the method of tilling could be changed during operation in order to make tilling specific for each type of site.

Modern tilling equipment has made it possible for a majority of plantations to succeed fairly well as long as good quality planting material has been available. There are, however, geographically and edaphically problematic areas, such as old spruce forests in the north. Tilling has not solved the ecological problems connected with the reforestation of these areas. The development of soil preparation methods and their application still calls for comprehensive studies if tilling is to give as large and long-lasting benefit as possible at each site.

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Preliminary Results on the Development of Scots Pine and Norway Spruce Plantations in Soil Tilling Experiments in Finland

By: Eino Mälkönen, Kaarina Niska, and Teuvo Levula

Abstract: Some preliminary results from long term trials to assess the effect of soil tilling and fertilization on the survival and growth of Scots pine and Norway spruce are presented. Height growth for eight years after planting was considerably increased by tilling, although survival of pine was sufficiently low to indicate that satisfactory regeneration methods for problematic soil conditions have not yet been achieved. The effect of fertilization was rather small, although no adverse effects were detectable up to this time.

Introduction

Soil preparation is frequently an essential measure in the regeneration of forests on mineral soil sites. Although experience with soil tilling has generally been positive, it is clearly evident that our knowledge concerning the effects of different types of site preparation on the soil is still in many respects deficient. Most of the studies carried out on the ecological effects of soil tilling in Finland cover relatively short periods of time, and hence there is little concrete information available on which to estimate the long-term effects of soil tilling. In difficult field conditions, technical considerations often dictate which soil tilling method can be used, and the method that is chosen is not always the most suitable with respect to other site factors.

In 1975 the Department of Soil Science, the Finnish Forest Research Institute, started to establish an extensive series of soil tilling experiments, in cooperation with the National Board of Forestry, in order to study the ecological factors associated with the tilling of forest soil. The aim was to include treatments representing different intensity levels of timber production in each of the experiments. Some preliminary results concerning the initial development of the young trees in these experiments are presented.

Material and Methods

The field experiments were established in areas with very different climatic conditions (Figure 1). The soils on the experimental areas are podzolized fine-sand tills. Before clear-cutting, the areas had been covered with old, conifer-dominated mixed forest. The sample plots were tilled and fertilized within one to two years after clear-cutting, and nursery-grown, bare root transplants were planted in spring of the year following tilling: Scots pine 1 + 1 yr, Norway spruce 2 + 2 yrs at spacing of 1.5 x 2.0 m. The seed originated from areas to the north of the reforestation experiments.

A split-plot experimental design was employed in which the main treatments were the three tilling methods (Figure 2), and the subtreatments fertilization at four different levels.

Soil tilling:

U = Untilled.

P = Tilt plowing with a heavy two-winged plough to form ridges on both sides of the furrow. Basic fertilizer was spread on the ground before ploughing in order that the fertilizer would be left under the tilt.

T = Tilt plowing and soil tilling with a chain rototiller to form a ridge for planting. Basic fertilization was carried out

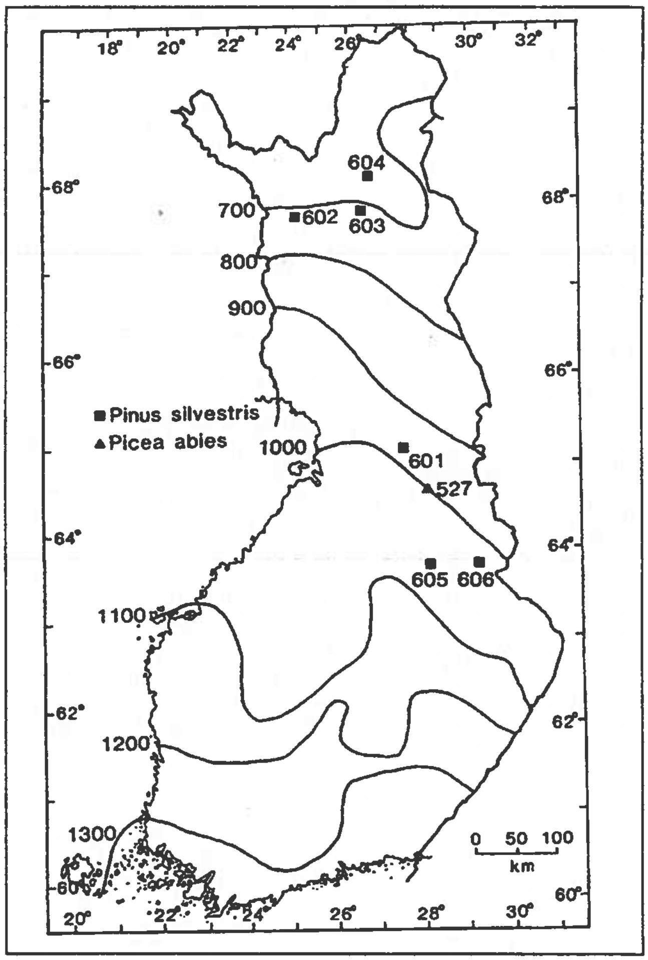

Figure 1. Location of the soil tilling experiments (numbered squares) and the isotherms of the effective temperature sum (degree days).

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after ploughing so that the fertilizer would become well mixed into the soil during chain rototilling.

Fertilization:

O = Unfertilized

1 = Basic fertilization with 3000 kg/ha of finely-ground limestone in conjunction with soil tilling and 800 kg/ha of rock phosphate by broadcast spreading.

2 = Spot fertilization with ammonium nitrate plus lime (22 g/seedling, 27.5% N) three years after planting.

3 = Basic fertilization and spot fertilization with NPK fertilizer (30 g/seedling, 20-4-8) three years after planting.

he size of each sample plot is 50 x 50 m. There are four replications in each experiment.

Soil samples were taken from the humus layer and the O-30 and 30-60 cm mineral soil layers prior to soil tilling. In addition, the thickness of the humus layer, the stoniness of the uppermost mineral soil layer and the diameter of the tree stumps of different tree species were also measured.

Needle samples were taken during the dormant period eight growing seasons after outplanting. Each needle sample represented current year needles collected from 15 randomly selected trees on each plot.

Results

Survival

The same rows of young trees were inventoried the first and eight year after outplanting. The proportion of living seedlings was calculated on the basis of the total number of trees at the first inventory carried out eight years later. Soil tilling improved the survival percentage in all the pine experiments except for those in Pudasjärvi (site 601) and Inari (site 604) (Figure 3). The number of surviving trees in Inari was one third, and in Pudasjärvi one half of the number planted even on hilled plots. The survival percentage on the Kittilä (site 602) experiments was 82% on the tilled plots, and 58% on the untilled ones. The corresponding values in Sodankylä (site 603) were 58% and 17%, in Sotkamo (site 605) 63% and 41%, and in Nurmes (site 606) 66% and 54%. Due to tilling the survival of spruce was quite good even in the severe conditions prevailing in Puolanka (site 527; Figure 4).

Fertilization had only a slight effect on the survival percentages of the young trees. The interaction of soil tilling and fertilization was statistically significant in the Kittilä experiment. When all the soil tilling treatments were taken into account, the best survival was obtained on the unfertilized plots (80%). In Inari, fertilization increased the

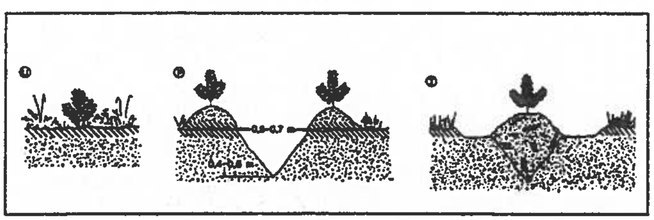

Figure 2. The profiles after different soil tilling treatments: U=untilled, P=tilt ploughing with a heavy two-winged plough, and T=tilt ploughing and soil tilling with a chain rototiller.

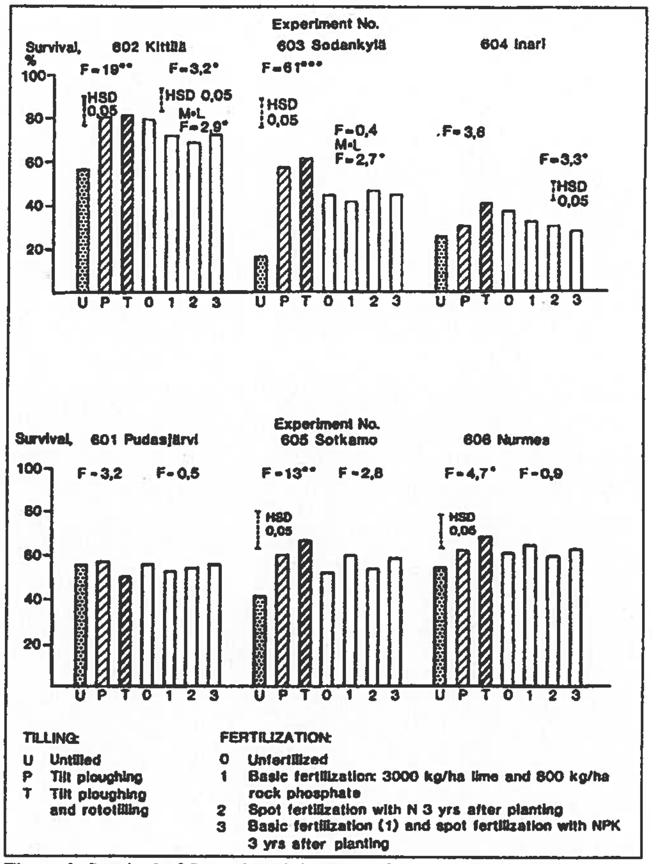

Figure 3. Survival of Scot pine eight years after planting. The results for tilling methods are averages of all the fertilization treatments (0-3) and the results for fertilization treatments are averages of all the tilling treatments (U, P and T.) M*L refers to the interaction between tilling and fertilization.

mortality rate with all types of soil tilling.

Height growth

Soil tilling increased the height growth of the transplants during the first summer in the experiments in northern Finland only, while in the second growing season it increased the height growth of the transplants in all experiments.

By the eighth growing season, soil tilling had increased the mean height of the pine transplants in the experiments in northern Finland on the average by 56 cm, i.e., 80% (Figure 5). In the Pudasjärvi experiment soil tilling doubled the height of pine transplants during the first eight years. The increase in the mean height in the Sotkamo and Nurmes experiments was 45 cm, i.e., 31%. Tilt plowing especially increased the height growth of the spruce transplants (Figure 4). Thus soil tilling had greatly increased the height growth in the case of both the pine and spruce transplants. In this respect, the results given by tilt ploughing and "full tilling" were approximately the same. Fertilization had only a slight effect on the growth of the transplants.

When the trees were measured eight years after planting, those in the tilled soils were considerably taller than those in the untilled soils. The transplants in the untilled soils were still short enough to be covered by snow throughout the winter and therefore not exposed to winter damage in the way in which trees in the tilled soils were. When young trees had

Table 1. The effect of tilling and fertilization on the nutrient content of current needles and height growth of Scots pine in the eighth year after planting in North Finland.

Treat-ment[1]	Previous year's leader growth. cm	N	P	K mg/g	Ca	Mg	Mn	Cu	Zn mg/g	B	Fe
					Current needle nutrient content						
					Experiment No. 602 Kittilä						
U	15.9	1.37*	0.14	0.35	0.14	0.79*	385*	4.0	38*	8.5	3.3
P	21.4	1.33	.14	.40*	.18*	.72	316	3.9	35	9.3	3.2
T	22.4*	1.35	.14	.38	.18	.71	372	4.0	38	10.4*	3.2
0	20.0	1.36	0.14	0.39	0.16	0.67	396	3.9	38	9.5	3.2
1	19.5	1.33	.13	.38	.16	.80*	282	3.8	36	8.5	3.2
2	20.5	1.38*	.14	.38	.17	.70	436*	4.0	37	9.4	3.3
3	19.5	1.34	.14	.36	.16	.75	315	4.1	37	10.2*	3.3
x	19.9	1.35	.14	.38	.17	.74	358	4.0	37	9.4	3.2
					Experiment No. 603 Sodankylä						
U	12.3	1.50*	0.15*	0.35	0.11	0.72*	333	3.8	36	10.2	3.1
P	18.7*	1.42	.14	.36	.13	.62	275	3.8	35	9.4	2.9
T	18.6	1.42	.14	.35	.16*	.64	335*	4.1	37	13.5*	3.0
0	15.9	1.46	0.14	0.36	0.13	0.65	363	3.8	35	11.5	3.0
1	16.5	1.43	.14	.35	.14	.69	270	3.8	36	10.3	3.0
2	17.3	1.46*	.14	.35	.13	.61	364*	3.9	36	11.3	3.1
3	16.5	1.44	.15	.34	.14	.70*	261	4.0	37	10.9	3.0
x	16.5	1.45	.14	.35	.13	.66	315	3.9	36	11.0	3.0
					Experiment No. 604 Inari						
U	10.7	1.34	0.13	0.36	0.13	0.85*	283	3.6	38*	8.6	3.0
P	14.9	1.32	.14*	.39*	.14	.68	276	3.4	33	9.7	3.1
T	16.2*	1.32	.13	.37	.14	.67	324*	3.7	26	11.7*	3.3
0	14.5	1.34	0.13	0.38	0.14	0.69	384	3.6	36	10.4	3.1
1	14.1	1.33	.14*	.37	.14	.80*	201	3.6	36	8.5	3.1
2	13.7	1.34	.13	.37	.13	.65	387*	3.6	35	11.1*	3.1
3	13.4	1.30	.14	.36	.14	.79	206	3.5	35	10.1	3.1
x	13.9	1.33	.13	.37	.14	.73	295	2.6	35	10.0	3.1

[1]See explanation in Materials and Methods.
*Difference between the means of tilling treatments. and between the means of fertilization treatments. statistically significant.

grown to a height exceeding that of the snow cover, there was an increase in mortality and incidence of different types of damage, especially in the case of the pines. It is thus to be expected that the development of the transplants growing on untilled soil will be poor during the coming few years.

Nutrient status of the transplants

The nutrient contents of the needle samples taken from the individual sample plots were compared using variance analysis (Tables 1 and 2). Soil tilling increased the needle calcium and boron content, and reduced in most cases the nitrogen, magnesium and zinc contents. The differences between the needle nutrient contents for the different soil tilling treatments were, however, relatively small, and it is not possible to draw any conclusions on the basis of these results concerning disturbances in the nutrient status of the transplants.

Conclusions

These general results are from locations representative of problematic reforestation areas in Finland which are characterized by a rather fine-textured and compact soil, a relatively high elevation with respect to normal forestry conditions in Finland, and a dominant role played by spruce in old stands prior to cutting.

Intensive soil tilling can produce considerable changes in

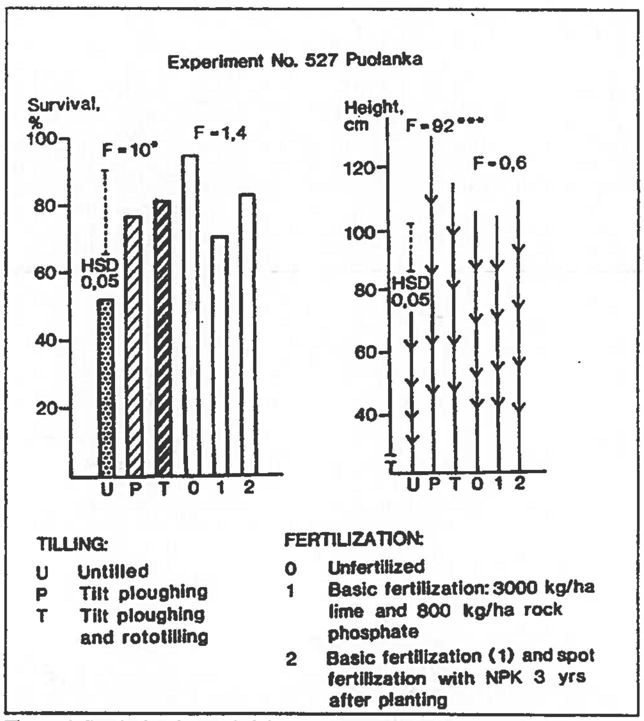

Figure 4. Survival and mean height of Norway spruce eight years after planting. The results for tilling methods are averages of all the fertilization treatments (0-2) and the results for fertilization treatments are averages of all the tilling treatments (U, P and T). The mean annual height growth during the last four years presented in the figure are based on measurements made eight years after planting.

Table 2. The effect of tilling and fertilization on the nutrient content of current needles and height growth of Scots pine in the eighth year after planting in East Finland.

Treatment[1]	Previous year's leader growth, cm	N	P	K	Ca	Mg	Mn	Cu	Zn	P	Fe
		Current needle nutrient content									
		mg/g					mg/g				
		Experiment No. 601 Pudasjärvi									
U	11.5	1.29*	0.13*	0.37	0.16	0.85*	304	5.1	47*	7.6	3.5
P	20.0*	1.21	.12	.36	.17	.68	317	4.8	35	8.5	3.3
T	18.1	1.22	.12	.34	.17	.69	362*	4.3	37	9.0*	3.3
0	16.8	1.22	0.12	0.35	0.17	0.67	452*	4.4	41	9.9*	3.5
1	16.4	1.19	.13	.34	.17	.87*	251	5.1	42*	8.7	3.3
2	16.4	1.28*	.12	.36	.16	.66	359	4.7	39	7.8	3.3
3	16.7	1.26	.13*	.37	.17	.76	248	4.7	37	7.1	3.3
x	16.6	1.24	.13	.35	.17	.74	328	4.8	40	8.4	3.4
		Experiment No. 605 Sotkamo									
U	27.6	1.24*	0.12	0.34	0.18	0.86*	466	3.5	49*	9.5	4.3
P	34.0*	1.18	.12	.39*	.20	.77	379	4.0	38	10.9	4.1
T	33.5	1.22	.12	.36	.22*	.82	471*	3.8	41	12.8*	4.4
0	31.5	1.19	0.12	0.37	0.20	0.75	517*	3.7	40	11.7*	4.3
1	32.0	1.23	.12	.36	.21	.91	374	3.7	43	10.8	4.3
2	31.9	1.22	.12	.36	.19	.72	503	3.9	41	10.8	4.4
3	31.3	1.21	.12	.37	.20	.91*	360	3.7	46*	11.1	4.1
x	31.7	1.21	.12	.36	.20	.82	438	3.7	43	11.1	4.3
		Experiment No. 606 Nurmes									
U	28.5	1.18	0.12	0.37	0.17	0.83*	401	3.4	44*	8.2	4.3
P	33.8*	1.21	.12	.38	.18	.70	380	3.5	37	10.1	4.1
T	33.6	1.25*	.12	.38	.21*	.79	416	3.9	40	11.8	4.4
0	32.4	1.19	0.12	0.38	0.18	0.67	452*	3.5	40	10.3	4.2
1	31.8	1.22	.12	.37	.18	.82	349	3.4	40	9.3	4.3
2	32.7	1.24*	.12	.38	.19	.74	496	3.5	41	10.3	4.3
3	30.9	1.20	.12	.39	.19	.85*	300	3.4	41	10.4	4.3
x	32.0	1.21	.12	.38	.18	.77	399	3.5	40	10.1	4.4

[1]See explanation in materials and methods.
*Difference between the means of tilling treatments and between the means of fertilization treatments. Statistically significant.

the physical and chemical properties of the soil, with the result that the initial development of the young stands is markedly speeded up. However, the mortality rate of Scots pine on sites which are difficult to reforest is so high, independent of the type of tilling method used, that the results cannot be considered to be satisfactory for problematic sites.

Despite the changes in the soil brought about by soil tilling, the nutrient status of the transplants appears to remain relatively stable, and no connection can be drawn between damage to the young trees and their nutrient status on the basis of these experiments. This is further supported by the fact that the effect of fertilization proved to be rather small. The problem will have to be analyzed more deeply in investigations which include the site requirement of the tree species, soil properties and the changes brought about in these factors by soil tilling.

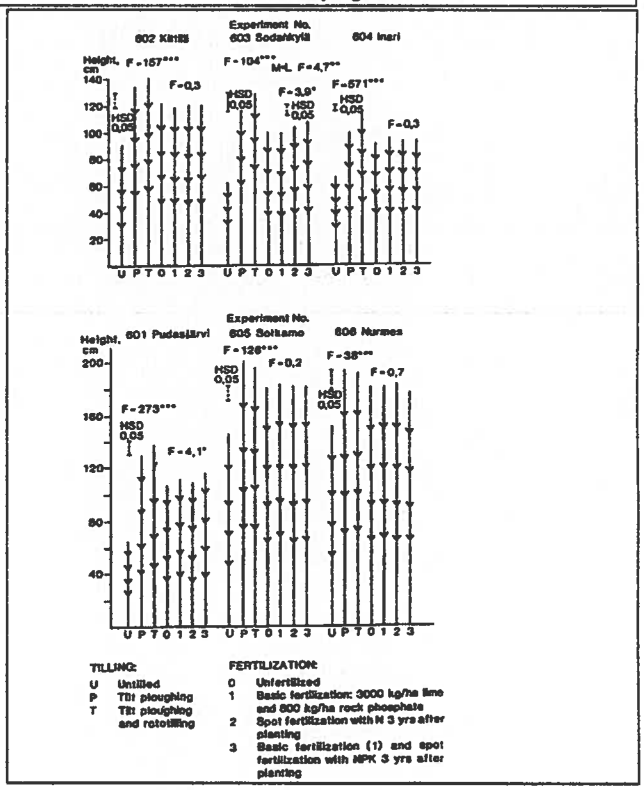

Figure 5. Mean height of Scots pine eight years after planting and mean annual height growth during the last four years. The results for tilling methods are averages of all the fertilization treatments (0-3) and the results for fertilization treatments are averages of all the tilling treatments. (U, P and T). M*L refers to the interaction between tilling and fertilization.

Adapted Site Preparation in Sweden: Biological Requirements and Technical Possibilities

By: Jan Fryk

Abstract: Adapted site preparation requires definition of the desired biological effects under various site conditions so that favorable conditions can be created. Biological knowledge can be systematized to classify desired influences. Different biological effects can be expected from different site preparation "principles." Most current site preparation equipment tests in Scandinavia are with "variation units."

Introduction

Site adapted forestry, at least verbally, has been fashionable in Sweden since the beginning of this decade. It primarily includes stand establishment treatments, but can include other activities such as fertilization of mature stands.

The objective is to adapt different measures (i.e., "adapted site preparation") to differences in site properties thereby reducing the risk of calamities and achieving optimal utilization of the productivity of the site. During the establishment phase, this could mean, for example, the proper choice of site preparation method, tree species and seedling type according to differences in basic biological conditions (Figure1).

Biological requirements for adapted site preparation

To choose the most suitable method for the site in question, one must know what biological effects are needed so as to create favorable conditions for seedling establishment and growth.

To determine the need for and the required severity of a site treatment and in order to judge the effects of different methods, one must consider some important site properties:

A. Climate - temperature and precipitation regime (Figure 2)

- temperature sum (T-sum >+6°C)
- risk of spring drought

B. Water supply

- soil moisture (classes from wet to dry)
- soil texture (classes from fine [sediments] to coarse [moraines])

C. Availability of nutrients

- indicated by vegetation
- indicated by depth of humus layer

These properties can be used in combination to characterize different site-types. For each type, the desired changes in site conditions needed for improved establishment and growth are then defined. An example is shown in Table 1.

Desired effect during establishment phase

The relationship between desired influence on soil moisture and soil temperature and different site properties can be illustrated as shown in Figure 3. Both soil temperature and soil moisture are very important during the establishment phase.

Desired effect on long term productivity

Site treatment should, if possible, lead to improved long term growth as well as create favorable conditions for stand establishment. At least conditions which bring about site deterioration should be avoided. Proper choice of method could lead to increased site index, while incorrect choice might produce the opposite effect.

The two most important factors affecting long term growth, which can be modified by site treatment, are the hydrology of the site and the availability of nutrients. The desired influences on these factors for different site conditions are illustrated in Figure 4.

Classification of desired influences

For specific sites it is thus possible to define, from a biological viewpoint, the desired influences on various site factors.

Various site properties have been formed into a matrix in Table 1. Each cell in the grid constitutes a specific site type. The four-digit combinations indicate the desired influence of the four site factors+temperature, moisture, hydrology and nutrient availability.

Site preparation decisions, of course, should take into account such technical factors as degree of terrain difficulty and risk of insect attack as well as the desired influences of

Table 1. Desired relative influence on soil temperature (T), soil moisture (M), hydrology (H) and nutrient release (N) on different sites.[1]

Class T/M	H and N
1 Moderate decrease/increase	No influence desired
2 Intermediate class	Low influence desired
3 Reference case - mineral patch	Low influence desired
4 Intermediate case	Moderate influence desired
5 Moderate increase/decrease	Moderate influence desired
6 Intermediate class	Strong influence desired
7 Strong increase/decrease	Very strong influence desired

[1]The four-digit units correspond to T, M, H, and N respectively. (Source: Bäcke et al. 1986)

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the four site factors.

Despite limited knowledge, it is important to use available information in order to apply the best site treatment for maximizing establishment conditions and minimizing the risk of future drawbacks. Systematizing present knowledge could simplify identification of the best treatment.

The decision process can be summarized as follows:

1. Describe the site from a biological viewpoint, utilizing the relatively few important site properties;

2. Determine the desired changes in these factors during the establishment phase and for long term productivity.

3. Establish which site preparation "principle" could most likely be expected to bring about these changes.

4. Choose the site preparation method that most closely matches this "principle."

Choice of site preparation method

Figures 3 and 4 illustrate how soil moisture and temperature, and hydrology and nutrient release should be influenced on various types of sites. The next step is to clarify the kinds of effects to be expected from different site preparation principles so that the most suitable method may be chosen.

The "principles" may be defined according to the way in which mineral soil and humus layers are affected. The six basic "principles" (1 to 6) are illustrated diagrammatically and are followed by seven additional more or less theoretical, "principles."

1. No site preparation: Unaffected humus layer.

2. Mineral soil patch: The humus layer is removed from a 0.5 x 0.5 m patch and the turf placed beside the patch. The mineral soil is undisturbed.

3. Trench of mineral soil: The humus layer is removed from an 0.5 m wide trench and the turf placed beside the trench. The mineral soil is undisturbed.

4. Mineral soil mound on mineral soil: A mound of 15:1 of mineral soil is placed on the mineral soil patch. The soil is taken from the patch. Degree of scarification corresponds to "principle" 2.

5. Mineral soil mound on inverted turf: A mound of 15:1 of mineral soil is placed on the inverted turf. The soil is taken from the patch. Degree of scarification corresponds to "principle" 2.

6. Thick bank of mineral soil on inverted turf: A thick bank (higher than the mound of "principle" 5) is placed on the inverted turf on each side of a plowed furrow. (Figure 5. Diagrams illustrating basic site preparation "principles.")

7. Patch of loosened mineral soil: As in "principle" 2, but the mineral soil in the patch is loosened.

8. Trench of loosened mineral soil: As in "principle" 3, but the mineral soil in the trench is loosened.

9. Soil bank on mineral soil: A bank of the same height as the mound of "principle" 4 is placed in a trench of mineral soil. The soil is taken from the side of the trench (affects the anticipated long term drainage effect).

Table 2. Estimated relative influence of some site preparation "principles" on soil temperature (T) and soil moisture (M) in planting spots for stand establishment on different sites.

Principle	Soil Moisture Class			
	Dry		Mesic-Wet	
	T	M	T	M
1. No site preparation	3	3	1	3
2. Mineral soil patch	3	3	3	3
3. Trench of mineral soil	3	4	3	3
4. Soil mound on mineral soil	5	5	5	5
5. Soil mound on inverted turf	6	7	6	7
6. Thick bank of mineral soil on inverted turf	6	7	6	7

[1]See Table 1 for meaning of units. (Source: Bäcke et al. 1986).

10. Mound of mineral soil mixed with humus: As in "principle" 4, but the mineral soil in the mound has been mixed with the humus removed from the patch.

11. Mineral soil bank mixed with humus: As in "principle" 9, but the mineral soil has been mixed with the humus removed from the trench.

12. Thick mineral soil bank on inverted turf: As in "principle" 9, but a thick bank is placed on the inverted turf. The mineral soil is taken from the trench. (Affects the anticipated long term drainage effect.)

13. Big mineral soil mound on inverted turf: A mound of the same height as the thickness of the mineral soil bank in "principle" 6 is placed on the inverted turf.

Using the classification in Table 1, the six basic "principles" can be said to affect soil temperature (T) and soil moisture (M) in planting spots for stand establishment as in Table 1.

A similar collocation concerning the estimated influence of the different "principles" on some factors important for long term productivity is shown in Table 3. (Note: Table 3 was not available).

Adapted site preparation in practice

Naturally one must bear in mind that adapted site preparation in practice might deviate from the somewhat theoretical approach outlined above. It is of primary concern that the field personnel who must make on-site judgements and decisions, are highly qualified in biological as well as in technical and practical matters. Furthermore, forestry planning procedures should be designed to identify, for example, different site preparation methods which have the same objective. The availability of various types of equipment is, of course, essential.

Site analysis

For some years, several Swedish forest companies have been working on the principles of site adapted stand establishment. Although practice does not always match ambition, rapid development is underway.

These companies normally do a site analysis in the planning phase. This includes a relatively thorough examination of the site to be reforested. The different site preparation

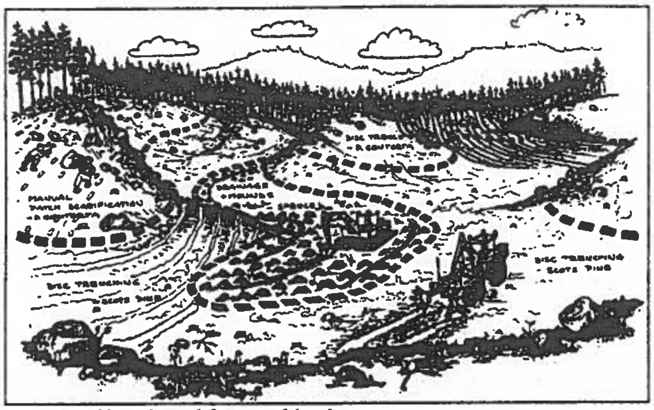

Figure 1. Site adapted forest cultivation.

methods, tree species etc. for the various site conditions within the area to be reforested are determined and noted on the planning sheet. The time for and the area of each treatment are noted. The number of seedlings of each species and the time for their delivery to the reforestation site are also noted. The boundaries of the various treatment areas are marked on a sketch or map (Figure 6) and on the ground. Normally, all planning data are fed into a computer for further processing after the field work has been completed.

Difficulties and requirements

As has already been indicated, satisfactory application of adapted site preparation is not easy. Swedish experience indicates that some of the important requirements and major difficulties are as follows:

- Highly qualified personnel, including machine operators, are needed;
- The planning process may be both time consuming and expensive and require rather sophisticated planning procedures; - the increased cost compared to more extensive and stereotyped treatments should be evaluated in relation to biological benefits;
- The equipment and machinery required must be available at the right time and place.
- Present site preparation equipment does not always perform as expected or desired; biological results are too often unacceptable; proper techniques are still unavailable for some site conditions.
- The economical and practical minimum size of treatment areas unknown.

Most site preparation equipment currently on the market is designed for-only one type of treatment. This often results in several different machines or units being required within a treatment block if adapted site treatment is desired. Apart from logistic difficulties, this also increases costs. The problem is exacerbated when many geographically scattered treatment areas must be prepared. Accordingly, a real break-through for adapted site preparation would be the development of machinery which could perform a variety of site treatments.

But first it should be of interest to give an example which indicates how present equipment performs on sites for which it is designed.

Biological results following mechanized site preparation

In order to illustrate the biological results to be expected when using present techniques, an example is given from a rather extensive study carried out during 1985.

Five different units (two types of mounders, two types of disc trenchers and a plow) were studied in three different locations in northern Sweden. In two locations conditions were easy to moderately difficult. The third was judged to be difficult. In each locality conditions were comparable for the five site preparation units tested.

Using the number of possible planting spots in mineral soil as a simple measure of biological result, Figure 7 shows that all units performed well.

However, if the number of planting spots on mounds or banks is considered, the results are somewhat different. The two mounders are comparable (50-60%) while the difference between the two disc trenchers is considerable (2-50%). The plow provided the highest number of mounds (80%). It should, however, be pointed out that evaluating results immediately after site preparation, as was done in this case, is risky. Subsequent examinations showed that more spots would be suitable for planting when the mounds/banks had been allowed to settle over winter.

An important consideration when judging results is the

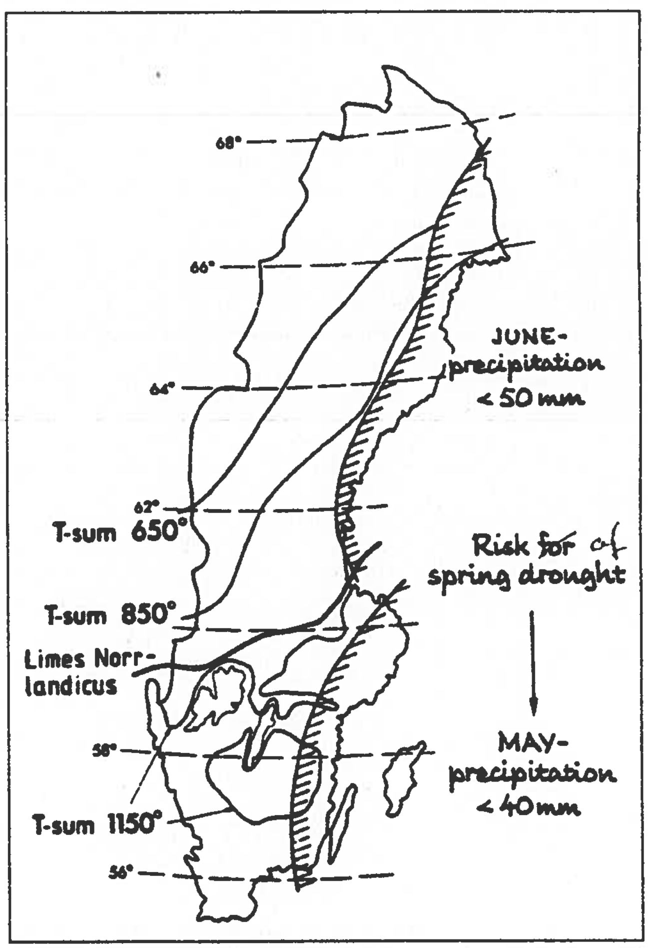

Figure 2. Climatic regions in Sweden.

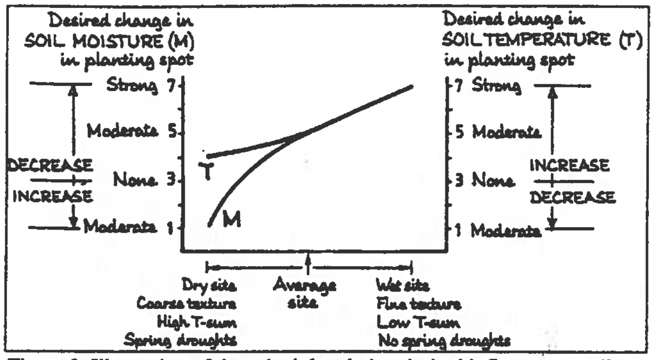

Figure 3. Illustration of the principle relating desired influence on soil moisture (M) and soil temperature (T) in the planting spat to different site conditions monitored 10 cm below the soil surface in a mineral soil patch. (Source: Bäcke et al. 1986).

relative area of disturbed soil when different methods are used. Taking into account the long term effects of nutrient leakage, it is undesirable on some sites to cultivate a larger area than absolutely necessary. The relationship between prepared area and distance between machine passes for the three different site preparation methods is shown in Figure 8.

Failure to create sufficient numbers of planting spots is normally due to stoniness, boulders, stumps, logging residues etc. The problem increases with increasing terrain difficulty, to which different machines have different sensitivities.

One must also bear in mind that it is not only the design of the site preparation unit limits the biological results. Much depends on the operator's skill in choosing the best working pattern according to terrain and in utilizing the full potential of the machine.

From this and other studies and from practical experience it is apparent that improved design of site preparation equipment is desirable and that the full potential of present equipment should be explored.

Technical developments in progress

To achieve real adapted site preparation on a considerable scale in practice, it is essential that a new type of equipment be developed whereby one unit can perform different types of site preparation.

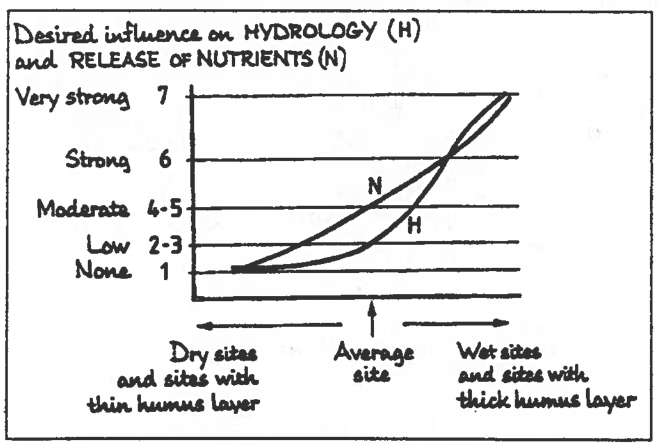

Figure 4. Illustration of the "principle" relating desired influence on hydrology (H) and nutrient release (N) to different sites taking into consideration long term productivity. (Source: Bäcke et al. 1986).

The unit should be capable of both intermittent and continuous operation. Then different types of cultivation could be obtained by varying contact time, pressure, angle and pattern of movement. In this way patches of various length and width, a continuous trench, or mounds or banks of different sizes could be produced.

At present, equipment design is proceeding along two lines. One, which might be termed "combination units" comprises two different pieces of equipment mounted together which are used in sequence. Examples of these are the Finnish TTS plow/disc trencher, the TTS disc trencher/mounder and the Swedish Bräcke pat mounder. The second line of development could be termed "variable units." In this case a single unit operates in different ways to produce different forms of cultivation. Examples are the Finnish Sinkkilä patch scarifier/mounder and the Marttiini AKLM 190 Plow.

Swedish technical developments now in progress second line. The focus is on the great potential of modern computerized control systems applied primarily to various types of trenchers. The potential for further development of these machines is considered fairly large. Since present patch scarifier/mounders already allow considerable variability, further development of this type of machinery is mainly concerned with technical refinements.

Equipment for adapted site preparation

At present, Swedish manufacturers and Skogsarbeten are cooperating in field trials of several ideas for the construction of adapted site preparation units. Some of these trials are briefly described as follows.

A. Cone Trencher: By switching from intermittent to continuous operation or visa versa while underway, this unit automatically changes its cultivation pattern as illustrated in Figure 9. By adjusting the angle and pressure of the cones from a control panel in the operator's cab, various patch and trench profiles can be obtained (Figure 10). The initial thought is that the machine operator should be able to choose among three basic unit positions for intermittent and continuous scarification according to particular site conditions.

B. Disc Trencher: When switching from continuous to intermittent discing, the arms carrying the discs are automatically raised and lowered to create patches (Figure 11). Another alternative, intended to create mounds by forcing the discs to work back and forth sideways, is being tested (Figure 12). A second method being tested for the production of patches is changing the contact angle of the discs cyclically (Figure 13).

Results from these tests will be evaluated from a biological viewpoint as well as technically during the fall and winter of 1986. Depending on the outcome of these evaluations, some equipment could reach the market in 1987.

Other Tests

Skogsarbeten is also carrying out other site preparation studies.

On several disc trencher units, Skogsarbeten is examining

1. No site preparation
   Unaffected humus layer.

2. Mineral soil patch
   The humus layer is removed from a 0.5 x 0.5 m patch and the turf placed beside the patch. The mineral soil is undisturbed.

3. Trench of mineral soil
   The humus layer is removed from a 0.5 m wide trench and the turf placed beside the trench. The mineral soil is undisturbed.

4. Mineral soil mound on mineral soil
   A mound of 15 l of mineral soil is placed on the mineral soil patch. The soil is taken from the patch. Degree of scarification corresponds to "Principle" 2.

5. Mineral soil mount on inverted turf
   A mound of 15 l of mineral soil is placed on the inverted turf. The soil is taken from the patch. Degree of scarification corresponds to "Principle" 2.

6. Thick bank of mineral soil on inverted turf
   A thick bank (higher than the mound of "Principle" 5) is placed on the inverted turf on each side of a plowed furrow.

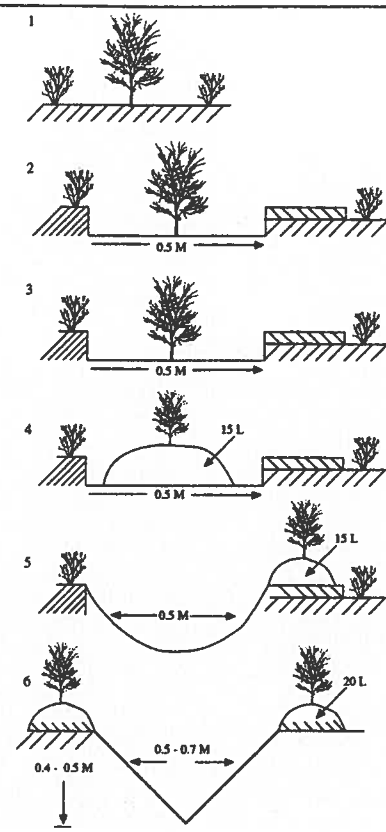

Figure 5. Diagrams illustrating basic site preparation principles.

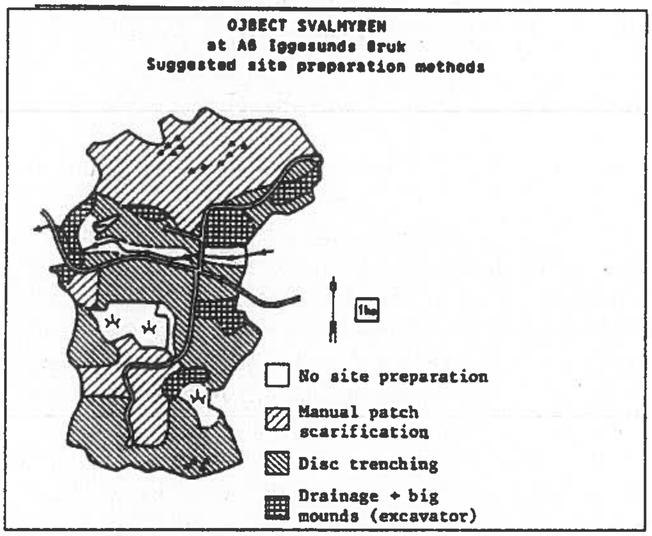

Figure 6. Site map for planned site preparation based on site analysis.

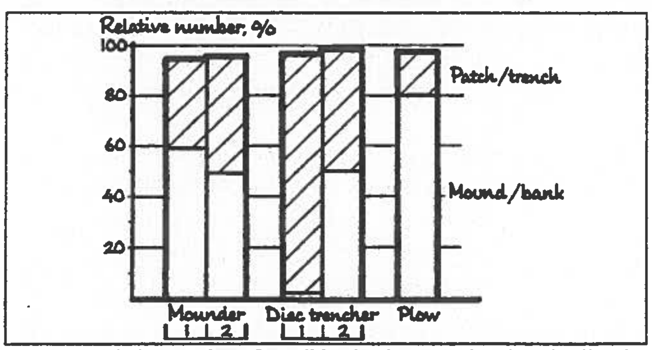

Figure 7. Relative number of possible planting spots in mineral soil and on mineral soil mounds/banks following site preparation by different equipment types. Two meter spacing between planting spots within rows.

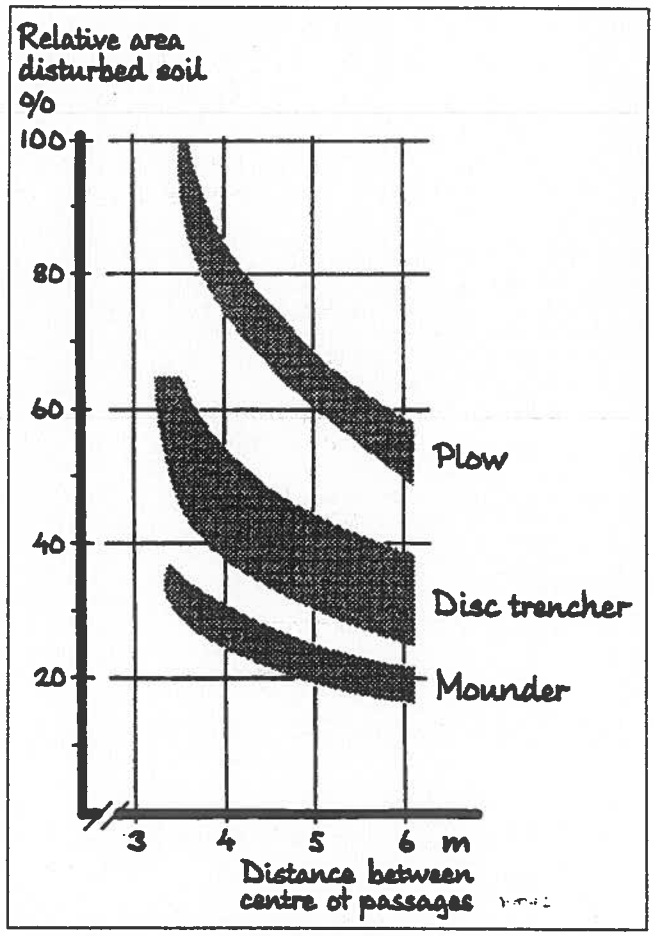

Figure 8. The relative area of disturbed soil at various distances between machine passes using different types of site preparation equipment.

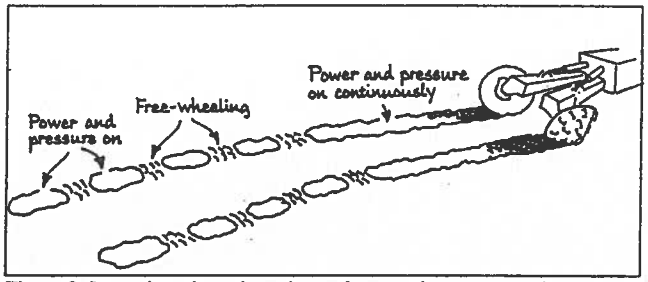

Figure 9. Intermittently and continuously operating cone trencher.

the possibility of a correlation between disc speed and biological result. If a correlation is found, continuous monitoring of the r.p.m. on a display in the operator's cab would give the operator an indication at any time, at least to some degree, whether or not the site preparation is acceptable.

Theoretically it is desirable in most locations in Sweden to have seedlings exposed to the south. However, standard disc trenchers expose every other row to the north when the unit is travelling is an east/west direction. If the discs could always be oriented to the same direction, without causing excessive strain on the prime mover, this problem would be eliminated Figure 16). This "south-side" solution, however, requires that the discs can be turned 180° when the prime mover travels in the opposite direction to the previous pass.

Other technical developments in which Skogsarbeten is involved include a 4-row disc trencher (Figure 15), a disc trencher for rectangular spacing (Figure 16), further development of mounders and using excavators for site preparation.

Experiments are being made at the faculty of forestry, Swedish University of Agricultural Sciences to determine whether sensors can gauge specific soil characteristics automatically. If this were possible, it is hypothesized that site preparation units with sensors could be to some extent self-adjusting for variations in soil characteristics.

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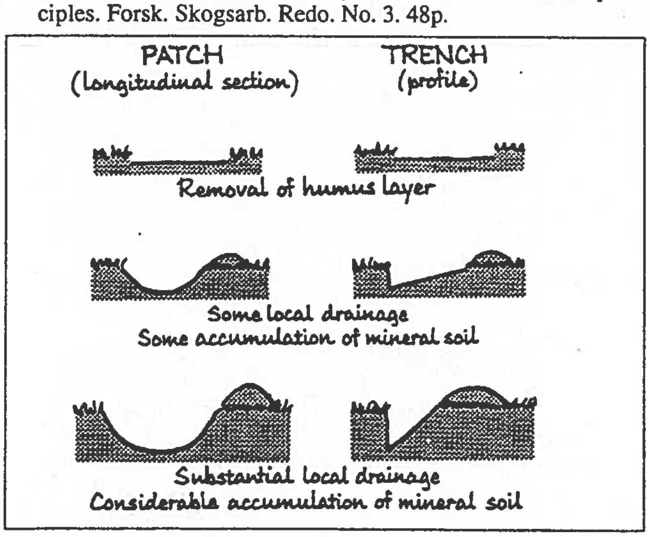

Figure 10. Profiles of patches (longitudinal section) and trenches (cross section) resulting from various contact angles and down pressures on the scarification cone.

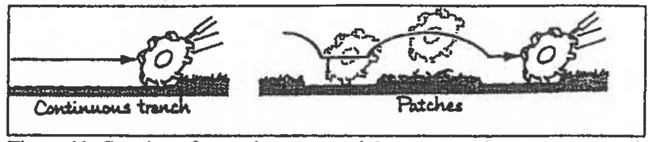

Figure 11. Creation of a continuous trench by constant down pressure and intermittent patches by automatically raising and lowering the scarification discs.

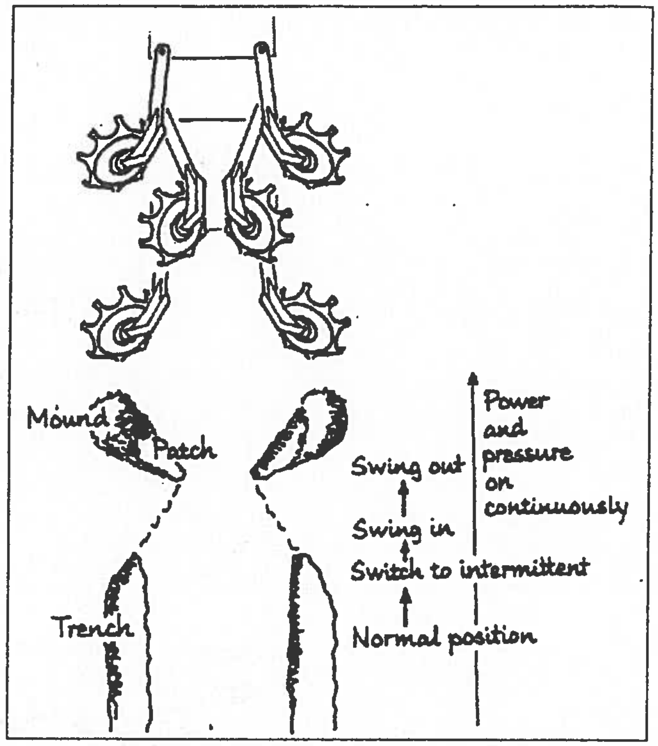

Figure 12. Creation of mineral mounds by automatically forcing the discs in and out sideways.

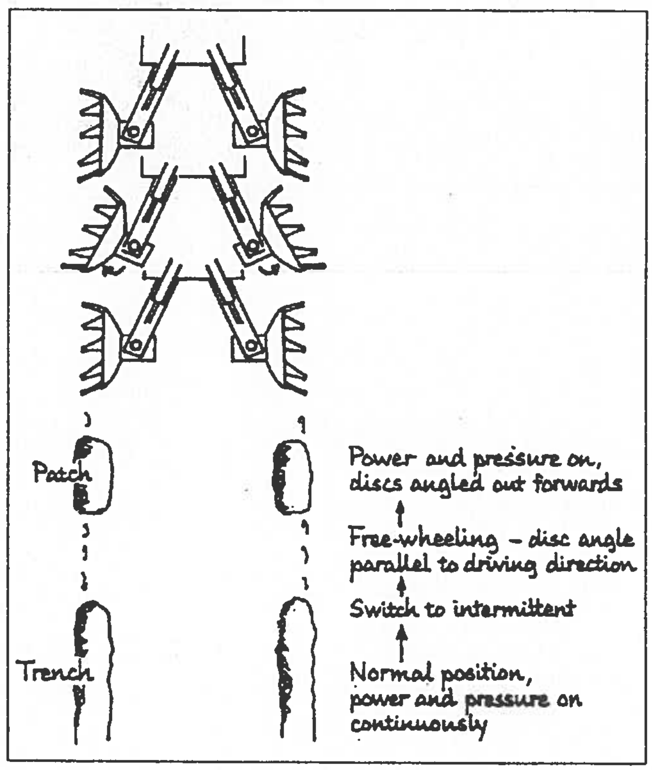

Figure 13. Creation of mineral soil patches by an automatic cycle varying disc contact angle.

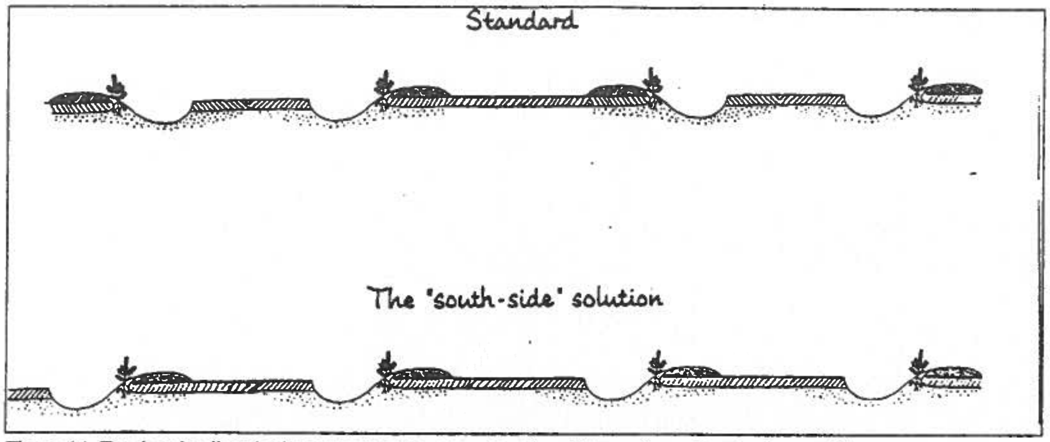

Figure 14. Turning the discs in the same direction can give all seedlings a favorable planting position.

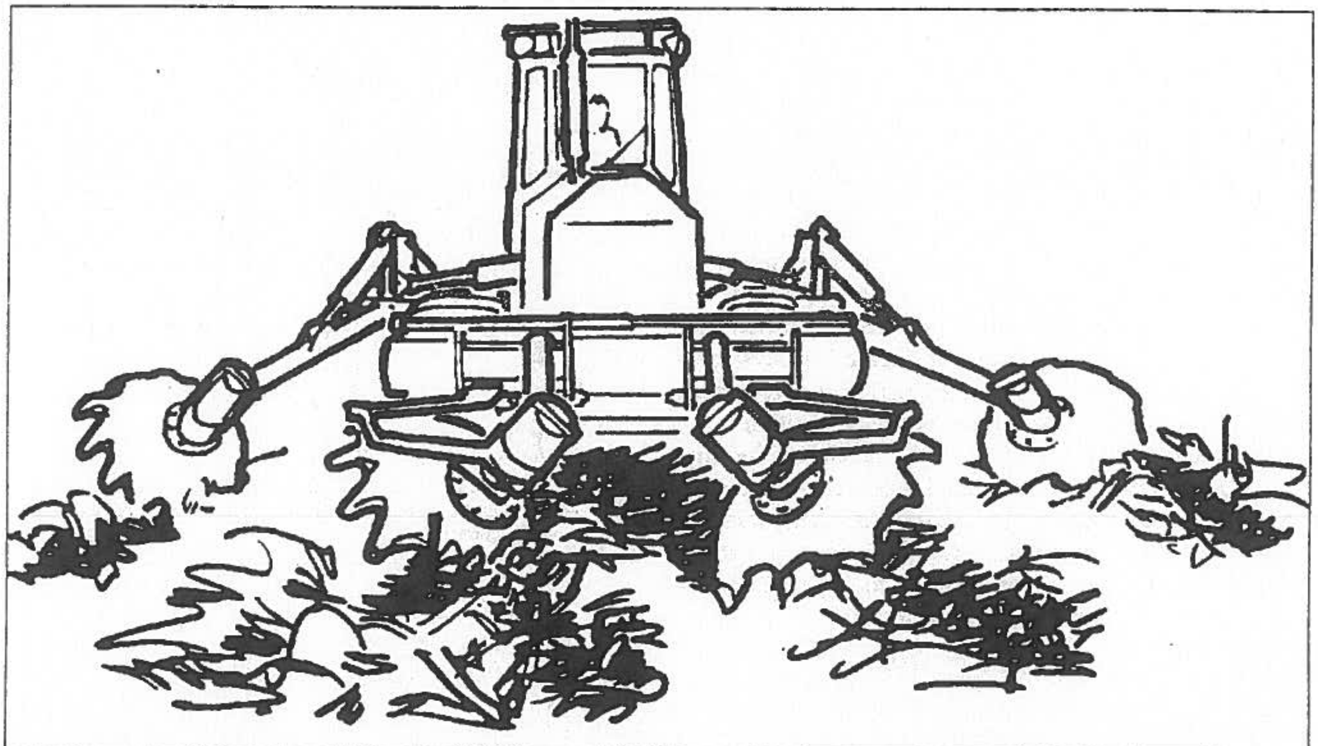

Figure 15. Four-row disc trencher.

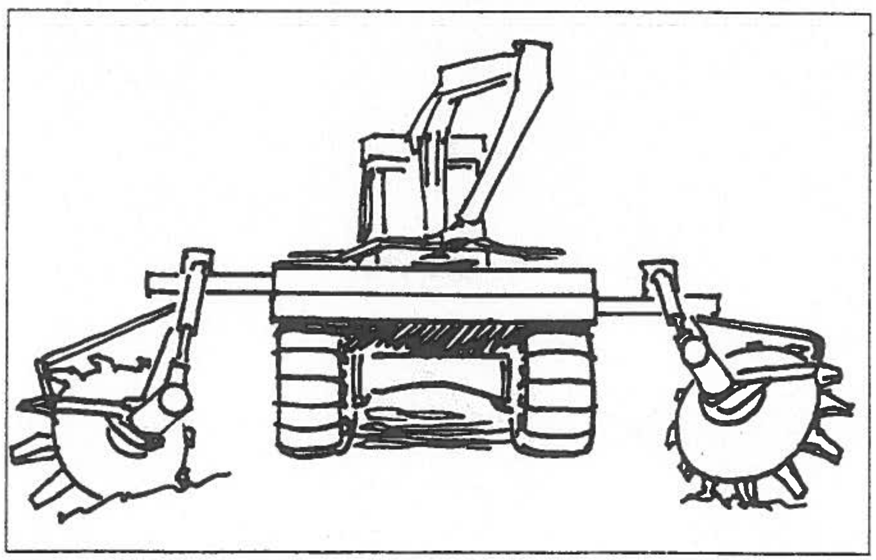

Figure 16. Disc trencher with variable two to four m spacing.

Conclusions on the Development and Regeneration of HMT Spruce Forests

BY: EERO TIKKANEN

Abstract: Hylocomium-Myrtillus type forests (HMT forests) in northern Finland include spruce forests developed from birch forests originating after fire. In spite of site alterations by forest ploughing, regeneration with pine has been unsuccessful in such areas, which are thought to be "exclusive spruce forest soils." Regeneration with pine is successful where spruce forests had developed from pine forests originating after fire. The principle causes of plantation failure are thought to be nutrient deficiency caused by a combination of factors compunded by the severity of the climate.

Introduction

An intensive program of regeneration of Hylocomium-Myrtillus type Norway spruce forests (HMT spruce forests) was undertaken in Northern Finland from the mid-1950's onwards, involving replanting with Scots pine seedlings after clear felling and broadcast burning. Scalping was introduced as well on a wide scale around 1960, and in 1963 over 25 000 ha of state-owned and private forest land was treated in this way, with a corresponding sharp decline in the proportion burned (Figure 1).

Setbacks in this program were experienced from 1965 onwards, however. A marked decline in the growth and condition of the pine saplings and ultimately death began to occur on both burned over and scalped sites. The reason for this was judged to be debilitation of the root systems caused by the coldness and compactness of the soil and an unfavorable oxygen and water balance (Valtanen 1968, 1970). The demise of the saplings was accelerated in many cases by diseases such as dieback and canker fungus (*Scleroderris* canker).

The plowing of forest land became common practice as a means of improving growing conditions and facilitating planting from the mid-1960's onwards. Some 20,000 ha was improved by plowing in the province of Lapland in 1967 (Figure 1). During the 1970s the mean area plowed annually stabliized at 13,000-14,000 ha, and the technique also began to be used in the regeneration of dry pine-dominated heath forests. Research showed the temperature sum and the aeriation of the soil to be greater in ploughing tilts (tilt is equivalent to "berm" or "furrow slice," tilt is derived from till.) than in either lightly tilled soils or undisturbed soils (Leikola 1974, Kauppila and Lähde 1975, Ritari and Lähde 1978). Forest inventories showed the early development of Scots pine seedlings planted in plowed areas to be usually good (Lähde and Pohjola 1975, Mutka and Lähde 1977, Pohtila 1977). Even so, there were many places in which abnormal growth was observed in the saplings once they had reached an age of about ten years. In some places they exhibited unnaturally lush growth and had lost their leader shoot dominance, while elsewhere their general condition was poor. The disturbances in growth and condition appeared to lead rapidly to the death of the saplings, and the general effect was found to resemble in many ways the decline of pine saplings noted in burned over and scalped areas in the 1960s.

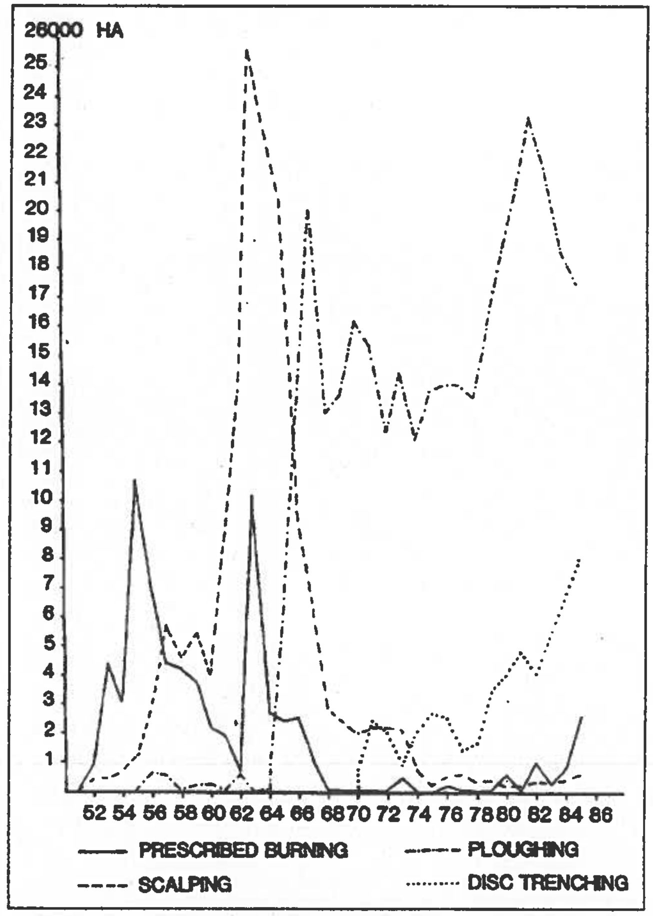

Figure 1. Use of various site preparation methods in the regeneration of state-owned and private forests in the province of Lapland in 1952-85.

Plowing forest land in Lapland intensified once again in 1981-83, when over 20,000 ha of forest land per year was treated in this way, the practice being more widespread on private land than in state forests. The peak was reached in 1982, when 23,000 ha of private and state land were plowed. The use of this technique had diminished again to some extent by 1985 (Figure 1).

Broadcast burning, scalping and mounding were employed only on a few hundred hectares of forest land per year in

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Lapland from 1970 onwards, whereas disc trenching became more popular and reached some 8,000 ha per year in 1985.

Exclusive spruce and pine forest soils

When the death of Scots pine saplings on burned and scalped sites in the 1960s was attributed to debilitation of the root systems due to the unfavorable physical properties of the soils concerned, the concept of "exclusive spruce forest soils" emerged to describe such sites which posed particular problems for regeration with pine (Sarvas 1971). Use of this term came to an end, however, with the spread of plowing as a soil improvement technique and the observation that pine seedlings usually thrived well on plowed sites. Since disturbances in the growth and condition of the pine saplings, often resulting in death, have now been found to be prevalent in plowed regeneration areas, the hypothesis may be put forward that some of the HMT spruce forests in Northern Finland do after all grow on "exclusive spruce forest soils."

The sites which may be regarded as possessing exclusive spruce forest soils are chiefly located in areas with a humid hill-slope microclimate on upland watershed zones. These areas lie above the highest postglacial shoreline and show pronounced podzolization. The soil is a fine-textured till with little in the way of soluble nutrients. The cool, moist climate, the flat topography and the fine-textured soil mean that these soils are generally cool and damp with a low soil oxygen content. Pronounced frost depths and frost heaving are also typical. These conditions together cause the surface of the ground often to be covered by a thick humus layer composed mainly of *Hylocomium splendens* (Hedw.) B.S.G.and *Vaccinium myrtillus* L. The forest floor may also present some features of paludification, and the spruce trees themselves can further promote humus formation by increasing the humidity of the air and reducing the temperature.

The success of the Norway spruce in these soils in Northern Finland may partly be attributed to its ability to develop adventitious roots (see Heikinheimo 1920), which mean that its root system is situated closer to the soil surface than that of the Scots pine and is thus better able to withstand unfavorable growing conditions. Correspondingly, the presence of birch among the spruces may be related to the ability of this species to transport oxygen from its aerial parts to its roots, which lie at a greater depth than those of spruce.

The opposite to an exclusive spruce forest site would seem to be an "exclusive pine forest site" (see Sarvas 1951), which normally consists of sorted sands supporting pine forest of the Cladonia or Calluna type. Alongside these exclusive sites one also finds areas in which either or both of these tree species can grow. The most "exclusive" of all sites can nevertheless be such that even the tree species which is in general best adapted to those conditions will experience difficulties in surviving.

Forests on exclusive spruce sites

The spruce forests growing on exclusive spruce sites in Northern Finland would appear to have developed from the shrub layer of a birch forest arising after a forest fire (see Keltikangas 1959), the spruce attaining a dominant position as the birches have aged. Such areas may be referred to as primary spruce forests (Siren 1955), the birches having spread there by seeding. Spruce forests developing from the shrub layers of these primary stands are then designated as secondary spruce forests. These frequently contain a certain proportion of old, degenerate spruces and some coppice birch growing from the stumps of the original seed-propagated trees. The low density of this type of forest and the frequent degeneration of both spruce and birch reflects the harshness of the climate and soil conditions. It seems to be in precisely these secondary spruce forests that the most "exclusive" spruce soils of all are to be found. The natural forest growth on such soils is normally regarded as having poor productivity in the official classification.

Forests on exclusive spruce sites and the HMT designation

The HMT forests form a dynamic and variable forest type (Figure 2) which includes not only spruce forests growing on sites affected by forest fires and then colonized by birch but also those developing from pine forests after forest fires (Keltikangas 1959).

Till soils, usually with coarser texture than fine sandy tills, excluding the exclusive pine sites described above, have a tendency to revert to spruce stands under the humid climatic conditions prevailing in Northern Finland. Where plants typical of HMT spruce forests are common in the forest floor vegetation of pine forests, these sites are usually counted among the HMT forests (Keltikangas 1959). The first predominant spruce tree cover to develop may be taken as representing a primary spruce forest and the subsequent element in the succession a secondary spruce forest. Some pine and birch normally grow among the spruce.

Regeneration of HMT spruce forests

Broadcast burning and scalping are evidently unable to alter the physical, chemical and biological properties of the soil in exclusive spruce forests sufficiently to ensure growth in the root systems of pine saplings and an adequate nutrient balance.

It seems that not even plowing can be of help for very long, since a decline in growth and condition followed by death of the saplings is observed around ten years of age. The fundamental reason for this is assumed to lie in a nutrient deficiency compounded by the severity of the climate, the deficiency itself being a combination of a number of factors, including the poor condition of the root systems (Tikkanen and Raitio 1984, Tikkanenf 1988).

The influence of the various factors giving rise to poor root condition in pine saplings is intensified in exclusive spruce soils, where paper pot container seedlings have been found to thrive less well than bare-root plants, presumably because the containers decompose slowly on account of the low level of microbial activity. Other detrimental factors would seem to be the coldness and compactness of the soil and the poor water and oxygen balance. The great fluctuations in temperature and humidity experienced in the plow-

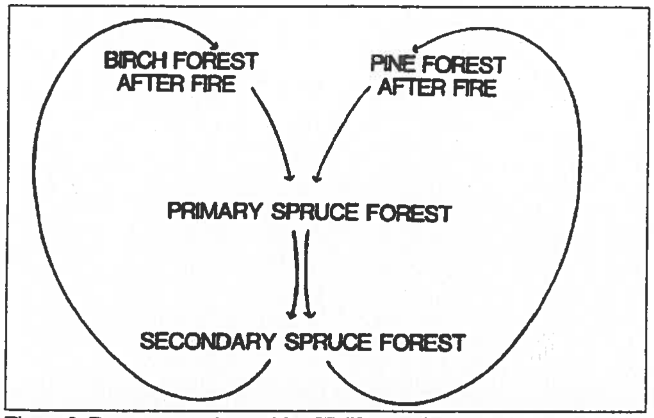

Figure 2. Forest successions with a HMT secondary spruce forest climax phase in "exclusive spruce forest soils" (left) and till soils, usually coarser than fine sand tills, invaded by spruce (right) in Northern Finland.

ing tilts may also restrict root growth. In addition the illuvial horizon of the podzol soil contains precipitations of aluminium and iron, which are transferred to the surface soil in the course of plowing. It is known that one of the direct toxic effects of aluminium is the damage it can cause to plant roots (Fleming and Foy 1968, McCormick and Steiner 1978, Wagatsuma 1983, Sheppard and Floate 1984, Huttermann 1985).

The best results when using pine seedlings to regenerate areas of HMT spruce forest would seem to be obtained in till soils which had supported pine immediately after a forest fire and reverted to spruce forest later. The natural conditions for pine growth are better here than in exclusive spruce soils. The reasons for the better success probably lie precisely in the adequacy of root growth and nutrient availability, since relatively coarse-textured tills possess better aeration and a more suitable water and oxygen balance. A sloping site topography can have a similar effect, and spruce forests arising out of stands, that were originally pine, are certainly to be found on the slopes of hills.

It seems to be important for the nutrient economy of saplings that their roots grow beyond the plowing tilt as soon as possible after planting. Even so, there are always many dangers threatening the nutrient balance of pine saplings. Regeneration of HMT spruce forests growing on sites originally occupied by pine is likely to succeed in any case when pine seedlings are used, whatever soil improvement technique is adopted, for planting with pine seems to be more successful in such places after broadcast burning than in exclusive spruce soils which have been burned.

Principal cause of the sapling deaths

Since there are some places in Northern Finland where pine grows in a humid hill-slope microclimate, climate cannot be the principal reason for the poor results obtained with pine saplings on exclusive spruce sites, any more than poor results can lie in the scarcity of soluble nutrients alone, since this tree species occurs naturally in poor soils, e.g. on exclusive pine forest soils. The major reason may lie instead in the fact that being poorly developed, the root systems of the pines are unable to take in sufficient amounts of nutrients.

In spite of the physical, chemical and biological alterations brought about in the forest soil by plowing, the saplings decline in growth and condition and eventually die in exclusive spruce soils at an age of about 10 years. Here, as in sites treated by other soil improvement techniques, the principal cause is assumed to be nutrient deficiency brought about by a combination of factors and compounded by the severity of the climate.

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Water and Nutrient Uptake in Relation to Regeneration Success

By: Göran Örlander

Abstract: The results of an experiment which compared control and reference pine and spruce seedlings with seedlings irrigated with and without fertilizer solution suggest that water stress is not normally the result of soil water deficit. It is concluded that the potential for improving seedling growth by appropriate site preparation is high.

Introduction

A clear-felled area has an abundance of water and nutrients. Nevertheless, planted seedlings suffer from water stress and probably also reduced growth due to nutrient deficiency. The insufficient water uptake usually found in newly planted seedlings (Örlander 1984, 1986) may continue for several years thus reducing growth of the planted seedlings and causing poor reforestation results. Seedling quality and scarification method influence water uptake. In this paper I will concentrate on some basic biological questions relevant to the choice of scarification method.

I will discuss the role of water and nutrient uptake by seedlings on the basis of results from an irrigation and fertilization experiment conducted in 1985 at the Field Research Station in Vindeln, Sweden, 64'15, alt. 225 m.

Methods

One-year-old seedlings of Scots pine were planted on May 30 and June 24, and two-year-old Norway spruce seedlings on May 30. The seedlings were grown in containers (Panth) filled with peat. The experimental design was randomized blocks with six-tree plots. Twelve replications were planted. The soil was prepared before planting and mounds of ca. 10 cm height were created.

Treatments

a) Water only: Water was supplied by a drip irrigation system from planting date to September. Water (ca. 200 cl/day, seedling) was supplied in small doses four times a day.

b) Water plus fertilizer: A liquid fertilizer (Superba S) containing all nutrients in optimal proportion was mixed with water to produce concentration nutrient solution (80 ppm N) and supplied as in a).

c) Control

d) References: Previously planted pine seedlings and naturally regenerated spruce seedlings were selected as references. The reference seedlings were somewhat bigger than the planted ones.

Measurements

Needle conductance and needle water potential were measured about once a week, and plant water conductance was calculated as described by Örlander (1984). Soil water potential and soil temperature were measured during the whole vegetation period.

Needle length and shoot length were estimated five times during the summer. On June 23 and September 3, some seedlings were excavated, and shoot and root growth were determined.

Nitrogen content (Kjeldahl method) was determined from needles of the current shoot harvested on three occasions.

Results and Discussion

Weather conditions

May 1985 was rainy and cold. June was drier than normal, especially at the end of the month. Precipitation in June was 28 mm (normally 56 mm). June was followed by a warm and dry period at the beginning of July, whereas August was extremely wet.

Soil water potential

The soil started to dry at the end of June, and in July the soil water potential became as low as -250kPa (Figure 1). Even the irrigated seedlings showed a tendency to drought. However, the soil water potential never fell below -40kPa for irrigated seedlings.

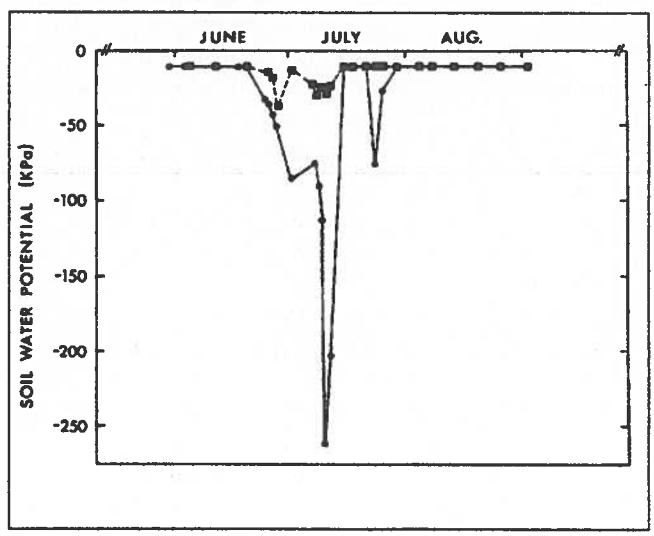

Figure 1. Soil water potential for irrigated seedlings () and control seedlings (•). Vindeln 1985.

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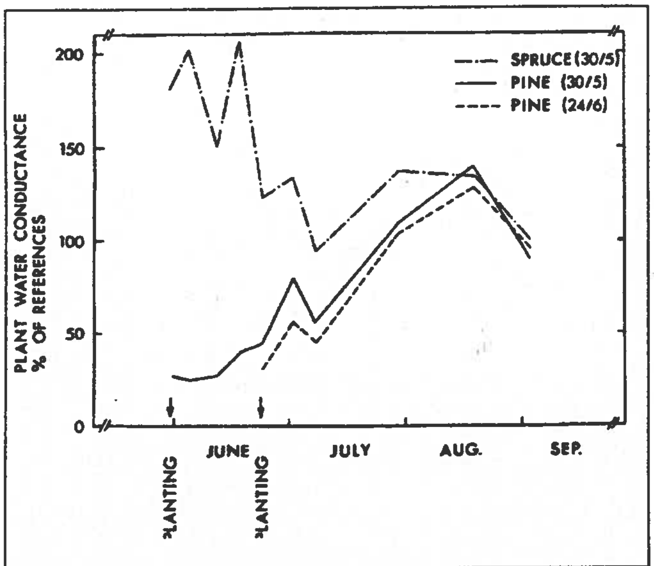

Figure 2. Plant water conductance for seedlings of Scots pine and Norway spruce planted on different occasions in Vindeln 1985. Mean of all temperatures.

Plant water conductance

During the first weeks after planting, plant water conductance in the planted pine seedlings was only about 25% of that of the established reference seedlings, irrespective of planting date (Figure 2).

The spruce seedlings showed unexpectedly high plant water conductance compared to the references. During the first weeks after planting the conductance of the planted seedlings was about twice as high as that of the references.

The effect of irrigation and irrigation + fertilization on the water relations of the seedlings was very small (Figure 3). On only one occasion the controls had significantly lower plant water conductance than the irrigated seedlings—during the dry period in July. This was most obvious for pine seedlings planted in late June (not shown in Figure).

The results obtained for the pine seedlings showed that the seedlings were subjected to sever water stress and that additional water supply to the soil did not increase water uptake. The poor water uptake can therefore not be explained as a consequence of soil water deficit. Probable explanations of the low water uptake may be poor seedling quality (this could not be seen with the naked eye) or unfavorable planting environment (for example low soil temperature).

The results obtained for the spruce seedlings are more difficult to explain. The author has never before found higher plant water conductance in newly planted seedlings than in established references (cf. Örlander 1984). The seedlings were grown in the nursery according to routine procedures. One possible reason for the result might be that the reference seedlings had low water uptake, but this explanation seems unlikely, since rather high absolute values of needle conductance and needle water potentials were also found in the reference seedlings. It might also be possible that there were more favorable conditions (e.g., higher soil temperature) in the mounds than below the humus layer, where most of the roots of the references were located.

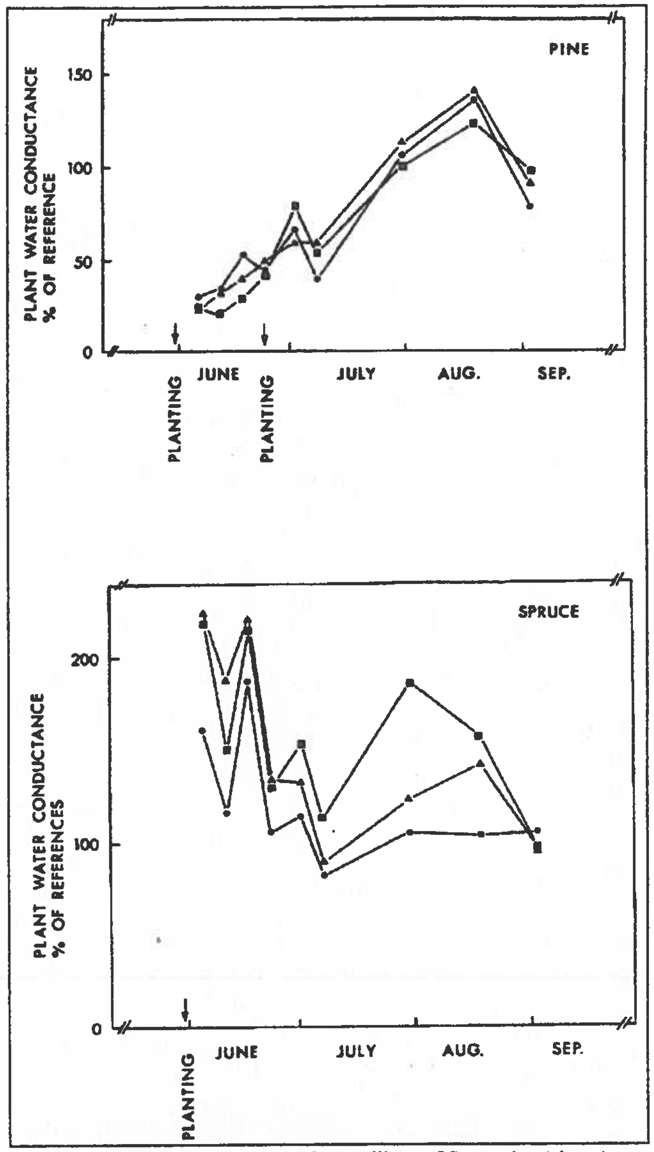

Figure 3. Plant water conductance for seedlings of Scots pine (above) and Norway spruce (below). Irrigated + fertilized () controls (•)

To sum up, irrigation and fertilization had little effect on the water relations of both pine and spruce seedlings.

Nutrient uptake

As soon as the development of current needles began, large differences in nitrogen content in the needles could be detected among the treatments. The irrigated + fertilized seedlings had more than 2% N-content compared to 1-1.5% for the irrigated seedlings and the controls (Figure 4).

Adding nitrogen to scarified patches before planting may be detrimental to the development of seedlings. Söderström (1976) found that rather small amounts of nitrogen (10 9N/ m2) added to scarified patches were detrimental to root growth and thereby water uptake of the seedlings. Low concentrations of nutrients, such as that added to the seedlings in the present experiment, obviously had no restrictive influence on the water uptake.

Seedling growth

The effect of irrigation and fertilization on the shoot growth was quite different for pine and spruce. The length of pine current shoot was affected very little by fertilization and irrigation. The growth was much slower for all planted seedlings than for the references. The poor growth can be explained as a direct effect of water stress (Bradford & Hsiao 1982). The current needles of fertilized seedlings were much longer than those of other treatments (Figure 5). At the end of the growing season the mean needle length was 60 mm for the fertilized seedlings compared to 40 mm for references and only about 30 mm for controls or irrigated seedlings. The highest increase in needle growth occurred after the most severe period of water stress immediately after planting.

Fertilization had a positive effect in spruce leader growth (Figure 6). The mean length for fertilized seedlings was ca. 140 mm, whereas it was only about 40 mm for irrigated ones and controls. The fertilized seedlings started a period of free growth in the late summer, which did not stop until the first frost nights at the beginning of September.

An increase in dry weight production was found for fertilized seedlings. For example, the mean shoot dry weight in September was 0.8. g for the control pine seedlings planted in May. The corresponding value for irrigated and fertilized seedlings was 2.2 g. Irrigation alone had little effect on shoot growth. Neither irrigation nor fertilization had any significant effect on root growth of the seedlings (Figure 7).

Conclusions

The experiment clearly demonstrates the role of water and nutrients for newly planted seedlings. The hypothesis that water stress is normally not an effect of soil water deficit seems to be correct. In my opinion, water stress is mainly a result of poor seedling quality and/or cold or waterlogged soil at the time of planting. Poor seedling quality can be a result of winter damage to the roots (Lindström 1986), insufficient winter hardening (Örlander & Rosvall-Åhnebrink 1984), the wrong growing substrate (Örlander & Due 1986,) or root damage on bareroot seedlings. The results achieved with the spruce seedlings in the present experiment are encouraging however and show that it is possible to plant without risking water stress.

The potential of site preparation seem to be very high. Previous research shows that the water uptake of seedling scan be improved by choosing the proper site preparation method (Örlander 1984, Örlander 1986). If nutrients could be added to the seedling in low concentrations continuously,

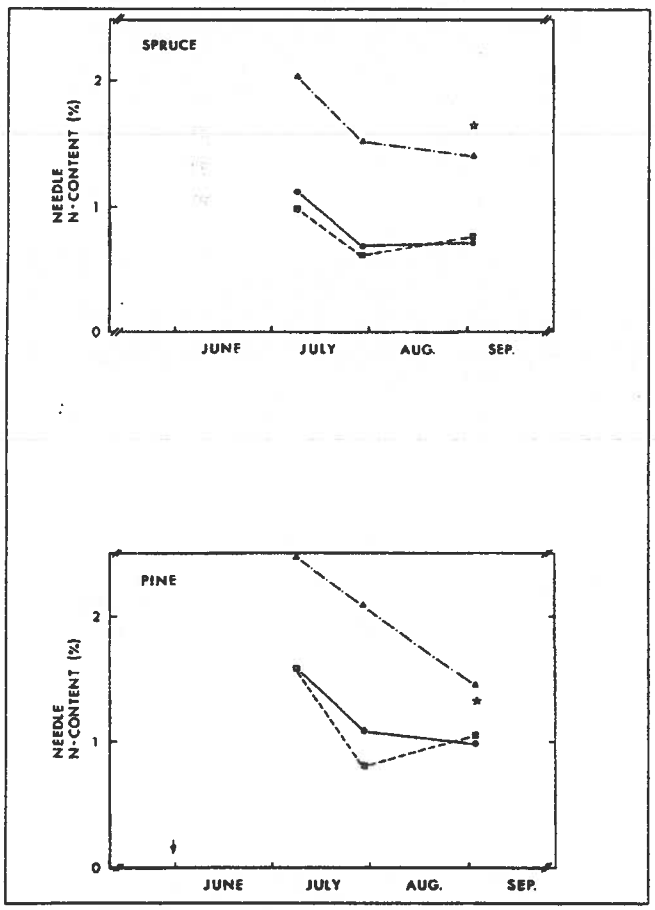

Figure 4. Nitrogen content in needles of Scots pine (below A) and Norway spruce (B) seedlings that were irrigated + fertilized (), irrigated (), controls (•), or references (*). Vindeln 1985.

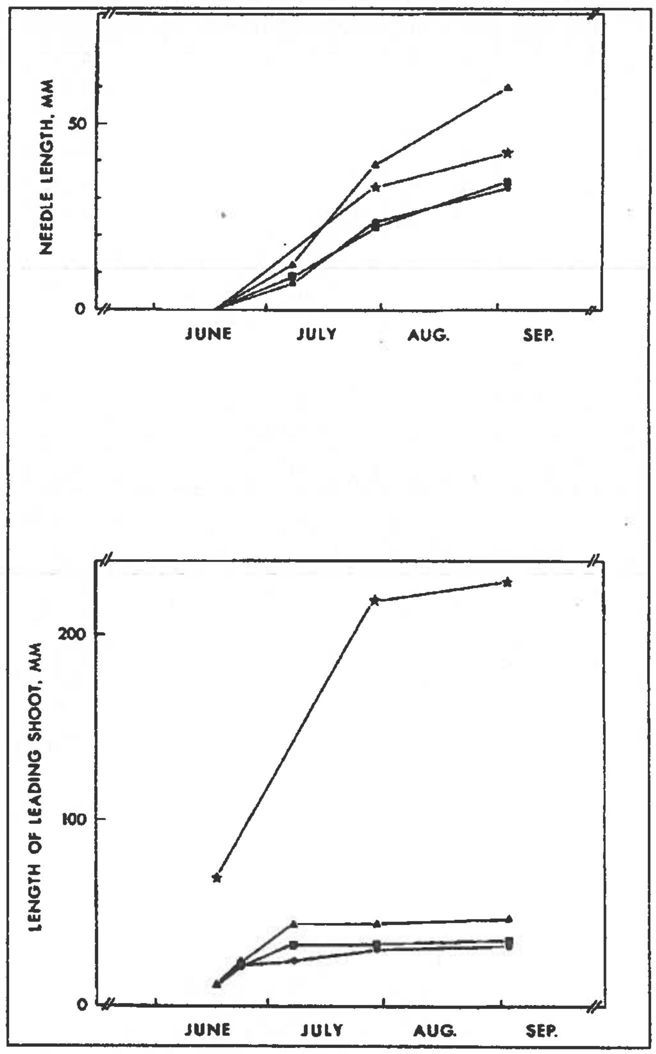

Figure 5. Mean needle and shoot length for pine seedlings that were irrigated (-), irrigated + fertilized (), control (•), and established references (*). Vindeln 1985.

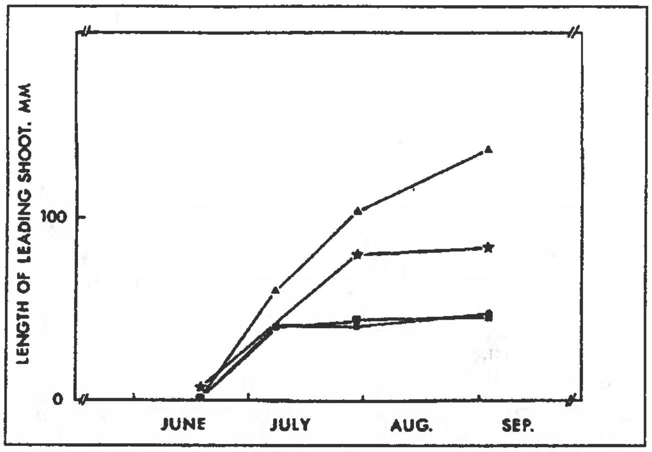

Figure 6. Mean shoot length for spruce seedlings that were irrigated (), irrigated + fertilized (), controls (•), and established references (*). Vindeln 1985.

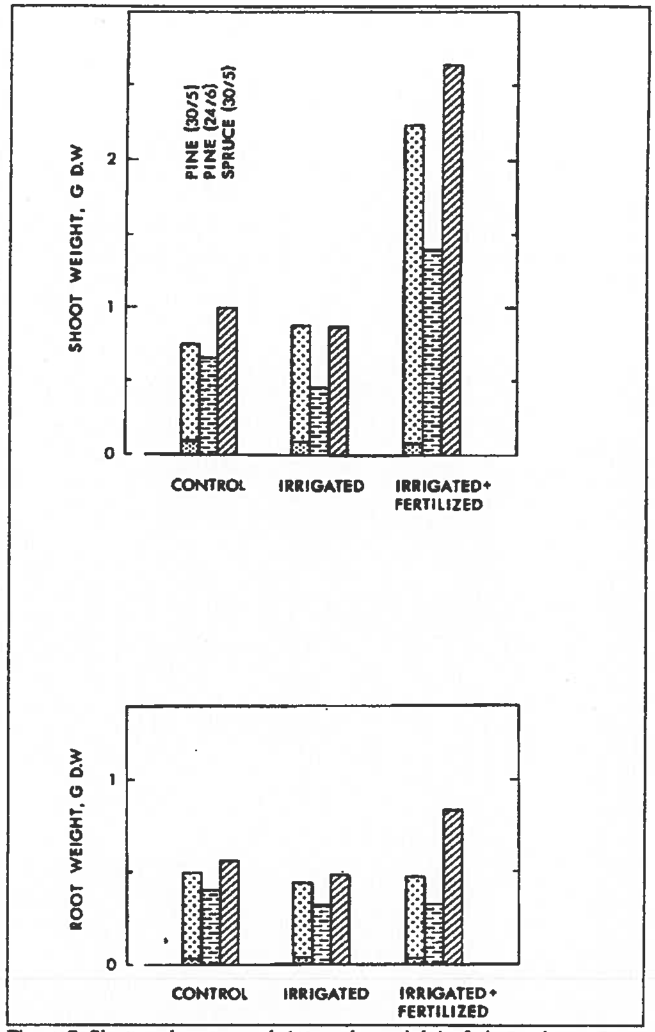

Figure 7. Shoot and root growth (mean dry weight) of pine and spruce seedlings planted on different occasions in Vindeln 1985. The seedlings were irrigated, irrigated + fertilized, or controls. The measurement was made September 3. For pine seedlings planted on May 30, values from an extra measurement made June 24 are also shown.

it should be possible to avoid the period of stagnation in growth after planting, even for spruce. The research of Lundmark (e.g., Bäcke et. al. 1986) shows that the mineralization of nutrients can be controlled by the choice of site preparation method. With more knowledge, it should be possible to use some of the water and nutrients available in large amounts on the clear-felled area to increase seedling growth.

I will not discuss the proper design of the site preparation methods. We know, however, that high soil temperature, well drained planting spots and good soil water availability promote a good seedling establishment. On many forest sites in Sweden we achieve, as far as it is known, the best results with mounding. Whether the mound should be placed on mineral soil or on humus depends on the site. One attempt to report the knowledge acquired concerning site-adapted site preparation is presented by Bäcke, Larsson, Lundmark and Örlander (Bäcke et al., 1986).

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Effect of Soil Plowing on the Phosphorus Cycle

By: Eero Tikkanen

Abstract: Research carried out into the reasons for the decline in growth of young pine in northern Finland have yielded new information on the effects of plowing on the phosphorus cycle. As organic matter decomposes due to the action of micro-organisms, phosphate is released, some of which is used by the micro-organisms themselves, and some is probably bound to metal ions to form insoluble secondary inorganic phosphorus, especially in the tilts. This means that the pine seedlings planted on the tilts have only a small amount of phosphate available to them. Phosphate is mobilized very slowly from mineral sources and some is immediately bound in secondary phosphorus compounds. Thus plowing can exacerbate the shortage of phosphorus associated with clear felling, largely through increased leaching and erosion and the formation of secondary phosphorus.

Introduction

Regeneration in spruce (*Picea abies* Karst) forests of the Hylocomium-Myrtillus type (HMT spruce forests) in Northern Finland was intensified in the late 1950's. Many such forests were clear-felled and replaced with Scots pine, which was regarded as more productive than Norway spruce. Setbacks were suffered later, however, as the growth and condition of the young pines planted on burned over and scalped sites deteriorated in many places and the trees died. The cause of this was said to be debilitation of the root systems due to the coldness and compactness of the soil and the poor water and oxygen balance (Valtanen 1968, 1970). The demise of the ailing trees was further accelerated by diseases, principally dieback and canker fungus.

Plowing as a means of improving forest land and facilitating cultivation gained in popularity from the late 1960's onwards, and was also readily adopted as an aid to regeneration in fairly dry pine forests. Research carried out in the 1970's demonstrated that soil temperature sum and soil aeration were greater in the tilts (tilt is equivalent to "berm" or "furrow slice" in North American literature) of plowed forest land than in lightly tilled or untilled land (Leikola 1974, Kauppila and Lähde 1975, Ritari and Lähde 1978). Forest inventory results showed the early development of pine seedlings in plowed areas to be generally good (Lähde and Pohjola 1975, Mutka and Lähde 1977, Pohtila 1977). Even so, by the time the trees had reached the age of about 10 years, around 1979-80, an abnormal growth pattern began to make itself evident in many places, one reason suggested for this being the presence of heavy metals in the surface soil, raised from the illuvial horizon by the act of plowing (Lähde 1984).

Death of Young Trees in Plowed Areas

Upon the commencement of research into the reasons for the developmental abnormalities in young pines growing in plowed forest areas in Northern Finland it was noted that these areas contained trees whose growth had been disturbed in a variety of ways. In some places affected trees were obviously debilitated, while in others they were growing vigorously but had lost their growing tip dominance. The young trees also suffered from a variety of diseases, including dieback and canker fungus, twisting rust and various needle cast diseases. Since the cases of sudden deterioration in condition and growth appeared to lead rapidly to the death of the young pines, and since the phenomenon as a whole resembled the withering of saplings observed in the 1960's, research was concentrated first on these cases.

Research commenced with a series of nutrient analyses performed on needle samples. Results enabled a preliminary hypothesis to be constructed according to which the debilitation of the trees was attributed to a deficiency chiefly in phosphorus and to some extent nitrogen, exacerbated by climatic effects (Tikkanen and Raitio 1984, Tikkanen, 1988). It was suspected that clear felling and the plowing of forest sites could well be the causes of many of the disturbances in nutrient balance affecting young trees. In the first instance, however, the phosphorus deficiency appeared to manifest itself most markedly via the chemical properties of the phosphate anion and the significance of this ion for the energy balance of the plant.

In terms of this hypothesis the phosphorus balance in the pine saplings planted on plowed land could have been disturbed by such factors as a reduction in the humus layer and alterations in its chemistry, an increase in the proportion of insoluble inorganic phosphorus compounds in the soil, a decline in microbiological activity in the soil, the poor condition of the root systems of the trees, the binding of nutrients in the surface vegetation, which is of a type that tends to promote soil acidity, and the leaching of nutrients from the soil. The hypothesis is currently being tested with respect to the first four of these factors. Preliminary results are presented here.

Results

Humus

The suggestion of "a reduction in the humus layer and alterations in its chemistry" as a reason for the assumed phosphorus deficiency suffered by the young pines was confirmed by investigations carried out at a forest site plowed 12 years previously. The "double humus layer," that which had been buried beneath the tilt, had been compressed and mixed with

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sand and contained a very much lower proportion of organic matter than the forest humus in general. It had also undergone chemical changes which had led to a lowering in the concentrations of nitrogen, potassium and magnesium in addition to phosphorus. Similarly the illuvial horizon in the tilt also had a lower organic matter content than corresponding horizons in undisturbed forest soil or in the soil beneath the tilt (Tikkanen 1988).

Inorganic phosphorus compounds

Many of the areas of HMT spruce forest in Northern Finland grow on fine-textured, highly podzolized till soils in which the illuvial horizon contains precipitations of aluminium and iron which are brought to the surface by plowing. Plowing also raises insoluble iron and aluminium phosphates representing "secondary inorganic phosphorus" within reach of the root systems of plants growing on the tilts. On the other hand, the illuvial horizon contains little soluble phosphorus which can be readily utilized by the plants.

Evidence for the role of the second factor proposed to explain the assumed phosphorus deficiency, "an increase in the proportion of insoluble inorganic phosphorus compounds in the soil," was also found in the same plowed area. Slightly more phosphate bound to iron was found in the illuvial horizon of the tilt itself than in the layers below the tilt or in the undisturbed soil. This finding lends support to the results of soil analyses which suggest that the highest concentrations of amorphous iron are to be found in the illuvial horizon of the tilt (Tikkanen 1985), since the amorphous or non-crystalline oxides of iron and aluminium are important for their action in binding phosphorus.

The situation as regards aluminium differed from that for iron in that large amounts of amorphous aluminium were found in all the illuvial horizon samples analyzed. The figures were higher in those horizons lying below the tilts or in undisturbed soil than in the those of the tilts. This was again confirmed by the findings in the phosphorus analysis, where aluminium-bound phosphates were present in the greatest concentrations in the illuvial horizons of the forest soil and the soil underlying the tilts. This was also the case with inorganic apatite phosphorus. It is possible that phosphates released from apatite phosphorus and aluminium compounds may have been leached out of the upper tilt layer and have become bound to iron oxides in the tilts, or else they may have been utilized by the plants. Similarly some of the aluminium may have been converted into soluble form and have leached out of the tilt along with the organic matter (Tikkanen 1988).

The concentration of soluble aluminium ions (Al^{3+}) in the soil was not especially high, nor were any very marked differences found between the samples from the illuvial horizons of the undisturbed forest soil, the soil beneath the tilts and that of the tilts themselves. One decisive factor governing the presence of soluble aluminium is the acidity of the soil, since the concentration of this cation increases with declining pH. It has been shown that pH (KCl) values for the illuvial horizon in plowing tilts approximately 10 years of age in Northern Finland normally vary in the range 4-5 and are frequently slightly lower than the corresponding values for the illuvial horizon buried beneath the tilt or that in adjacent undisturbed soil.

Microbiological activity

Microbiological activity in the soil was measured by enzymatic methods in samples from an area plowed about 10 years ago. The enzymes selected for this purpose were dehydrogenase, which reflects general microbiological activity in the soil, and acid phosphatase and pyrophosphatase, which enable phosphorus mobilization. The results showed the activities of these enzymes to be poor in the illuvial horizons,although in the illuvial horizqn of the tilt the activity was higher than in that of the undisturbed forest soil or in the soil beneath the tilt. Values in the double humus layer were much higher than in the mineral soil samples and of the same order as in the forest humus (Tikkanen, unpublished manuscript). It is impossible from these results to say whether any decline in microbiological activity had taken place with time in the tilt, and thus the third factor adduced to explain the assumed phosphorus deficiency in the young pines, "a decline in microbiological activity" could not be shown to hold good. The weakness of the enzyme activity in the illuvial horizon of the tilt itself nevertheless provides some indication that the insoluble phosphate bound by the metal ions cannot have been mobilized in any manner which would make it particularly easily available to the plants. The enzyme activity measurements obtained from the double humus layer in turn support the observation that quantitative and chemical changes had taken place in this horizon.

Condition of the root systems

Investigations into the condition of the root systems of the young pines were begun by examining the root anatomy of the ailing trees at a site which had been plowed 8 years earlier. These roots were shown to be in as poor condition as the aerial parts of the trees, possessing short, thin-walled cells with highly limited nutrient reserves, and the root tissues of some trees actually contained cavities (Hohtola and Tikkanen, unpublished manuscript). It could only be concluded that these root systems were incapable of taking in and transporting water and nutrients in the normal way. Thus the fourth reason proposed for the phosphorus deficiency was shown to hold good, even though it was impossible to demonstrate whether this condition of the roots was the cause of the weakness observed in the aerial parts of the plant or a consequence of this. Attempts were made to study the role of aluminium in relation to this root damage, but no concrete conclusions could be reached on this score.

Discussion

Phosphorus as a plant nutrient

Phosphorus is present in all plant cells in the structure of nucleic acids, lipids and some carbohydrates. Apart from its role in the nucleic acids, it is also of considerable importance in events related to the storage and transfer of energy. Photosynthetic phosphorylation gives rise to a number of high-energy compounds, the most important of which is adenosine triphosphate (ATP), which acts as a direct energy transfer agent in plants. Thus any deficiency in phosphorus will be reflected in the whole metabolism of the plant (Halstead and McKercher 1975).

Phosphorus is present in both organic and inorganic form in soil, with the former accounting for between 15% and 80% of the total. Organic phosphorus is made available to plants through the action of micro-organisms, while the chief inorganic forms are primary apatite phosphorus and secondary bound phosphorus contained principally in various iron and aluminium compounds, the mobilization of these inorganic forms for plant use again requiring the action of micro-organisms (Alexander 1977, Amberger 1979, Mengel 1979, Mengel and Kirkby 1979). Phosphorus is mobilized in soil largely through the effects of extracellular enzymes (Burns 1978) and is taken up by plants in the form of phosphate anions in an active, energy-requiring process. This phosphate moves slowly through the soil towards the roots by means of diffusion (Raitio 1983), an action which is retarded by low temperatures or the presence of fine soil fractions to which it is easily adsorbed. This means that the roots have to grow in the direction of the phosphate in order to guarantee an adequate supply of this nutrient. Mycorrhiza play a considerable part in the uptake of phosphorus by plants.

The phosphorus cycle in forests and clear-felled areas

The phosphorus cycle in forests and clear-felled areas (Vitousek 1983) is described in Figure 1. In forest soils it is mineralized from organic compounds by the decomposing action of micro-organisms, which themselves consume some of the product, while the majority is utilized by the trees and other vegetation. A little phosphate also becomes bound to minerals, predominantly iron and aluminium, to form secondary phosphorus. A small amount of phosphorus is also mobilized from phosphorus minerals, chiefly apatite.

Clear felling has an obvious impact on the phosphorus cycle, since phosphorus is removed from the forest ecosystem both in the timber and by virtue of leaching and soil erosion. More phosphate becomes bound by microbes than in forests, but less by the surface vegetation. Similarly, more is converted to secondary phosphorus. Clear felling alone can lead to a shortage of phosphorus, as that removed from the ecosystem or converted to secondary form is replaced only very slowly by phosphates mobilized from phosphorus minerals.

Effect of plowing on the phosphorus cycle

The research carried out into the reasons for the decline in growth and condition observed in young pines in Northern Finland has yielded new information on the effects of plowing on the phosphorus cycle. Although the role of leaching in the alleged phosphorus deficiency was not studied here, it can be assumed from other sources (Kubin 1984, Davner 1985) that both this and erosion are more pronounced in plowed areas than in clear-felled areas (Figure 2). As organic matter decomposes due to the action of microorganisms phos-

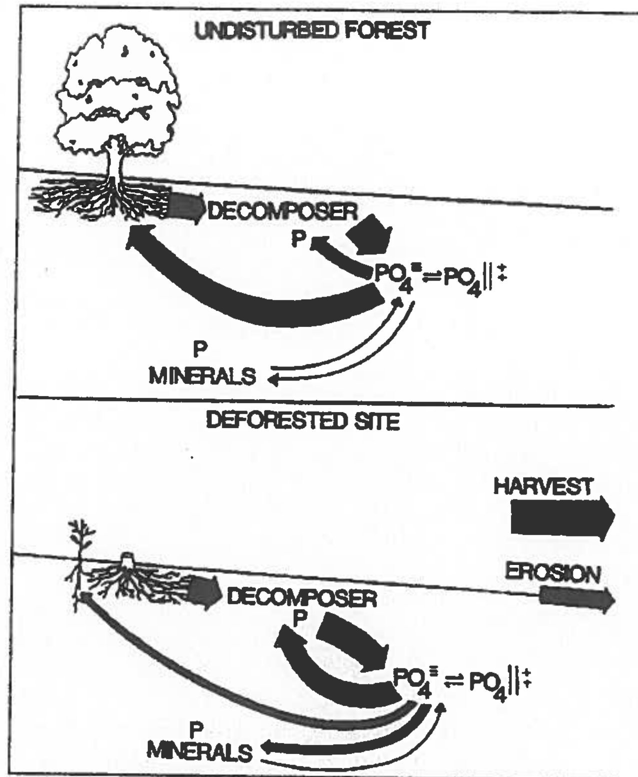

Figure 1. The phosphorus cycle in an undisturbed forest and at a deforested site (Vitousek 1983).

phate is released, some of which, as elsewhere, is used by the microbes themselves, and some is probably bound to metal ions to form insoluble secondary phosphorus, especially in the tilts. This means that pine seedlings planted on the tilts and other plants growing there have only a small amount of phosphate available to them, which they receive chiefly through those roots which extend to the double humus layer. Again phosphate is mobilized very slowly from mineral sources to replace that removed from the ecosystem or converted to insoluble compounds, and some of this in any case immediately becomes bound in secondary phosphorus compounds. Thus plowing can exacerbate the shortage of phosphorus associated with clear felling as such, largely through increased leaching and erosion and the formation of secondary phosphorus.

This scarcity of phosphorus may also become more pronounced with time as the humus in the plowed soil decreases in amount and alters in quality so that its reserve of organic nutrients diminishes. This effect may also be accompanied by an increase in the concentration of insoluble phosphates in the tilt, especially those bound to iron. The decline in organic matter and its alteration may lead in turn to lower microbiological activity in the soil on account of the lack of phosphorus or the presence of soluble aluminium, soil concentrations of which usually increase once the pH (KCl or $CaCl_2$) drops below 4.2 (Foy 1978, Ulrich 1983, Matzner and Ulrich 1985). The toxic character of aluminium manifests itself indirectly, chiefly in the form of disturbances in the nutrient balance. It binds phosphate and certain other anionic nutrients in insoluble form and hinders the uptake and transport of cations, and may also cause root damage

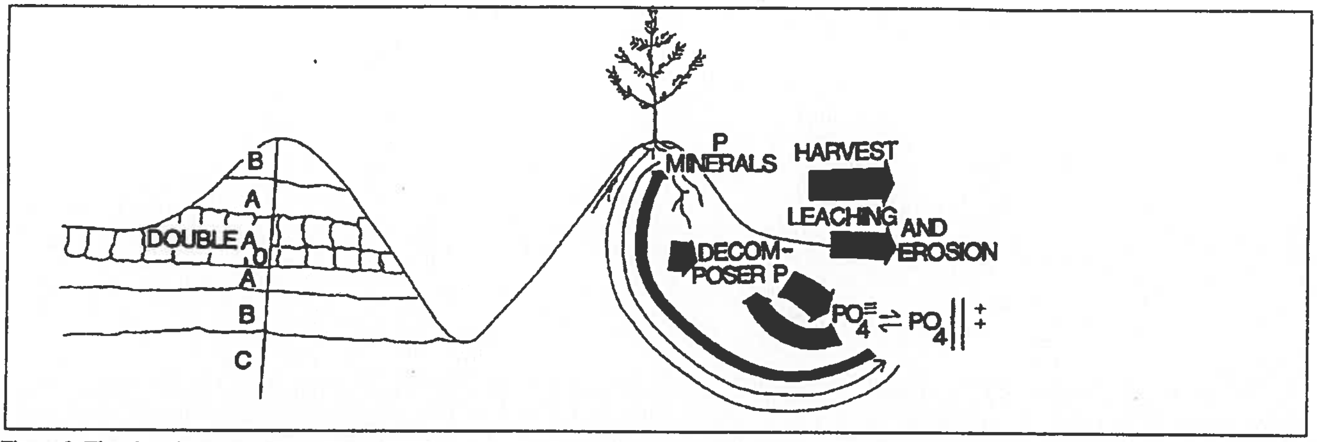

Figure 2. The phosphorus cycle at a ploughed site.

(Clarkson and Sanderson 1971, Foy 1978, Evers 1983, Bergmann 1983, Rost-Siebert 1983, Hüttermann 1985, Gomes et al. 1985).

It may thus be concluded that lowering soil pH in the tilts and decrease in humus content and alteration in the nature of this humus in all probability lead to an increase in the solubility of aluminium, which not only disturbs the nutrient balance but may also damage the root systems of the young pines, interfering with the uptake of phosphorus and other nutrients. In addition to this effect, the phosphorus balance of the trees in plowed areas may also be affected in the course of time by the leaching of nutrients and their being bound in the surface vegetation.

Conclusions

The present research into the decline in growth and condition in Scots pine saplings planted on plowed forest land in Northern Finland has focused above all on the availability of phosphorus. New information is provided on the detrimental effects of plowing on the phosphorus cycle and other aspects of the nutrient balance in the soil, including depletion of nitrogen, potassium and magnesium reserves caused by the accompanying reduction in the humus layer and changes in its nature. It is now understood that harsh growing conditions can combine with the chemical properties of the phosphate anion to render phosphorus a more sensitive indicator of environmental changes and disturbances than many other nutrients. It should be emphasized, however, that the existence of a phosphorus deficiency in the ailing pines in plowed forest areas, and to some extent the resulting demise of these pines, still remain unproven assumptions.

The present cases of debilitation of young pines in plowed areas resemble earlier descriptions of decline in saplings planted in burned over and scalped areas in the 1960's (Valtanen 1968, 1970). Plowing has evidently not provided any permanent remedy for all the undesirable features of local growth conditions to which the weakness of the root systems and death of the saplings was attributed. Plowing may indeed have introduced new detrimental factors or exacerbated earlier latent factors. At least it is now known that plowing can accentuate phosphorus deficiency and increase the solubility of aluminium in the soil (Tikkanen 1985) and can create more extreme temperature and humidity conditions in the tilts than in lightly tilled or undisturbed soils (Kemppainen 1985). Tilling provides good conditions for the early growth of pine seedlings planted in plowing tilts, but it is important that the roots should spread beyond the tilt as quickly as possible, as the nutrient supplies there will gradually be exhausted.

The failure of forest regeneration with pine in the 1950's and 1960's on burned areas which formerly supported spruce forest seems to suggest the existence of "exclusive spruce forest soils." That is, if pine will not thrive in areas previously characterized by HMT spruce forests, it probably would not have grown there even under natural conditions following a forest fire. Instead the first dominant species to emerge after such a fire would be birch, with low, shrub-layer spruces which would then attain dominance later in the succession, as the birches aged. If this tree cover of a primary spruce forest managed to survive without any further forest fire, the smaller spruce forming its undergrowth would later develop into a secondary spruce forest (Tikkanen 1986). This exclusive preference for Norway spruce is evidently governed by climatic factors, and thus the approach adopted here must be that given sites are of this kind "here and now," i.e. under the environmental circumstances prevailing in Northern Finland at this time. It is impossible to predict what soil changes would be brought about by a pronounced warming of the climate, for instance, or how these changes might be reflected in plant growth.

The success of given tree species on exclusive spruce forest soils is determined by such factors as the condition of their root systems and the availability of water and nutrients. Root growth and the uptake of nutrients in pine saplings at such sites may be restricted by the compactness and coldness of the soil or by poor water or oxygen balance. A further factor of relevance where plowing has taken place is the presence of aluminium. The pre-eminence of Norway spruce on such land may well be related to the superficial location of its root system and its ability to develop adventitious roots (Heikinheimo 1920). The importance of the root system in plants normally increases under northerly conditions, the vitality and extent of the roots being an essential factor in ensuring an adequate supply of water and nutrients and providing for the storing of energy.

The results of the present investigations into the physical, chemical and biological properties of the soil and the biology of the young trees themselves suggest that the reason for the decline in condition and frequent death of young Scots pines planted in plowed areas of forest land in Northern Finland lies in a disturbance in their energy balance brought about by a combination of stress factors. Examinations of the effects of plowing carried out in areas plowed some ten years ago indicate that this measure alone can give rise to a phosphorus deficiency in the course of time.

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New Finnish Site Specific Machines for Soil Preparation

By: Sven-Eric Appelroth

Abstract: In Finland test results of the TTS-Delta HJ indicate that the quality of work can be controlled by the operator and that the rate of travel of the prime mover has little impact on this. Inverted mounds, about 20 cm high, can be made using the Sinkkilä II Model 1985 mounding scarifier. The distance between planted spots on the mounds exceeds 4 m. When the site is water-logged and requires drainage the soil from the ditches can be dropped as mounds for planting. Normally the cost of such combined operations in Finland has only been about twice that of ordinary site preparation.

Key words: mounding, site specific, soil preparation, TTS Delta disc trencher, Sinkkilä II mounding scarifier, Donhög 190, Mitsubishi excavator MS180-3, Vammas Major back-hoe tractor excavator, quality of site preparation.

Introduction

Research and the development of machines for site preparation has been ongoing since the beginning of the 1960s. The developments described by Appelroth (1970, 1980, 1981, 1984) have continued. This paper deals with 1985 field test results of site preparation operations using the TTS-35 HJ Delta disc trencher, the Sinkkilä II M/1985 mounding scarifier, the Mitsubishi MS 180 excavator and the Vammas Major back-hoe excavator.

Work quality is greatly dependent on the machine operator. The technical properties of the machines merely set some maximum limits on the range of productivity and work quality. A large range in the types of performance that can be had enables site specific soil preparation. The more easily the operator can control his machine, the better soil preparation can be adapted to site specific treatments for different parts of each cut-over.

The number of planting spots per hectare depends on the spacing between the driving lines (rows) and the distance between the planting spots within the rows.

The distance between the driving lines (rows) depends on the *operator's* knowledge, skill and motivation to follow instructions, and is limited by a combination of *terrain difficulty* and technical properties of the *machine*.

The distance between planting spots depends on the *operator's* knowledge, skills and motivation to adjust the spacing according to instructions, and the combination of *terrain difficulty* (including soil depth) and technical limitations of the *machine*.

The productivity and cost per hectare likewise depend on the machine operator's knowledge, skill and motivation, and the limitations set by the combination of terrain and machine (Appelroth 1985). So far the relationship between machine productivity and site preparation work quality has been insufficiently studied and reported.

TTS-35 HJ DELTA

The TTS-35 HJ Delta differs from the ordinary Delta in having hydraulically powered discs. The machine weighs about 2900 kg and requires a prime mover with a minimum of 100 kW. Technical information is given in appendix 1 driven by an engine with minimum power equivalent to 110 kW.

Adjustments

The field test included the following alternative adjustments of the trencher:

–Hydraulic *down pressure* of the discs: 1 = no down pressure, 2 = medium down pressure and 3 = maximum down pressure without raising the rear wheels of the prime mover.

•*Disc Revolution* (powered) discs in 1 = not powered, 2 = powered.

•*Disc angle* (adjusted manually a bolt in alternative holes) 1 = sharp angle, 2 = medium angle, 3 = dull angle (wide screef).

•*Rate of Travel*: 1 = slow, but still realistic when working as whole season, 2 = normal and 3 = maximum realistic to be maintained throughout a whole season.

Work Quality

The quality of the work was measured: vegetation removed, exposed mineral soil, center of furrow, and percentage of interruption of the continuous furrow.

Work difficulty classes

Stoniness was measured by pushing a steel rod into the soil and measuring to a depth of 20 cm the average depth of stone. The stoniness classes were 1 = 7–11 cm, 2 = 12–16 cm and 3 = 17–20 cm. The humus thickness classes were 1 = 3–9 cm, 2 = 10–16 cm and 3 = 17–24 cm. The slope classes were 1 = min to 8 % downhill, 2 =-9 % to 7 % and 3 = minimum +8 % uphill.

Test layout

Test plots were marked in advance where plots were 25 m long and accommodated a pair of furrows in an area of uniform terrain difficulty class double parallel furrows for each combination could be made in same terrain difficulty

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Table. 1 The different classes of rate of travel in km/h

	X	S	MIN.	MAX.
1	2.5	0.54	1.3	4.8
2	3.4	0.44	2.3	4.4
3	4.0	0.55	2.3	5.2

class. Both were replicated within blocks.

The data basis included measurement of 16,000 m furrows. Large amounts of slash on the ground were not included, because commercial thinnings are applied in Finland leaving only 200 - 300 m³/ha of sawlogs for final cut and normally almost a year passes before site preparation takes place so that needle and leaves have fallen off the branches. Stumps are cut very low in Finland.

Areas with large amounts of slash excluded because of fuel cut only 200 - 300 m³/ha of sawlogs remain and site preparation is done a year later when needles have fallen off the branches.

Results

The *rate of travel* could be between 1.5...4.55 km/h regardless of slope (Figure 1).

This also means that productivity may vary over a large range depending on the motivation of the operator. The effect of rate of travel on the quality of work is only marginal (Table 1).

The effect of *hydraulic pressure* in Figure 2 shows that the width of exposed mineral soil varied by some 20 cm at a low rate of travel and by some 10 cm at a high rate of travel. The *hydraulic powered* discs increased the width of exposed mineral soil only slightly (5...10 cm). The main benefit of hydraulic powered discs is obtained in heavy slash. It was not possible to check this in this study because no such sites with heavy slash could be found in the area. The high rate of travel reduced the width of exposed mineral soil in the furrow compared with the lowest rate of travel.

The effect of adjustments on the *width of vegetation removal* (Figure 3) was similar to the width of exposed mineral soil. However, here the rate of travel had almost no effect. The disc angle 3 made a somewhat narrower furrow than other angles. Regardless of disc angle the correlation between different work quality factors remained high as follows:

Table 2. Effect on work quality of different rate of travel for TTS Delta

Depth of furrow	X	S	Min.	Max
	CM			
Speed 1	9.0	3.5	2.2	21.8
Speed 2	8.3	3.5	1.7	17.7
Speed 3	9.0	3.7	1.8	19.6
Width of furrow				
Speed 1	47.4	15.0	15.6	75.4
Speed 2	44.2	15.9	10.0	82.2
Speed 3	46.1	18.5	9.0	108.3
Width of exposed mineral soil				
Speed 1	29.1	16.5	0.0	62.7
Speed 2	24.1	16.7	0.0	66.0
Speed 3	26.2	17.4	0.8	70.6
Percentage of continuous furrow, %				
Speed 1	79.8	20.0	17.4	100.0
Speed 2	73.3	21.7	29.6	100.0
Speed 3	79.3	20.6	22.0	100.0

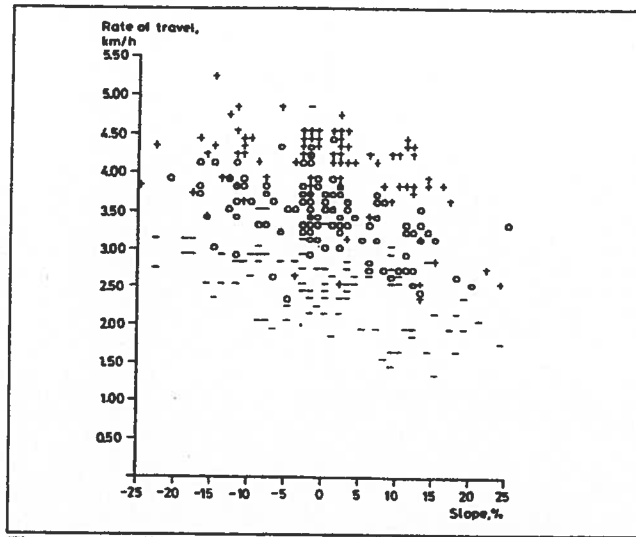

Figure 1. The effect of slope on the rate of travel for a TSS Delta.

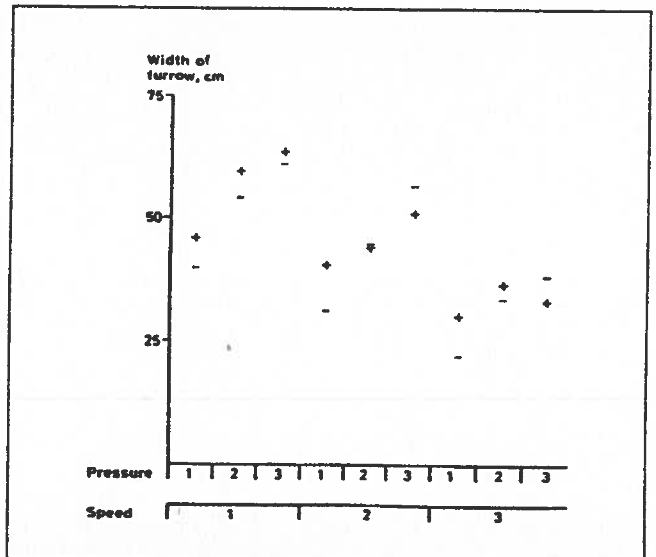

Figure 2. The effect of hydraulic downpressure and powered discs on the width of exposed mineral soil of the furrow with disc angle 1.

Percentage of continuous furrow

It is desirable to have almost continuous furrows in order to have a great choice of planting spots, especially in stony soils. The percentage of continuous furrow was overall so high (Figure 4) that no major differences occurred between different adjustments.

Summary

When the removal of vegetation or the exposure of the mineral soil is required in site preparation, width of the fur-

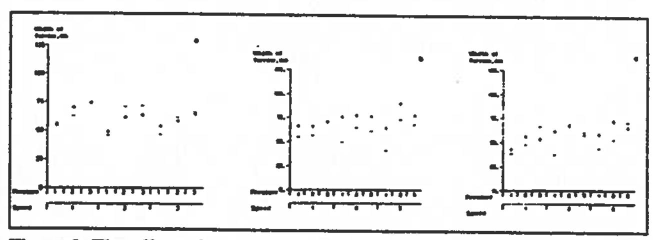

Figure 3. The effect of adjustments on the width of removed vegetation in the furrow.

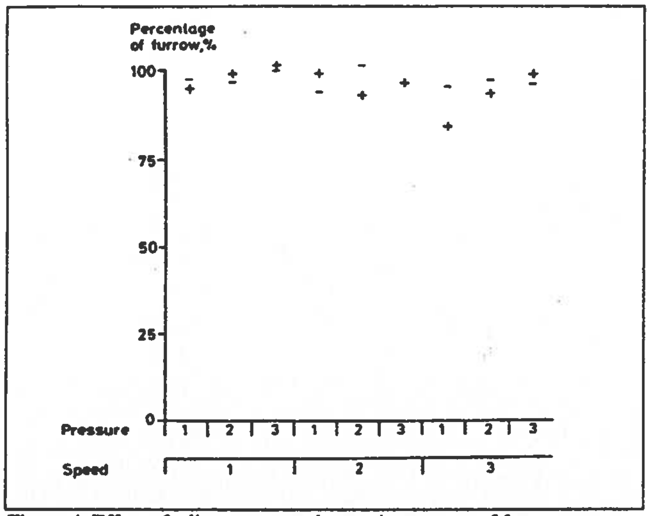

Figure 4. Effect of adjustments on the continuousness of furrow.

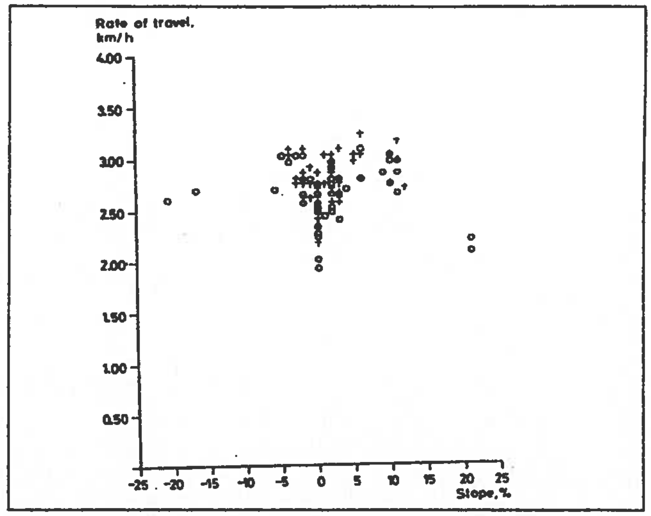

Figure 5. The effect of slope on the rate of travel for a Sinkkila II.

row may be increased from the operator's cabin by increasing hydraulic down pressure on the discs and to some degree by applying hydraulic power for rotating the discs. To change the disc angle the operator has to step down from his cabin and lock the discs in a different position. The generally known experience that hydraulic discs improve the quality of soil preparation where substantial slash occurs could not be verified in the study because sites with large amounts of slash were not found.

SINKKILä II MODEL 1985 (DONHöG 190): The Sinkkilä II mounding scarifier was used in field operations in Finland and Sweden in 1985. The principle of the machine is that free-rolling wheels donned with four pairs of double rippers can be fixed for a specific period in one of three alternative angles. As the pulling prime mover moves, the rippers dig in the ground as step on, rip up a mound and turn it into an inverted mound. When the wheels are released to roll again they may be stopped again in step two so that the rippers compress the mound and prevent it from being turned back to the screef from which it was taken.

Adjustments

The functions of the machine may be adjusted by knobs on the control box (appendix 2). A long screef makes a high mound and a short screef a low mound. Further, when only the exposure of the mineral soil is required the trees may be planted in the screef. When mounding is necessary the trees may be planted on top of the compressed mound.

Table 3

Depth of furrow	Width of furrow	
Disc angle 1		
Width of furrow	0.91	
Width of exposed mineral soil	0.85	0.89
Disc angle 2		
Width of furrow	0.91	
Width of exposed mineral soil	0.87	0.93
Disc angle 3		
Width of furrow	0.91	
Width of exposed mineral soil	0.92	0.88

Test layout

The field test included the following alternative adjustments. The angle of the ripper in positions 1, 2 and 3 where 1 is a sharp angle and 3 is a dull angle. Braking time is S (slow), M (medium) and F (fast) in the first step and the only M and F in step two. With knob 10 adjustments, the operator was also asked to drive at three different rates of travel. The layout of the test was the same as in the previous one.

Work quality

The quality of the work was measured for the two rows in one pair as follows. Length, width and depth of the screef; length, width and depth of the mound (the height after down pressing with the foot as in firming the soil around a planted tree) and the distance between the planting spots on top of the mounds. The data basis included measurements of 5400 meters of site preparation tracks.

Results

The rate of travel has a narrow range and was between 2.05...2.83 km/h, and the terrain was almost flat (Fig 5). The work quality in table 2 indicated that the screef was very long, which in addition to the length of the mound, the long range of the long rippers together with delay time until the ripper had dug into the soil for the next screef made the distance between the planting spots more than 4 m. For the productivity and economy of site preparation the average distance between trees should be short and the distance between row pairs long (Appelroth 1979). This defect of the Sinkkilä II model 1985 has been changed in the 1986 model by means of shorter rippers and a modification in the automatic mechanism. The newest lightweight (500 kg per unit) Sinkkilä III model 1986 permits a distance between the planting spots of some 2 m.

The shortest average distance between planting spots for the Sinkkilä II model 1985 were reached with a high rate of travel (2.5 and 2.8 km/h) and sharp ripper angle (position 1), the minimum average distance for the left row 377.2 m and

Table 4. Work quality for the Sinkkilä II

		X	S	MIN.	MAX
Length of screef					
	Left	197.7	130.6	35.0	1 300.0
	Right	190.9	114.2	30.0	990.0
Width of screef					
	Left	70.5	19.1	20.0	200.0
	Right	68.8	20.5	20.0	280.0
Depth of screef					
	Left	11.3	4.6	2.0	36.0
	Right	12.0	4.7	2.0	30.0
Height of mound					
	Left	18.2	9.2	2.0	57.0
	Right	18.6	9.6	2.0	55.0
Length of mound					
	Left	55.8	18.9	20.0	140.0
	Right	55.0	18.8	20.0	145.0
Width of mound					
	Left	60.0	18.5	20.0	140.0
	Right	61.0	17.2	20.0	140.0
Distance between planting spots					
	Left	479.1	308.0	80.0	2 120.0
	Right	468.1	277.0	80.0	2,090.0

for the right row 385.0 cm. The corresponding height of the mounds was 16.1 cm and 17.8 cm.

Conclusion

The Sinkkilä II Model 1985 permits planting either in exposed mineral soil on sites with good water penetration or on top of the mound where inverted mounds are needed. The long distance between the planting spots requires a short distance between driving

passes in order to maintain sufficient planting density (number of trees per hectare), and that increases the site preparation costs per hectare. This shortcoming has been overcome to some extent in the Sinkkilä II Model 1986 and to a considerable degree in the Sinkkilä III Model 1986. These provide possibilities for site specific soil preparation.

MOUNDING BY MITSUBISHI MS180-3 EXCAVATOR AND VAMMAS MAJOR BACK-HOE TRACTOR EXCAVATOR: Mounding by excavator has been carried out in Finland on a small scale for about 15 years. The costs per hectare have been about twice that of ordinary site preparation machines. Work has, therefore, only been carried out on waterlogged sites with dense mineral soil or peat. Shallow ditches have been dug to control moisture in the top layer and the soil from the ditches has been tipped from the bucket into mounds on top of which the trees have been planted. Thus, part of the costs should be attributed to drainage and part to soil preparation.

Two machines were included in the study, the main aim being to explore the biological effect of such soil treatment and to find out how much sprouting of broadleaf trees would be reduced if in the same operation, each broadleaf stump were to be covered by a full bucket of soil. Simultaneously a pilot time study was carried out. The two machines were the 19 ton Mitsubishi MS180-3 excavator with a reach of 9 m and the 10 ton Vammas Major back-hoe tractor excavator.

Table 5. Comparison of work methods for Mitsubishi and Vammas Excavators

	Machine	
	Mitsubishi	Vammas
Ditch spacing, m	15	10
100 litre mounds		
Depth of ditch, cm	49	43
Height of mound, dm	29	23
300 litre mounds		
Depth of ditch, cm	75	49
Height of mound, cm	33	34
Ditching without mounds		
Depth of ditch, cm	53	33

Study layout

Because of the different reach of the machines different ditch spacings were used. (Table 5).

Results of the time study

Figure 6 shows the observed time in minutes per hectare for different ditch lengths. When the ditch length is less than 100 m the time for moving to the next ditch considerably increases time and cost per hectare.

VL= Vammas, for spreading the soil without mounding and screefing a patch to remove vegetation.

V300= Vammas; 300 1 mounds.

V100= Vammas; 100 1 mounds.

ML= Mitsubishi, for spreading soil without mounding and screefing a patch to remove vegetation.

M300= Mitsubishi; 300 1 mounds.

M100= Mitsubishi; 100 1 mounds.

The additional observed time for burning the stumps naturally depend on the number of stumps per hectare (Fig. 7.) There are no major differences between the two machines (Mitsubishi x = .22 min and Vammas x = .23 min per stump) only a difference in the costs.

V = Vammas

M = Mitsubishi

Summary

For site specific soil preparation in conjunction with drainage one alternative could be mounding by excavators. Since the observed time and the costs per hectare increase substantially when the length of ditches is less than 100 m, excavators are economically feasible only where large reforestation areas occur. The costs for such mounding are highly dependent on the availability of excavators in the neighborhood and the local price per hour charged for such machines.

The TTS-35 and TTS-35H have been by far the most popular traditional site preparation machines. In the north of Finland where thick raw humus layers and abundant logging residues after the final cut of old Norway spruce stands are common, Marttiini plows are used. Sinkkilä I spot scarifiers (which are as much as 20 years old) are still in operation where the mineral soil exposure is sufficient for planting, direct seeding or natural regeneration.

Lately more site specific soil preparation has been consid-

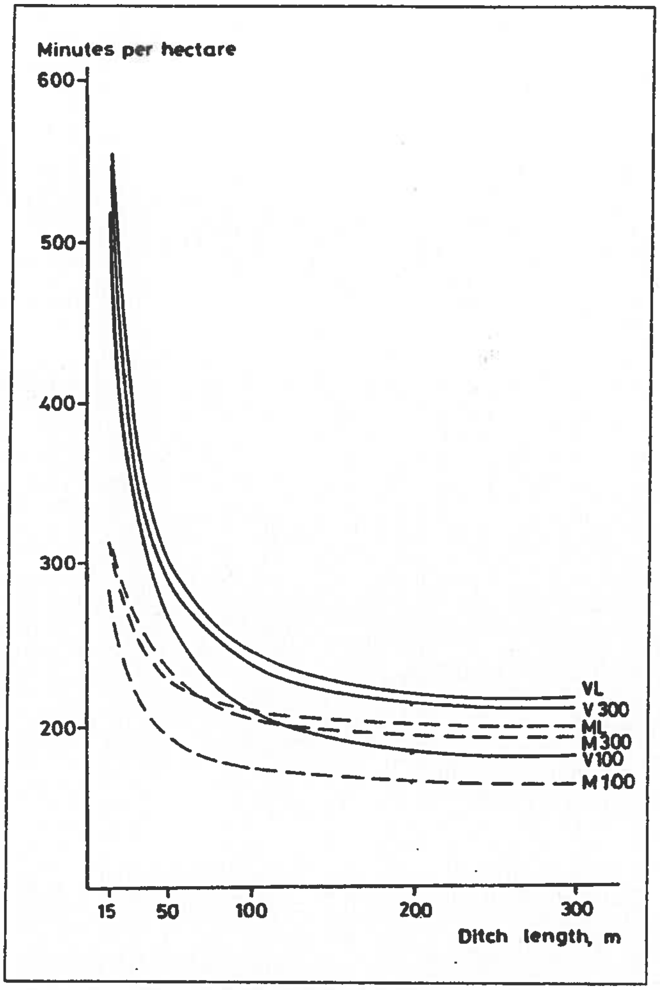

Figure 6. The observed time for different operations of Vammas and Mitsubishi Excavators for different ditch lengths.

ered desirable. Preferably, different parts of the same cut-over are given different types of soil preparation by the same machine. For some years the Marttiini AKLM-190 plow has provided possibilities for alternative treatment on parts of the same cut-over. For mounding, new Sinkkilä mounders have been developed as well as a mounder for TTS machines. Prescribed burning has also increased during the past year. However, prescribed burning also requires mechanical soil preparation. In Finland, the method of soil preparation chosen for each site is based on long-term local experience.

Today the forest manager must know in detail what type of soil preparation would be optimal on each part of each cut-over. The forest manager must tell the machine operator what kind of work quality is optimal. The machine operator has to know how to adjust his machine and what rate of travel should be chosen to obtain the prescribed work quality. He should also be motivated to follow the prescriptions. Short-term contracts of rather small annual site preparation areas with long or numerous transports results in high costs and poor quality of site preparation. Also it is expensive to move in many different machines to one cut-over for different soil preparation of parts of the same cut-over. Long-term contracts with a large annual area of site preparation each year

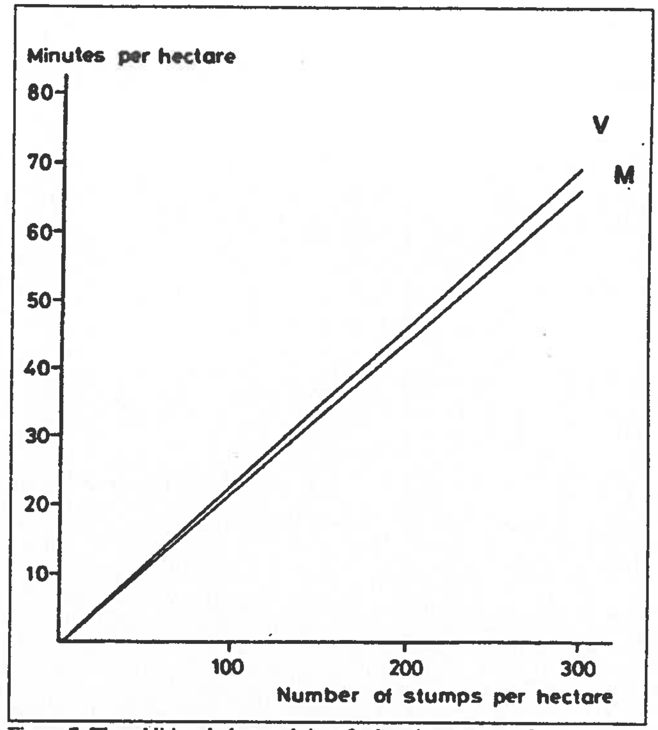

Figure 7. The additional observed time for burning stumps of broadleaves by Mitsubishi and Vammas Excavators.

for each machine helps to improve the understanding between machine operator and forest manager regarding work quality. This reduces costs and results in good quality forest renewal.

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Appendix 1: *Technical data for the Delta unit*

Disc trencher TTS - 35 HJ Delta
Weight including lifting device: 3 ton.
Two discs in plowing angle.
Powered discs with 15,6 litre hydraulic motors.
Hydraulic down pressure of discs.
Adjustable disc angle.
Size of discs: Diameter 1300 mm; number of teeth 10; length of tooth 270 mm
Prime mover
Valmet Volvo 886 K forwarder
Gross weight: 14 ton
Effect of engine 125 kW (170 HP)
Pumps of hydraulic crane

Appendix 2: *Technical data for the Sinkkilä unit*

Mounding spot scarifier Sinkkilä II/M85 (also called Tuunari and Donhög 190)
Double row unit with two sets of four rippers on each ripper wheel.
Diameter of ripper wheel: 1.85 m
Distance between centers of rows: 2 m.
Weight of two ripper wheels: 2.4 ton
Weight of lifting device: 0.8 ton
Gross weight: 3.2 ton
The free rotating of ripper wheels may be halted in three alternative angles from direction of movement of machine in step I (1=63°, 2=71°, 3=79°) for ripping and in one position (116°) in step for preventing the mound from falling back.
Prime mover
Lokomo 928 forwarder
Weight: 14 ton
Effect of engine: 110 kW

Appendix 2a: *The Sinkkilä II 1985 mounding scarifier control box.*

Number of each knob on the control box of the Sinkkilä II 1985 mounding scarifier.

1. Main switch for electric current. By pushing the red button STOP the ripper wheels are released for free rolling.
2. Signal light POWER for electric power indicating that the electric power is on.
3. Knob for turning on continuous braking MAN or intermittent braking AUTO of the two ripper wheels.
4. Left signal light LEFT indicating that the left ripper wheel is braking.
5. Right signal light RIGHT indicating that the right ripper wheel is braking.
6. Knob for setting the angle of the ripper as on the picture when braking in step I. The deeper spot (angle 1) the more mineral soil is mixed into the inverted mound. 1 = deep screef, 2 = medium deep screef, 3 = shallow screef.
7. Knob for stepless control of the braking time of the two ripper wheels. F = (fast) short time), M = medium time, S = (slow) long braking time in step I.
8. Button for stopping both rippers in ripping position in step II. Selecting position 1 the mound compressed if it tends to turn back i.e. when driving uphill. Only shallow scratching can be made by this. Also, raking of debris can be made in this way. The ripper wheel is freely revolving in position 0.
9. Knob for stepless control of the braking time of both ripper wheels while in ripping position (see picture in step II. F = (fast) short braking time, M = (medium) braking time, S = (slow) long braking time.
10. Knob for simultaneous and stepless adjustment of the time of the functions controlled by both knobs (7) and (9) according to the rate of travel of prime mover. F = fast drive, M = medium drive, S = slow drive.

Systems for Assessing Regeneration Performance

By: David G. Brand

Abstract: As Canada's rate of reforestation intensifies, foresters will have increasing difficulty monitoring regeneration performance and diagnosing problems requiring silvicultural action. This paper proposes that biologically defined criteria with quantifiable standards are necessary precursors to the increasingly extensive plantation assessment programs now evolving. A pilot system is described which incorporates electronic notebook field data collection with a secondary diagnostic model to predict the free-to-grow status of plantations. The model considers the growth habit and relative height of competitors and planted trees to assess whether trees are in danger of overtopping by brush. The model and associated field survey techniques are site specific, but applicable over wide areas without modification.

Introduction

The rate of artificial reforestation in Canada is rapidly expanding. Recent projections indicate 40% annual increases in seedling production from 1984 to 1986 (Canadian Forestry Service 1986). Further, with a five-year, one billion dollar Federal-Provincial forest development fund in place, scaled to increase from year to year (Duffy 1985), this upward trend in reforestation will continue into the near future.

The major objective of this expanding reforestation program is to sustain Canada's forest-based industry in perpetuity. Therefore, these plantations and naturally regenerated areas are considered a developing forest crop. Owing to present limitations on staff and other resources, the vast majority of this crop is managed on an "extensive" basis. Silvicultural programs are applied broadly to hundreds or thousands of hectares with the aim of enhancing forest productivity. This type of extensive management is oriented towards short-term cost effectiveness, often at the expense of site specific prescription flexibility. Such flexibility is needed to accommodate a number of factors, including planting stock quality, planting practices, weather patterns, environmental stresses, vegetation competition, and pest damage, which all interact to determine regeneration performance. These complex situations do not lend themselves well to blanket prescriptions. As a result the forest crop in Canada is risk-prone to failure.

As the rate of reforestation increases, foresters have increasing difficulty keeping track of the performance or silvicultural requirements of an ever-increasing area of regeneration on a site specific basis. This leads to the evolution of extensive management systems requiring a number of systematic surveys or assessment procedures that could be used universally to describe the status of areas and assist in prescription development. Many of the basic assessment criteria, however, are subjective and are monitored with arbitrarily determined standards. Site specific management can only be practised on an extensive basis if the assessment criteria are biologically defined and the assessment standards are flexible enough to deal with a wide variety of conditions. In this paper, I propose this type of biological definition for the criteria of regeneration assessment, and show how biological standards could be set for one of these, the free-to-grow criteria.

Criteria for Assessing Regeneration Performance

Assessing performance of anything requires criteria and standards. A criterion can be considered the basic principle by which something is judged. A standard is set within that criterion to indicate a level of performance required for a particular objective. If we consider the specific case of forest regeneration, the criteria define the features to be assessed, and the standards set levels or terms of acceptability.

The current policy in most Canadian provinces appears to indicate four criteria for regeneration assessment which underlie the various survey techniques in use. These are species acceptability, tree establishment, free growing status, and stocking. These four terms are frequently used, but rarely defined in biological terms. Because they are used subjectively, it is difficult to provide universal definitions which fit the current usage of these terms in all jurisdictions. For example, in attempting to provide a definition for what constitutes a free-growing tree, I found a great deal of overlap with the question of what constitutes an established tree. To avoid confusion, however, these criteria must be discrete and must form a complete framework within which to set standards for regeneration assessment. I would like to outline my understanding of the definition of these four criteria, then go on to the question of how site specific standards can be set for one of them, the free-growing criteria:

1. Acceptable Species - The primary decision in consid-

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ering the regeneration status of a forest unit pertains to the acceptable crop species. The basis of this decision must be both ecological and economic. Klinka and Feller (1984) have proposed selection criteria, in the context of timber production, for southwestern British Columbia which might be considered a model for other parts of Canada. They recommend species be considered based on productivity, reliability, and silvicultural feasibility. Standards for tree species selection, then, are provided relative to the biogeoclimatic land classification of B.C., using edatopic grids in field guides as the final product. The application of these criteria to set standards in other areas of Canada would require an ecological framework or classification on which to assess relative productivity, and an approximation of crop reliability and feasibility on various site types relative to management objectives.

2. Establishment - The use of the term 'establishment' in reference to everything from the point of planting to a point where all early hazards such as competition or browsing are past, has led to confusion over its definition. I would propose that an established tree must be of acceptable species and be physiologically able to survive and grow on the particular site concerned. Using this definition, tree establishment is a function of the physiological condition of the tree, which is in turn a function of stock quality and environment. It does not consider externally developing factors. Establishment standards, then, would define acceptable growth within an ecological framework.

3. Free Growing - The term "free-growing tree" is a relatively recent introduction in regeneration assessment. It was introduced in response to a growing dissatisfaction with regeneration standards based solely on stocking and survival. It implies that the tree is of acceptable species, is established, and is not likely to succumb to external hazards such as brush competition, browsing, or tip weevils. It has particularly been used in reference to brush competition, because there has been a history in Canada of established plantations being suppressed by more rapidly growing non-commercial species.

As it is infeasible to completely eradicate competition, standards are used to set some acceptable threshold against which to consider free-growing status. Because these stresses are dynamic, trees with currently acceptable levels of competition must be projected as able to maintain their competitive status. A tree assessed as free-growing must be free from future need for competition control.

4. Stocking - Stocking refers to the evenly distributed density of trees relative to some reference density. A minimum stocking standard is a minimum percentage of full stocking or a minimum number of trees evenly distributed relative to the reference density. The reference densities used in Canada are set intuitively based on a desire for sufficient trees to allow the option of thinning, crop tree selection, and some protection from irregular mortality.

Stocking, used with any of the above terms, provides a method of considering the status of a whole plantation or naturally regenerated unit. An established plantation, for example, would have sufficient stocking of acceptable, established trees. A free to grow plantation would have sufficient stocking of acceptable, established, free-growing trees.

The objective of this definition framework is to provide an improved basis for assessment of regeneration. These terms are now discrete, but together provide basic criteria covering most aspects of regeneration success or failure.

A Pilot System of Regeneration Assessment

The assessment criteria outlined above require translation into quantifiable, biologically-based standards. The silviculture research effort at the Petawawa National Forestry Institute is geared to unlocking the processes of establishment, competition, and other determinants of regeneration success, with the objective of providing a methodology for forest

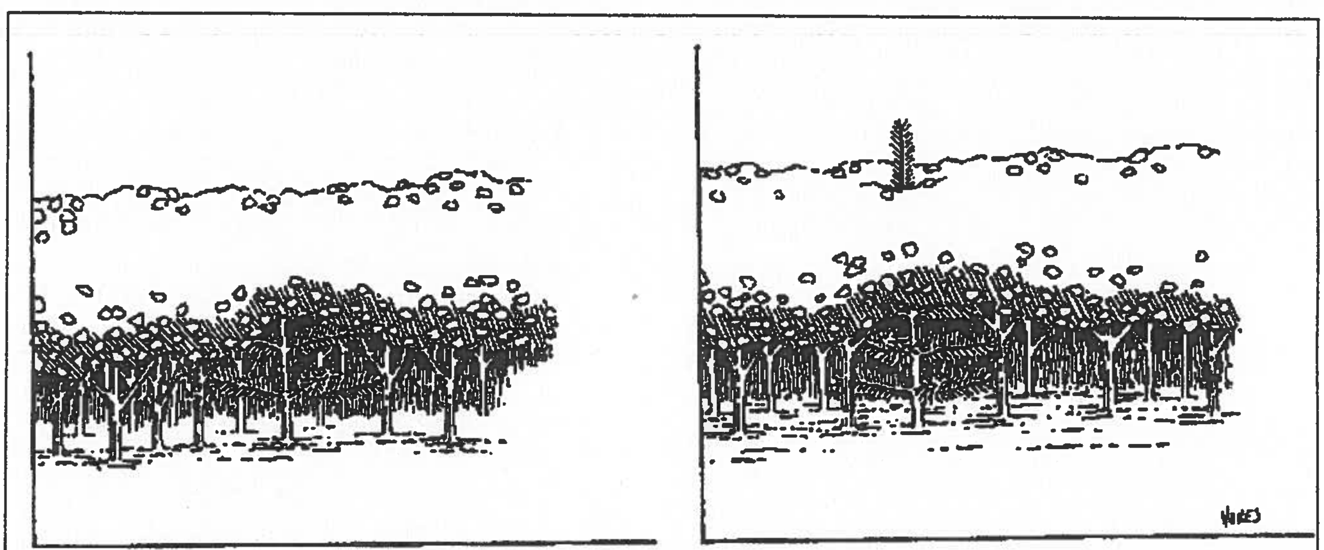

Figure 1. Examples of trees with currently unacceptable and acceptable levels of brush competition.

managers to use in setting these standards. A dual approach, involving experiments in establishment biology and developmental work proposing new plantation assessment systems, is being used.

As part of the developmental work, a trial system for assessment of the free-to-grow status of regeneration has been produced. This system is a first attempt to integrate electronic notebook technology with biologically-based projection and summary software for regeneration assessment.

The Free to Grow Assessment Model - Biological Foundation

The benefit of field data loggers is not so much in the collection of the data, but in the ease with which they interface with secondary computer programs that assist the forester in decision-making. In this case, the model considers whether regeneration is free-to-grow relative to competing vegetation. The free-to-grow decision is based on a threshold level cf acceptable competition, and a projection model of tree and brush growth to determine whether trees currently appearing free-to-grow are in danger of future suppression.

The competition threshold is considered the point at which the crop tree has a diminished ability to maintain a normal height growth pattern. Considerable evidence suggests that this occurs when a tree is overtopped (Vincent 1965, Howard and Newton 1984, Brand 1986). The threshold, then, can be defined as the point at which there is direct shading on the terminal leader. Figure 1 illustrates trees slightly above and below this threshold level. A tree with a competition level below the threshold is considered currently free to grow, but must be further projected to determine whether the competing vegetation will outgrow it.

The projection algorithm used first calculates the current ratio of tree height to competition height. It then projects the future potential height of the tree and competition to determine whether the brush is gaining in height relative to the tree. Calculation of potential height growth in conifers is based on a relative production rate of height growth (Brand

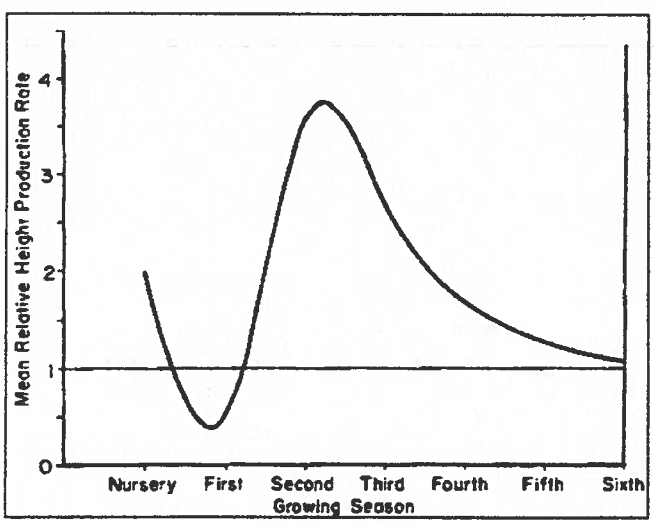

Figure 2. A typical trend in the relative height production rate (RHPR) of plantations. RHPR = current year height increment divided by previous year height increment.

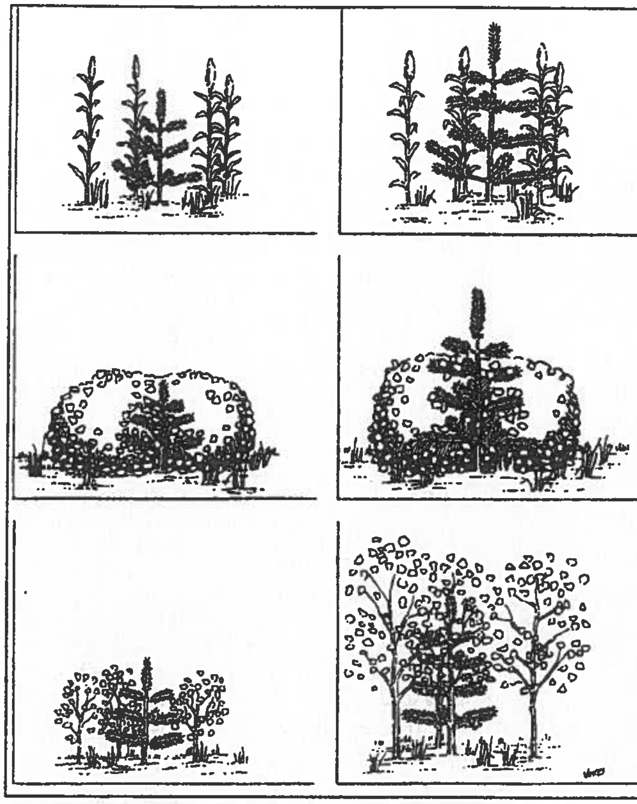

Figure 3. Examples of the dynamics of competition when the brush species are herbaceous, shrub, or tree species, respectively.

and Weetman 1986) (Figure 2). The relative production rate is the ratio of height increment between two successive growing seasons. Trees initially increase height growth rapidly from year to year, but by age six or seven have reached a relatively constant annual height increment (relative height production rate of 1.0). Knowledge of the current height increment and the trend in relative height production rate allows projection of the future potential height increment of the tree.

The brush projections are based on the class of competitor. Three classes are recognized: the herbaceous vegetation, woody brush with maximum height of 2 to 5 meters, and trees. These vegetation classes are projected differently to reflect their different height growth patterns (Figure 3). Free-to-grow consideration is not carried out until plantations are established and at least three growing seasons are past. By this point herbaceous perennials are no longer increasing in height from year to year, low brush is growing asymptotically, and trees are in an exponential growth phase similar to the crop species.

The model projects each brush species present based on its current size and growth habit. The relative height ratio is then recalculated against the projected height of the crop tree using the tallest projected brush species. The different projection patterns will result in a change in dominance among competitors as trees succeed brush, for example.

Free-to-Grow Assessment System

The pilot system developed has three phases: field data collection using a portable data logger, transfer of data into personal computer, and data manipulation with the projection and summary model. All phases are integrated so that field data are written directly into the format for the projection model, and the model uses information collected by the prompt screens of the data logger.

The field data logger used for the pilot system was the Husky Hunter. It has an 8-1ine, 40 character width display, allowing programmed screens to be set for alphanumeric data entry. The program provides screens for administrative information, individual tree data, and brush competition data (Figure 4). If only stocking and regeneration performance information are required, the brush competition screens are suppressed. Data is entered into each screen in succession, with full editing capability if errors are made. The survey work is identical to normal plot measurement, but data is keyed in, rather than written on tally sheets.

After returning to the office, the Husky Hunter is connected to an IBM-PC and the data is transferred into a file, formatted for the free-to-grow/regeneration performance program. The output of the program is a summary of free-to-grow stocking, plantation height growth pattern, and major projected competitors in the following growing season. There is also a summary showing the potential increase in stocking available with release treatment (Figure 5).

```
            ASSESSMENT DESCRIPTION
Location
Admin unit
Ecological unit
Tallyman
Plot size (0.XXX) ____
Comments
Data (ddmmyy) ______        Valid (Y/N/M)

Previous plot:      tree:
                 PLOT DATA
Tree no.                              1
Planted/Natural                       _
Species                               _
No. growing seasons completed       ____
Height (x.xx m)                      __
Valid (Y/N)                         ____

Competitor 1  PRPE
Class (1 = herb  2 = shrub  3 = tree)  3
Height (x.xx m) ____
Current ht. incr. ____
Prev. ht. incr. ____
Comments

Valid (Y/N)
```

Figure 4. Screen displays for field data collection using the Husky Hunter programmed with the regeneration survey-free to grow assessment system.

STOCKING SUMMARY AND FREE TO GROW STATUS
(Test Data)

UNIT	SPECIES	PLANTED/ NATURAL	AGE	PLOTS WHERE PRESENT	TOTAL PLOTS	STOCKING (stems/ha)	FREE TO GROW STOCKING (stems/ha)
1	SS	P	4	4		233.33	166.67
1	DF	P	4	6		400.00	200.00
TOTAL	AGE 4				6	633.33	366.67
TOTAL	UNIT 1				6	633.33	366.67
2	SS	P	5	4		142.86	57.14
2	DF	P	5	5		400.00	314.29
TOTAL	AGE	5			7	542.86	371.43
TOTAL	UNIT 2				7	542.86	371.43
STOCKING SUMMARY					13	584.62	369.23

TOTAL MEAN TREE HEIGHT
FREE TO GROW TREES (m)

(Test Data)

	1982	1983	1984	1985	1986	1987 PROJECTED
Unit 1						
Sitka Spruce 1986 age = 4	--	0.40	0.64	0.99	1.51	2.16
Douglas-Fir 1986 age = 4	--	0.33	0.59	0.92	1.47	2.10
Unit 2						
Sitka Spruce 1986 age = 5	0.41	0.71	1.17	1.63	2.43	3.33
Douglas-Fir 1986 age = 5	0.33	0.57	0.91	1.50	2.24	3.20

SUMMARY OF COMPETING VEGETATION*
(Test Data)

SPECIES	FREQUENCY	AVERAGE CANOPY HEIGHT (m) Current	Projected
CLASS 1: Herbaceous			
Anaphalis margaritacea	0.23	0.87	0.87
Epilobium angustifolium	0.46	1.43	1.43
Pteridium aquilinum	0.38	1.18	1.18
CLASS 2: Low Woody Brush			
Acer circinatum	0.38	1.79	2.26
Ribes lacustre	0.08	2.81	3.37
Rubus idaeus	0.15	1.32	1.47
Rubus parvifolium	0.69	1.19	1.46
Rubus spectabilis	0.38	0.97	1.29
Rubus ursinus	0.15	0.20	0.25
Sambucus racemosa	0.15	2.29	2.90
Vaccinium parvifolium	0.15	1.32	1.59
CLASS 3: Tree-Like Brush			
Acer macrophyllum	0.38	3.79	4.75
Alnus rubra	0.15	2.37	3.25
Alnus sinuata	0.08	2.20	3.38
Betula papyrifera	0.23	2.16	2.52
Populus nigra	0.08	0.64	0.89
Prunus glandulosus	0.31	3.75	4.53
Pseudotsuga menziesii	0.08	3.13	3.95
Rhamnus purshiana	0.08	2.87	3.30
Salix scouleriana	0.15	1.03	1.33

* Based on data from 13 plots

Figure 5. Output from the regeneration survey-free to grow summary and projection model.

The advantage of fully automated data collection and processing is that a more complex biological projection model can replace a simple height standard or subjective decision in regeneration assessment. The biological projection model used here is site specific, because all calculations are based on the growth habit and size of the brush species and planted trees on the site concerned. Yet the data collection tools and programs can be applied extensively to all areas under management without modification. This allows standardized training of field staff, compilation of summary statistics for large areas, and straightforward quality control in contract surveys.

In summary, there is opportunity to carry out site specific regeneration assessment and silvicultural projections within the extensive forest management systems used in Canada. It requires that the criteria used in regeneration assessment be biologically defined and that standards are flexible for the variety of conditions encountered. Use of automated data collection and projection models will allow more detailed analysis of plantation conditions without any increase in time spent in the field.

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Ten Years of Swedish Experience with Mounding Site Preparation

By: Lasse Edlund and Folke Jönsson

Abstract: Cost per meter of height growth per hectare of plantation is suggested as a good method of reforestation cost accounting. Tens years of experience in Jamtland indicates that even though patch scarification may be a slightly cheaper method of soil treatment initially, the lowest reforestation cost on suitable sites follows preparation by inverted humus mounding.

Background

The objective of the Swedish Silviculture Law is to ensure the production of high timber value forests while recognizing environmental and other values. Svenska Cellulosa AB's (S.C.A.) corporate philosophy, firmly entrenched since World War II, is to work within the intent of the Law but with the ambition of achieving even higher levels of forest management than required by the law. These intensive efforts give immediate returns from our own forests and higher land production through closer utilization. Accordingly, long-range returns come from increased growth capital through successful regeneration treatment.

Despite an uneven age class distribution with a surplus of old forests and deficit of middle-aged forests, there is the potential for consistent and more productive harvests. But, as the cutting of the older poorly stocked forests accelerates, the area requiring regeneration treatments increases for each cubic meter harvested. This presents a challenge to forest managers to keep pace and avoid backlog areas requiring treatment. To meet this challenge regeneration efforts must be as cost effective as possible.

Cost accounting for harvesting has advanced over the last one hundred years. Today, it is possible to keep track of harvesting costs, production and returns from sales even as the harvest is in progress. Unfortunately, cost accounting for regeneration projects has not kept pace. Measures for successful regeneration are most often based on stocking and survival. Measures of success are poorly defined and ambiguous. Generally, the cost of a treatment per hectare or the purchase price of a scarifier, figure prominently in the economic analysis of a regeneration treatment.

We must develop better measures of success and cost. One approach would consider the cost per meter of height growth per hectare of plantation. Survival and growth are combined. Factors that influence tree growth such as insects, diseases, stability and competitive ability would also be included in this simple measure.

Our company's experience shows that mounding site preparation (Edlund 1979, Edlund and Hultin 1980, Marek 1985) is a cost effective method when the cost per meter of height growth is the standard used. Compared to other methods, seedlings planted in mounds with a mineral soil capping above inverted surface organic (inverted humus mounds) prepared by the Bracke Mounder show superior survival and growth.

This paper compares the growth of seedlings planted in mounds to that of seedlings planted in other microsites. The cost per meter of height growth is compared.

Practical Experience with Mounding (1976-1986)

Tests of mounding site preparation began in 1974. Larger operations followed in 1976 on S.C.A. land in the Province of Jamtland. To date, mounding has been carried out on 2,000 ha in the Östersünd District and the development of these plantations has been followed carefully. A number of features have been studied. Some specific examples follow.

The data in Table 1 show that mounding produced trees which averaged 50% taller than trees in patch treatments. Patch treatments, including survival, was no better than no treatment. Seedlings in the mounding treatments were planted in the mineral soil over the inverted humus layer. Seedlings in the patch treatments were planted in the scalped mineral soil. On most sites, patch scarification produces better growth when seedlings are planted in the berm of inverted soil and humus. The Bracke Mounder produces larger, well defined inverted humus mounds with a greater frequency than those produced by standard Bracke Patch Scarifiers.

With the exception of the Hälsingekojan plantation, all patches were made by a Bracke Patch Scarifier. In the Hälsingekojan plantation, patches were made by a Leno scarifier. The Leno scrapes a patch similar to blading rather than digging and overturning the soil. For aerating the soil, which is important for root development, scraping is less effective than Bracke scalping. Some of the growth differences between the mound and patch treatment in the Hälsingekojan plantation may be attributed to different growth rates between *Pinus contorta* and *P. sylvestris*. However, observa-

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Table 1. Comparison of total height of *Pinus contorta* 8 to 10 years after planting in different site treatments.

Location	Year Planted	Total Height (cm) Untreat[1]	Patch[1]	Mound[1]	Height Increment (cm) Untreat	Patch	Mound
Nästelbron	1977	122	93	156	---	---	---
Nyslättberget-Glitterbacken		---	87[2]	99	---	23	27
Mellersbodarna-Mellersbodarna	1979	---	122	199	---	28	40
Sothrännä	1980	50	83	112	13	22	28
Bölejärnvägen	1978	62	52	85	10	8	13
Halsingekojan	1979	---	61[3]	114	---	14	26
Relative average height		94	100	154	---	19	27

[1]Measurements made in 1986.
[2]Survival is generally 10-50% lower in untreated than in patch or mound treatments.
[3]A Leno scarifier was used and patches planted with *Pinus sylvestris*.

tions on *P. contorta* and *P. sylvestris* planted on mounds just a few kilometers from this site show P. contorta to have only a slight advantage.

Volume indices (a function of root collar diameter and height) show even greater gains with mounding. Table 2 summarizes the volume indices for the different sites. A near tenfold advantage over patch scarification was observed at the Mellersbodarna site. Larger and fuller crowns are associated with mounding treatments. It is of interest to observe the difference in response between the untreated and patch scarified areas (where seedlings were planted in the mineral soil of the scalp) in the very poor lichen type on gravel at Bölejärnvägen (Table 2).

More detailed studies established in 1980 by the Royal College of Forestry Institute of Soil Science (Lundmark 1986) and Stand Establishment (P.O. Bäckström 1984) show preliminary results similar to those presented here.

Table 3 presents an economic analysis of mounding using cost per meter of height growth. In this case, mounding was 50% more expensive than patch treatment, but the cost per meter of height growth was less. Experience has shown that planting costs are often less on mounded sites because the spacing and definition of the planting spot is clear. In the last five years, mounding costs have been only 16% greater than conventional patch scarification. Thus, mounding becomes economically even more attractive.

In addition to improved growth rates and economy, we have observed that the mounding treatment improves the plant's stability over other treatments. This should increase seedling survival.

Table 2. Comparison of *Pinus contorta* volume indices following planting in different site preparation treatments.

Location	Volume Index Untreated	Patch	Mound
Nyslättberget-Glitterbacken	---	100	239
Mellersbodarna-Mellersbodarna	---	100	920
Sothrännä	32	100	842
Bölejärnväagen	172	100	385
Halsingekojan	---	100[1]	509
Average	102	100	579

[1]Patches were made with a Leno Scarifier and planted with *Pinus sylvestris*; all other patches were made with a Bracke cultivator.

Summary

Our ten years of experience with mounding in Jämtland lead us to believe that mounds consisting of mineral soil on inverted humus are desirable on all sites where it is physically possible. Observations made in other locations in Sweden show similar trends. It should be noted that even in fine-textured soils, mounding is advantageous as it has been found to promote growth and reduce frost heaving.

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Table 3. Cost per meter of height growth for the Nastelbron Trial.

Item	Untreated	Patch	Mound
Site Preparation	---	233[1]	353
Cost of Planting	999	799	799
Total cost of establishment	999	1032	1152
Number of trees planted/ha	2000	2000	2000
Number of surviving seedlings/ha	1610	1830	1860
Average height/tree (meters)	1.22	0.93	1.56
Meters of height growth/ha	1964	1702	2902
Cost per meter of height growth	0.51	0.61	0.40

[1]SEK/ha (1977 SEK) (1SEK = 0.139 $US)

Silvicultural Prescription: Implications

By: R. F. Sutton

Abstract: Silvicultural prescriptions should emphasize schedules, specific measures, given sites, and management objectives. Researchers and practitioners should attempt to evaluate the effectiveness of prescriptions in terms of crop performance, the ultimate measure of prescription effectiveness. Such evaluation would be facilitated by the use of standardized planting stock for bioassay. The need to understand soil temperature in the formulation of prescriptions is given as an example of input data needed for formulating prescriptions.

Introduction

For the last four days at this S1.05-02 IUFRO Workshop, we have deliberated on and around the theme: "Developing Site Specific Forest Renewal Prescriptions;" and in the two excellent field tours, as well as in the papers presented, we have seen and heard further evidence of the need to restrict the formulation of silvicultural prescriptions to specific sites.

The definition I favor for the term "silvicultural prescription" is: a schedule of specific silvicultural measures intended to transform the existing vegetation cover of a given site into one that includes an established stand of crop trees compatible with the objectives of management (Sutton 1988).

That definition says a mouthful. I would particularly draw your attention to the words schedule, specific measures, given site, and objectives of management. Inclusion of schedule and specific measures in the definition means that a time frame is established for whatever silvicultural treatments are included in the prescription. The definition also makes clear the fact that a silvicultural prescription applies to a specific site and has the aim of producing a vegetation cover that is in harmony with the objectives of management. A silvicultural prescription must be specific on all counts if it is not to become analogous to a prescription of "medicine" of unspecified kind for unspecified "sickness."

Clear enunciation of these objectives may well be the most difficult part of silvicultural prescription; but the objectives of management must be defined specifically enough to permit assessment of progress. If the objectives of a given silvicultural prescription, or of a given treatment within a prescription, are vague or unstated, there is no logical basis for determining whether the prescription or treatment was good, bad, or indifferent.

Similarly, unless the effects achieved by silvicultural treatment(s) within a prescription are ascertained, the extent to which they are compatible with the objectives of management cannot be established.

Thus, without clear objectives and unless the effects of treatment are known, the opportunity for constructive feedback is lost, and neither biological nor economic evaluation is possible.

Role of Research

The role of research in all of this is to furnish the prescriber with a reasonable basis for identifying and ameliorating the constraints that, on a given site, would otherwise be likely to interfere with the attainment of the objectives of management. Because constraints on crop performance can never be removed completely, the principle of limiting factors (i.e., that the level of crop production can be no greater than that allowed by the most limiting of the essential growth factors) must be kept well in mind. Trade-offs will always be necessary, and the prescriber, in devising a treatment to overcome one or more constraining factors, should guard against substituting another constraint that may be equally severe or worse.

Before I turn to some of the limitations that are of particular consequence in boreal regions, I wish to make a general point that I believe to be very important.

When we, as researchers or practitioners, are attempting to identify and evaluate the strength of the constraining factors at a given site, and, further, when we attempt to evaluate the effectiveness of a silvicultural treatment or prescription, the only rational measure by which to do so is crop performance. How a treatment appeals to the eye or the heart of the prescriber is immaterial. What counts is what the crop makes of it.

Crop Performance

Now, if crop performance is to be our yardstick, performance must obviously be determined. However, many factors influence field performance, particularly in the early stages of plantation establishment. Factors such as species, ecotype, provenance, stock type (e.g., bareroot, plug, or containerized), class (e.g., 2+0 or 1.5+1.5 bareroot stock; 16-week or overwintered containerized stock), and the grade, season of lifting, condition at lifting, conditions of storage (if stored), handling (throughout the sequence from lifting in the nursery to planting in the field), planting quality, and weather (before, during, and after planting) may interact with one another and/or with the treatment(s) within a silvicultural prescription.

My point is that it is essential to establish the "credentials" of the crop trees used for bioassay purposes. To use the performance of "mongrel" stock (lacking pedigree and therefore lacking reproducibility) is equivalent to attempting to measure temperature with a different uncalibrated ther-

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mometer at each measurement.

This is why I regard the development, for bioassay purposes, of standardized planting stock, grown to rigid specifications, as a need of the highest priority for plantation establishment research. This would be easier with containerized than with bareroot stock, but the principle applies equally to both. Finnish foresters have already advanced a long way towards this goal (cf. Räsänen 1972) even with operational bareroot stock, and have adopted nursery production schedules that are designed to promote reproducibility of both morphological and physiological characteristics. Use of standardized bioassay stock would not preclude the use of other stock of interest.

Boreal Considerations

I should now like to turn to some considerations specifically germane to this workshop.

These include a suite of climatic problems presented by: a short growing season, a shorter frost-free season, low mean annual temperature, high-velocity winds, and temperature fluctuations that, especially in the case of Chinook winds, may be both rapid and great. For instance, monthly extremes of temperature of +6 and -46°C for February, +15.5 and -32°C for March, +27 and -19°C for October, +14.5 and -37°C for November, and +9 and -48°C for December were recorded at Peace River, Alberta, in an unexceptional year (1946) of no particular significance. To these may be added a moderately low rainfall and variable and varying snow depth. The biological consequences of such a climate are great.

Soil Temperature: Example of a Constraint

Let us consider soil temperature as an example of a constraining factor in boreal situations. Low soil temperature commonly constrains root growth and is probably the most important environmental factor that influences the rate of water uptake (Kramer 1940). Water is twice as viscous at O°C as at 25°C (Kozlowski 1943). At low soil temperatures, movement of water through the soil to the root and extension of roots into untapped soil are hindered; but the main cause of decreased absorption of water at low temperatures is probably the increased resistance to the movement of water through root cells. The uptake of nutrients, especially uptake against a concentration gradient, is also inhibited; in the case of phosphorus, this inhibition is not relieved by high levels of soil phosphorus.

Not only roots but all biological activity in soil is affected by temperature. For example, for 40 species of ectomycorrhizal fungi, the optimal temperature for *in vitro* growth ranged from 15 to 30°C, and most isolates grew best at either 20 or 25°C (Dennis 1985). Also, the production of CO_2 by soil decreases disproportionately more than the decrease in temperature when soil temperatures drop below 5 or 6°C (Keen and Russell 1921), reflecting a decrease in biological activity disproportionately greater than the decrease in temperature. Nitrification decreases disproportionately with decreases in soil temperature below 7 to 9°C (Keen and Russell 1921).

The consequences of these effects, especially on newly outplanted bareroot stock, may be severe; the root system of the outplant is inevitably undersized, and the root/soil contact is inevitably imperfect (Sutton 1978).

Relief of Soil Temperature Constraint

If low soil temperature has been identified as a constraint that needs to be relieved, what can be done about it?

We know that the primary source of heat that influences soil temperature is direct short wave solar radiation. The amount of solar radiation received by a soil surface is determined by a variety of factors (Gates 1965). These include shading by vegetation and aspect, both of which can be manipulated by silvicultural treatment. Vegetation can be reduced or removed; and site preparation can change aspect, at least on a microscale, so as to increase the amount of solar radiation received: in the northern hemisphere, a surface with a slope of one degree to the south is equivalent, in terms of insolation received, to flat ground 100 km further south (Shul'gin 1965). Hence, by modifying either the surface configuration of a planting spot or the kind and amount of shade-casting vegetation, or both, the amount of solar radiation received by a piece of ground can be changed.

At the soil surface, short wave radiation is either reflected or absorbed. Reflectance (albedo) may vary between 85% for fresh snow and 2% for dark, wet clay; however, most vegetated surfaces reflect between 10 and 25% of incident radiation (van Wijk and Scholte-Ubing 1966). To some extent, the reflectance of a ground surface can be controlled by silvicultural treatment. Reflectance may be minimized, for instance, by site preparation that exposes dark soil material in place of a lighter-colored surface of greater reflectance.

The short wave radiation that is not reflected is absorbed at the soil surface in a layer a fraction of a millimeter thick (van Wijk and de Vries 1966). The temperature of this surface, as of the soil beneath, depends on the apparent thermal conductivity of the soil and on the temperature gradient.

If a silvicultural prescription calls for regeneration by seeding, whether natural or artificial, then the surface temperature regime is of crucial importance. In dry conditions, "the effect of strong insolation in scorching tender stems at the level of the soil surface is widely recognized as a very important cause of seedling mortality" (Daubenmire 1943). Ground surface temperatures as high as 66.5°C (Li 1926) in New Hampshire, USA, and 68.9°C (Hide 1943) in Kansas, USA, have been reported, and Vaartaja (1949, 1954), in studies in southern Finland at latitudes between 60 and 62°N, recorded maximum surface temperatures of 50 to 70°C and considered this range to be normal for exposed sites in large areas of northern coniferous forest. Even brief exposure of recently emerged seedlings to surface soil temperatures of 55°C or more is commonly fatal (Li 1926).

Heat flow through soil occurs via solid particles, water films coating the particles, water annuli at points of contact between particles, and, to a very limited extent, air in the soil pores. Liquid water may move in response to surface tension differentials created by temperature differentials; surface tension decreases as temperature increases. Heat also moves in soil by water vapor diffusion from warmer regions to cooler.

Soil temperature and soil moisture are, in fact, highly interrelated (Voorhees et al. 1981). A change in temperature will change moisture relations, and vice versa. The influence of moisture on temperature is exerted through major effects on the volumetric heat capacity and heat conductivity of the soil. Dry soil has but 20 to 50% of the heat capacity of water (Keen 1932, Chirkov 1979) and conducts heat much less readily than does moist soil.

Hence, any silvicultural prescription that sets out to increase soil temperatures in the rooting zone of outplants, for instance, must also consider the repercussions this would have on soil moisture relations.

Freezing and Thawing

Freezing and thawing of soil are important special cases of temperature relations that can be modified by silvicultural treatment. Soil freezing or thawing may be influenced to a greater or lesser degree by treatments that change the amount of short wave radiation received at a surface, the albedo of that surface, or the moisture relations (and, thus, the heat capacity and conductivity) of a soil; and treatments that loosen or compact a soil, or that produce a mulch, will also modify soil freezing and thawing.

Snow Cover

Snow cover may be considered a temporary mulch with great influence on frost penetration. In a study in Kansas, for instance, frost penetrated soil twice as deeply (to depths of 60 to 64 cm) where snow had been removed as where it had not been left in place (Barnett 1944). Soil freezing may have a variety of conspicuous effects, such as pulverization of surface soil, rearrangement of soil particles, alteration of soil moisture content, and frost heaving, which may cause breakage of plant roots and/or ejection of plants from the soil (Barnett 1944).

Snow cover, which also influences the temperature of aerial parts of vegetation within it, is amenable to manipulation through vegetation management (which includes harvesting) and, less readily, by means of ground shaping. Anything that affects wind speed and/or the amount of solar radiation received will influence snow depth (Odin 1979a, b) and thus soil temperatures. If an even cover of snow is desired, the vegetation and any residual slash must be evenly distributed and of uniform height (Odin 1979a); if localized accumulation of snow is desired, a differentially rough surface must be provided. The small study of snow depth manipulation in relation to outplant performance that we saw at the Stewart Lake experimental area on the field trip from Dawson Creek, British Columbia, is an excellent illustration of the importance of snow cover to young outplants, especially, but not exclusively, in Chinook country.

Winter Damage and Frost Heaving

"Winter damage," sometimes called "winter browning," may seriously affect young plantations in boreal regions; it deserves to command the attention of researchers both in the field (in relation to snow cover dynamics) and in the nursery or phytotron (in relation to winter vigor and conditioning). As we saw at Stewart Lake, the damage is often expressed most severely as dieback of leading shoots of outplants whose height increment during the first growing season has been better than average.

The problem of frost heaving of young crop trees also has dimensions that extend into soil temperature, soil moisture, soil texture, and forest floor and surface conditions. Frost heaving damage was not widely evident during our field trips, but there is no doubt as to the serious and widespread, albeit variable, nature of the problem, especially in relation to fall planting and containerized stock.

Prescription and the Web of Interrelationships

I have discussed here only one very limited aspect of what must go into a silvicultural prescription that is intended to ameliorate soil temperature. I have tried to illustrate, in terms of biologically important processes and thresholds, the complex web of interrelationships that have to be sorted out and interpreted, even when only one factor is under consideration.

In this regard, it is encouraging to see evidence that researchers are organizing and putting into field-usable form very large amounts of silviculturally valuable data. The "Field Guide to Forest Ecosystems of West-Central Alberta" (Corns and Annas 1986), for instance, will be immensely helpful to anyone who has the task of formulating a silvicultural prescription in this region.

Many other points of consequence for boreal silvicultural prescriptions might be made, but I would conclude by mentioning two problems for which answers must be found. The first is that of managing the boreal mixedwoods, and the second is the related, though not exclusively boreal, question of whether or not herbicides will remain available for silvicultural use.

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Epilogue

By: Lasse Edlund

While I must stress that I am not familiar with local conditions in this part of Canada, I feel that it is pertinent to ask some general questions concerning forestry and foresters:

•are we reliable?

•do we have endurance?

•are we forward looking?

•are we profitable?

We foresters have a great responsibility to the future in the way we handle forest soils, trees, the whole ecosystem. Many of us have a good knowledge of how to do the right things if we have adequate resources. We must think in terms of at least one rotation ahead and what kind of inheritance we will be giving the next generation. We must know the whole ecological chain involved in forest practice.

Additionally, we must know the goal and purpose of silviculture and the management of nature. Are we "tree-miners" or "forest-builders?" I think that we must answer these questions. If we can answer in the affirmative that we are forest-builders, we can tell the world around us how to create new forests which will last forever and ever by handling the basic biological factors properly. Roy Sutton analyzed these basic factors— but I want to underline and stress the importance of oxygen for the roots even more strongly than my friend Roy.

It has been of great interest to me to see and to take part in, the discussions concerning the eco-regions, the forest types, and the important trials and experiments established on different soils. I have full respect for what Canadian foresters of all kinds are doing. I am, however, concerned about your viewpoint on the future management of trembling aspen and the other "weed" trees.

While I have no personal prescription for managing your forests and do not know your goals and political constraints, I will give you some reflections.

Easy

Starting new stands in your subalpine regions does not seem problematic to me. It should be helpful to know your microsites well and more site preparation might be worthwhile.

Money

Regeneration of the mixed wood and lower elevation forests should be no problem if the necessary procedures are undertaken without delay after harvesting. They require action and funding.

Young, lower elevation, backlog stands are a greater problem. I consider that the use of herbicides is undesirable. Use of large seedlings planted in good microsites after removal of aspen and other weed trees, followed by precommercial thinning within four to five years seems to me a possible rehabilitation prescription. Regeneration release cuts are standard practice in my district in Sweden.

Time

Older, lower elevation, backlog areas close to the mill now occupied by 10 to 100 year old aspen on the best sites are a greater problem. Why not join nature instead of trying to beat it? Practice aspen silviculture and only slowly change these stands into spruce forests over the longer term. It must surely be easier to find a market and change the manufacturing processes than to change the forest. The main objective of the forester is to store the sun's energy in the trees in a fully stocked stand.

Anyhow, it seems to me that the most important point is to build new forests knowing the biological factors operating in these ecological systems, utilizing the wood values present as far as possible. The two field trips and the indoor sessions indicate that new thinking has begun in Canadian silviculture.

To end on a personal note, I wish you, Canadian foresters, all the best in the future. Close your eyes and see young, green forest stands everywhere.

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