ADVANCES IN LODGEPOLE PINE REGENERATION

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ABSTRACT

Successful regeneration of lodgepole pine is still an art, but the attainment of target stands with sufficient numbers of healthy, well-distributed seedlings has been made more attainable by scientific and operational advances since the 1973 symposium.

Clearcutting is still the predominant method used to regenerate stands of lodgepole pine, and partial cutting practices are restricted to use in special situations, particularly in the southern part of the natural range. In all areas successful natural regeneration depends upon the manipulation of seed supply and exposure of mineral soil. Methods for estimating seed supplies, and improvements in site preparation techniques, have increased the ability of silviculturists to achieve an optimum combination of seed supply and seedbed over a wide range of sites. Excessive stocking is a larger problem than inadequate stocking in Canada.

Artificial regeneration by means of direct seeding is used very little, but new spot seeding techniques coupled with seed protection from rodents could lead to a resurgence of interest because of the relatively high costs of planting.

Planting efforts have increased substantially as a means of both replacing pine stands and displacing other species. Ease of establishment, precise stocking control, rapid early growth, and the promise of shortened rotations are the major attractions. Results are usually excellent but there have been some problems in nursery practices. Early root development in planted stock is another related major concern.

Continued progress in regeneration, whether natural or artificial, is highly dependent on systematic reviews of performance.

INTRODUCTION

The successful regeneration of lodgepole pine, in the form of its most widely distributed variety (*Pinus contorta* var. *latifolia* Engelm.), is still an art. But our ability to create stands of healthy, well-distributed trees has been raised to a level of high achievement when judged by North American standards. This feat has been accomplished by a variety of scientific and operational advances that have taken place since regeneration of the species first because a subject of concern, with the assistance of the lavish reproductive capabilities of lodgepole pine.

Our aim in this paper is to describe the most important of the advances made since the last symposium in 1973, and to assess prospective advances. Using as our starting point the summaries of North American knowledge and United States practice prepared by Lotan (1975*a*, *b*) and Alexander (1974), and complemented by the Canadian work of Smithers (1961), Armit (1966) and Clark (1974), we move on to examine the most notable trends in regeneration practices. We deal in greater depth with specific advances in natural regeneration, direct seeding, and planting, using the recently issued summary reports by Lotan and Perry (1983) and Reid, Collins Nurseries Ltd. (1983) as sources of references and ideas. In our conclusion we make some proposals for silvicultural emphasis in the future.

TRENDS IN REGENERATION PRACTICES

Western foresters on both sides of the border were quick to recognize that lodgepole pine reproduced best in the open on disturbed soil and that the prolific seeding habit reduced the problem of regeneration after clearcutting. Nevertheless, it wasn't until the 1950's and early 1960's that resource exploitation and partial cutting practices began to fade, and even-aged management by means of clearcutting was accepted as the best way to convert old-growth pine to productive young forests. By the time of the last symposium, Lotan (1975*b*) had noted the universality of clearcutting as a regeneration method. He also noted public concern about the environmental impact of clearcutting lodgepole pine, particularly in the central and southern Rockies where foresters were under pressure to recognize non-timber values in management. This had led to the work of Alexander (1972, 1974), which provided the first detailed guidelines for maintaining continuous cover in lodgepole pine stands occupying sites of special value for recreational or hydrological purposes.

Interest in more intensive management of lodgepole pine, involving substantial investment of resources in seedling production and planting, was restricted to areas where natural regeneration had failed, to experimental situations, and to locations such as Sweden, Ireland, and New Zealand where lodgepole pine had been introduced and shown promise as an exotic plantation species.

While the predominant theme today is still low-cost timber management of the lodgepole pine resource by way of clearcutting, there have been some significant changes in the last ten years. Better utilization practices, changing logging machinery, stricter reforestation standards, and research extension efforts have created a greater silvicultural awareness of regeneration needs among foresters in all parts of the species' range. Serotiny is no longer a foreign word, and overstocking is as much a concern as understocking. There has also been a surge of interest in intensive management, partly in response to rising lodgepole pine timber values and also as a reaction to concern over future wood supplies. In terms of regeneration practices this means that foresters are now advocating the use of planting as a means of improving seedling distribution and density in young pine stands, and as a means of reducing regeneration delays. The rapid early growth of planted pine has also prompted British Columbia foresters to plant pine on large numbers of sites where the old-growth pine component was negligible or nonexistent. These trends have led to a major expansion in the use of planting stock, especially in Canada as follows:

	1973	1983
	thousands of seedlings	
B.C.	5,400	19,650
Alberta	1,700	4,250
Idaho, Montana, Oregon, Utah, Washington	not available	9,940

Thus, while natural regeneration is still the predominant regeneration technique, planting of lodegpole pine is much more prominent than it was ten years ago and our paper reflects this fact.

ADVANCES IN NATURAL REGENERATION

Although lodgepole pine stands are considered to be relatively simple to regenerate, the forest manager must still consider a wide range of factors and weigh their influence before making any regeneration decision. To assist the manager, Lotan and Perry (1983) have distilled experience from many quarters and prepared a simple guide to the decision-making process, concentrating on natural regeneration. They have proposed that forest managers ask four questions before deciding which combination of silvicultural system and cutting practice to use on any given site. In summary form they are:

1. Is the natural regeneration potential sufficient to meet stocking goals? If the goals are set at a high level, or potential is low, artificial regeneration may be required; otherwise, managers must consider manipulation of seed supply and seedbed in both harvesting and site preparation operations to ensure that the regeneration potential is realized.
2. Are serotinous cones available and sufficient? If not, and natural regeneration is planned, cutting practices must be adjusted to ensure adequate seed-fall either from seed trees or cut block edges in the first years following harvesting.
3. Is dwarf mistletoe (*Arceuthobium americanum* Nutt. ex. Engelm.) a problem? If so, cutting and site preparation practices must be adjusted to minimize future infection from old-growth stems (whether in cut block, or on the boundaries) and from advanced regeneration.
4. Is windthrow a hazard? If so, cutting practices must be modified to minimize the risk.

Lodgepole pine windthrow problems have not been the subject of any innovations since the work of Alexander (1974). However, there have been several advances in the past ten to fifteen years that assist foresters both in answering the first two questions on natural regeneration potential, and in coping with dwarf mistletoe. Our ability to estimate the potential for natural regeneration on any given area has been improved substantially as a result of experimentation and careful observation of operational results. Site preparation techniques have been greatly improved, especially in Canada, as have measures for protecting naturally regenerated stands from infection by dwarf mistletoe.

Estimating the Potential for Natural Regeneration

The potential for natural regeneration can be assessed if the supply of cones and seed is known, and if the forest manager has some idea of the amount of seed required to produce satisfactory stocking after harvesting under a variety of site and seedbed conditions.

Prediction equations using stand variables have been developed to estimate the amount of cones on an area basis and, when combined with an estimate of the number of viable seeds per cone, they can be used to calculate a value for seed supply prior to harvesting (Lotan and Jensen, 1970; Lotan, 1975*b*). Harvesting reduces the seed supply of serotinous stands because cones are buried, crushed, or removed from the site. Clark (1974) found the reduction to be between 90% and 95% on cutovers in southern British Columbia, but Lotan and Perry (1983) suggested the loss could be much less. In a more recent study Clark (1984) reported on cone distribution after logging operations using feller-buncher/grapple-skidder equipment. He found that minimum stocking levels were reached on most areas, but recommended in addition cone bearing slash should be left to ensure more rapid and more consistent regeneration results.

Seed supplies in non-serotinous stands can be calculated by using the same estimation procedures, with a reduction factor to account for the average ten-year production of cones that is stored in serotinous stands (Lotan and Perry, 1983). Seed traps can be used to obtain better estimates (Dahms and Barrett, 1975).

Post-harvesting seed supply estimates can be converted into a value for potential seedlings with the use of the seed/seedling ratios developed for a range of site and seedbed conditions by several authors, and summarized by Lotan and Perry (1983). The example provided in table 1 shows how a forest manager might use this information to make a regeneration decision.

Table 1.—Estimating regeneration potential

Suppose site has moderate moisture and temperature conditions, and vegetative competition on Douglas-fir/Calamagrostis site type is moderate and mineral soil exposure from winter logging on snow is limited.

STEP 1 Cone supply = 690,000/ha

STEP 2 Viable seed content = 24 seeds/cone

STEP 3 Potential seed supply = step 2 × step 3 = 16,560,000/ha

STEP 4 Reduction factor for winter logging (feller-buncher/grapple-skidder) operations, with eradication of advanced regeneration infected with dwarf mistletoe = 0.10

STEP 5 Post-harvesting seed supply = step 3 × step 4 = 1,656,000/ha

STEP 6 5th year seedling/seed ratio
- a. without site preparation to improve seedbed conditions = 1,000:1
- b. with site preparation = 100:1

STEP 7 Regeneration potential:
= step 5 step 6a = 1,656 trees/ha
step 5 step 6b = 16,560 trees/ha

Conclusion: Manager can either forego site preparation and plan to improve number and distribution of seedlings through planting, or modify site preparation procedures to reduce total mineral soil exposure. Juvenile thinning may be required in either case.

A post-harvesting approach to estimating regeneration potential has been developed by Glen (1979) and is used in the interior of British Columbia. Site preparation treatments are recommended on the basis of the distribution of cones, their total numbers, and the numbers of cones on suitable seedbeds (see next section).

One major problem with both methods of estimating regeneration potential is that their reliability has not been fully tested. Part of the reason for this is that managers must wait a long time between the survey of potential, site treatments (if any), and the completion of stocking. Crossley (1976) and Johnstone (1976) have shown that ingress of regeneration takes place for at least 15 years in the boreal and sub-alpine forests of Alberta. In British Columbia and Alberta regeneration surveys are commonly delayed for 5 to 7 years after harvesting or site preparation, by which time it is estimated that only 60-80% of regeneration has occurred.

There are at least two other factors that should make readers wary of the unqualified application of either method of estimating regeneration potential. The fact that conifer seed predation by small mammals can reduce seed supply substantially has been known for some time, but Sullivan and Sullivan (1982) have shown that predator populations and damage from seed loss vary considerably on lodgepole pine cutovers in southern B.C. Heavy predation on one cutblock could convert a potential success story into a miserable failure. Changing logging techniques may also remove more seed from the site than previously expected. In another study from southern B.C., Clark (1984) has reported a study of the effect of whole-tree logging using feller bunchers and grapple skidders on subsequent pine regeneration. Initially, there was fear that the numbers of serotinous cones, and therefore regeneration potential, would be reduced because entire trees were being removed to the landings with little ground contact. Results to date show no reasons for special concern.

Improving Seedbed Conditions and Cone Distribution

Efforts to improve seedbed conditions and cone distribution have been concentrated in Canada because the climate is moist and cool, litter accumulations on lodgepole pine sites are often substantial and additional mineral soil exposure is essential for successful natural regeneration, particularly after harvesting on snow. The early attempts to improve germination were based on experience with blade scarification on spruce sites—a practice that proved to be expensive. In Hinton, Alberta, the idea of using tractors to drag heavy anchor chains to break down cone-bearing slash and deposit cones close to mineral soil was introduced in the early 1960's. This practice, drag scarification, became accepted in British Columbia by 1970 as regeneration results from broadcast burning proved to be negative (Clark, 1974), and better stand utilization practices reduced the need for slash disposal. By the mid 1970's early results from drag scarification were encouraging (Glen and Ackerman, 1978; Thompson, 1978) but quite variable (see table 2), and studies were initiated to examine ways of improving the reliability of the technique.

Table 2.—Drag scarification results from central interior of British Columbia[1]

Regeneration Density Class	Areas Surveyed
----stems/ha----	----%----
less than 1,000	7
1,000- 2,000	13
2,000- 4,000	31
4,000- 6,000	21
6,000-10,000	18
more than 10,000	10
	100

[1]Based on 73 areas, data from Glen and Ackerman (1978)

Detailed guidelines for drag scarification in British Columbia have been prepared by Glen (1979). They are based on the following factors:

1. Slash rating, which influences choice of scarification equipment;
2. Number and distribution of cones,which influence choice of regeneration method, scarification equipment, and timing of scarification;
3. Depth of duff, which influences choice of equipment and its weight;
4. Slope, which influences choice of method and direction of operations;
5. Stump density and height, which influence choice of method; and
6. Soil moisture, which influences choice of towing equipment and timing of scarification.

Recommendations are based on the need to avoid both overstocking and understocking. Examples are shown in table 3 and the principal types of equipment used are shown in figure 1.

Table 3.—Drag scarification recommendations for a mechanically logged lodgepole pine stand (from Glen, 1979)

	No. of Cones After Harvesting[1]		
Cone Distribution	Total	On Satisfactory Seedbed	Recommendation
Good	10+	7+	Use light anchor chain one year following harvest to uproot germinants.
Good	3-10	less than 3	Use heavy anchor chains in spring following harvest to increase suitable seedbed.[2]
Patchy	3-10	less than 3	Use heavy and light anchor chains to increase seedbed and improve chances of germination.
Good	10+	less than 3	Use sharkfin drums to produce limited increase to seedbed and concentrate regeneration in rows.

[1]Based on survey using 5-m^2 plots

[2]Alberta Forest Service recommends delaying scarification until pine slash is well dried to improve distribution.

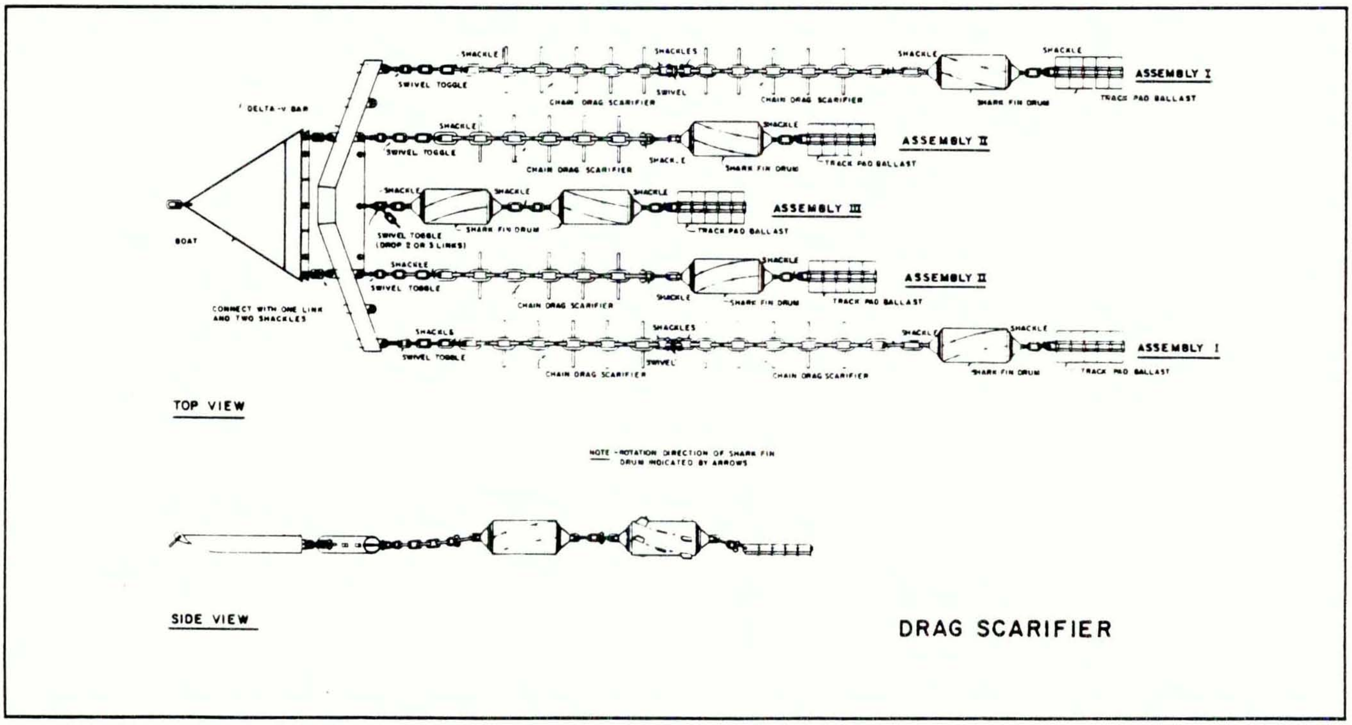

Figure 1.—Three examples of drag scarification equipment combinations (from Glen, 1979).

The scarification guidelines are based almost entirely on experience and basic knowledge of the requirements for successfully regenerating lodgepole pine, but trials have been established to check their validity (Glen, 1978; Herring, 1981; Vietnieks, 1983).

Reducing Risk of Mistletoe Infection

If regenerating stands are threatened by dwarf mistletoe infection, forest managers can now refer to a great deal of accumulated knowledge (e.g. Scharpf and Parmeter, 1978) before deciding how best to reduce the risk to an acceptable minimum. Special silvicultural extension efforts have been made (Baranyay and Smith, 1972; Hadfield and Russell, 1978), and local guidelines prepared (e.g. Vyse, 1981). As a result, foresters on both sides of the border now plan layout of cutblock boundaries in mature pine with the risk of infection from edge trees kept in mind. Furthermore, the removal of residual stems after harvesting has become common practice in British Columbia. Large live residuals must be cut by the logging contractors, and a variety of methods, including hand cutting, drag scarification, and machine crushing, are used to destroy the smaller stems. Broadcast burning has been proposed specifically for sanitation purposes (Muraro, 1978) but is not practised because of the risk of an undesirable reduction in seed supply (Clark, 1974).

ADVANCES IN DIRECT SEEDING

If natural regeneration of lodgepole pine has been judged as unlikely or as having failed, planting is considered to be a much better artificial regeneration option than direct seeding. Results from seeding pine have not been good and consequently the method has been all but abandoned in every part of the natural range except Alberta. There, seeding is used to supplement the natural seed source after scarification, but the annual area treated is small (Ferdinand, 1983).

This situation might change if utilization and harvesting developments lead to an increase in natural regeneration failures. Rising plantation establishment costs, or limited seedling supplies, might also lead to decisions that prohibit planting on low productivity pine sites. These last two factors have already taken effect in British Columbia and there has been a minor resurgence of interest in two spot-seeding techniques: the use of seeding in conjunction with patch scarification equipment, which improves germination conditions; and the use of the Finnish shelter cone method, which improves germination and growth conditions. The combination of spot seeding with patch scarification has shown promise in Ontario (Winston and Schneider, 1977) and should work elsewhere, although trials conducted to date have not been successful (Ferdinand, 1983). The shelter cone method, which forms a mini-greenhouse over the seed and seedling, has shown more promise in British Columbia[1], but suffers from the drawback of requiring careful manual placement. It may prove useful in evading short-term limits to seedling production.

One major factor contributing to a lack of success in direct seeding operation is seed predation by small mammals. Sullivan and Sullivan (1982), have found that the application of alternative and preferred food in the form of sunflower seeds will increase the survival of lodgepole pine seed by four times or more on cutovers with high animal densities. Spot or row seeding combined with an alternative food treatment deserves a trial on low-productivity sites.

ADVANCES IN PLANTING

Practical experience suggests that lodgepole pine is easy to establish as a planted seedling throughout the west. There are many healthy plantations spread over a wide variety of sites across the species's natural range and beyond. Part of this success is attributable to the natural resilience of lodgepole pine, but it is evident to us that much has been learned about establishing plantations in the last decade. A number of studies dealing with ways of improving stock production and planting programs have been published. Not all the ideas contained in those studies have been implemented, but in total the increase in knowledge represents an advance at least as much as that made in actual area planted. We have chosen to focus on a few key topics of special interest to field foresters.

Increasing Survival on High Moisture Stress Sites

Adequate survival can be difficult to obtain on sites where high moisture stress is a major factor contributing to mortality. Drought-attributed mortality of planted seedlings commonly occurs on south slopes in northern Wyoming, Montana and Idaho (Lotan, 1964; Alexander, 1974). The ability of seedlings to avoid desiccation or drought is highly dependent on fast root extension. The absence of lodgepole pine on very dry sites has been attributed to slow initial root elongation; but once established, survival is favored by a sensitive inherent control of water loss (Lopushinsky, 1975; Brix, 1978). Thus, nursery production of seedlings with a high root-regeneration capacity, and handling procedures which preserve the viable root systems, should increase drought avoidance ability.

Provenance variation in survival and growth during drought, and in rate of photosynthesis of lodgepole pine seedlings (Sweet and Wareing 1968; Dykstra 1974) and family variation in water stress resistance (Perry *et al.*, 1978) indicates the potential for control of losses on dry sites through tree improvement programs.

There is also evidence that "large" stock will perform better than "small" stock on drought-prone sites (Baerr *et al.*, 1977)

[1] Unpublished results from silvicultural trials made available by D. Wallinger, Silviculture Branch, Ministry of Forests, Victoria, B.C.

and this is supported by studies of other species. With Douglas-fir this is a response to shoot/root ratio rather than to absolute size.

Reducing Root Deformation and Juvenile Instability

Root deformation and instability of planted lodgepole pine trees is a topic of recurring interest and debate (Van Eerden and Kinghorn, 1978). The instability of planted lodgepole pine trees is attributed to the shortage of well-distributed primary lateral roots and the inability of the trees to regenerate new ones (Burdett, 1979*a*; Selby and Seaby, 1982). It may occur with both bareroot and container-grown stock, though the nature of this deficiency in the two stock types is different.

All container systems presently in use, regardless of their design features, create a vertical root cage (Van Eerden, 1982). As lodgepole pine does not produce adventitious roots, container-grown seedlings have markedly distorted root systems. In the early years of rapid height growth these distortions *may* predispose the planted trees to basal sweep, instability and, under certain climatic and soil conditions, toppling or windthrow.

Several techniques have been tested to eliminate the characteristic effect of container on root form. A chemical root pruning technique involving the use of containers coated on the inside with latex paint containing cupric carbonate has been developed (Burdett, 1978). The wall coating inhibits root growth and thereby prevents lateral roots growing down or around the container wall. The arrested root tips resume growth when the trees are removed from the container. The chemically pruned trees show enhanced side root development and height growth after outplanting compared with the controls (McDonald *et al.,* 1982; Burdett *et al.*, 1983). The chemical pruning does not, however, appear to be universally applicable without modification. In particular, it is useful only when the container is small (McDonald *et al.,* 1982). To counter these problems, Burdett (1982) has proposed a mechanical method for box pruning the roots of container-grown stock. Seedlings are grown in slot-sided trays which permit lateral root pruning on one or more occasions before extraction.

Seedlings grown in bareroot nurseries can also have deficient root systems. Lifting and transplanting reduces the number of primary lateral roots, and survivors become thickened and severely disturbed. Possible solutions include wrenching and lateral pruning and the initiation of more lateral roots by auxin treatment. Watering soil-grown lodgepole pine seedlings with auxin solution has induced the development of a large number of primary lateral roots (Selby and Seaby, 1982).

Poor planting of bareroot stock can increase the risk of instability by producing either a compressed bilateral root system in the planting slit or a unilateral root distribution (J roots) in which the roots become balled in the planting hole. The problem is much reduced with container stock.

After outplanting, any root problems that may exist can be aggravated by slow root growth and rapid early height growth. Basal bowing or toppling are likely consequences (Lines and Booth, 1972; Reid, Collins Nurseries Ltd., 1983). Site preparation techniques that encourage root growth through favorable increases in soil temperatures, aeration and nutrient availability can alleviate this problem. McMinn (1978) has found that the root mass of lodgepole pine bareroot seedlings planted in mixed microsites where (vegetation and duff were incorporated into mineral soil) greatly exceeded that of seedlings planted in blade scarified or untreated plots (table 4). The root/top and root area/crown height ratios of the container lodgepole pine seedlings were improved by planting in mound microsites rather than patch microsites (Martinsson, 1983).

Table 4. – Root mass of lodgepole pine bareroot seedlings five years after outplanting in variously treated sites[1]

Site Treatment	Growing Seasons After Planting				
	0	1	2	3	5
untreated	0.7 a	1.0 a	2.1 a	5.5 a	39.7 a
blade scarified	0.7 a	1.2 b	3.3 ab	6.6 b	63.4 b
mixed	0.7 a	1.3 b	4.0 b	13.0 c	103.3 c

[1]from McMinn 1978

Although the effects of root deformations in planted stock of lodgepole pine have led to serious losses in some locations (Chavasse, 1978; Burdett, 1979a), the overall risk of significant economic losses can be small if the simple evasive techniques discussed above are implemented (Van Eerden, 1982).

Improved Quality of Container Seedlings

Much has been learned about container stock production over the past ten years. Guidelines on rearing high quality, containerized lodgepole pine are now available in several compilation reports (Tinus and McDonald, 1979; Carlson, 1983). This knowledge is augmented by the numerous papers on refinements of the techniques and by the regional recommendations presented in the proceedings of two symposia on containerized production (Tinus *et al.*, 1974; Scarratt *et al.*, 1982). Several advances deserve specific mention here.

Performance studies of containerized seedlings uniformly show that the largest plant that can be grown, handled, and planted economically produces the best growth and highest biomass after outplanting. The survival and growth was positively related to increased stock age, stock size, and container size (Endean and Hocking, 1973; Dobbs, 1976; Walker and Ball, 1981). The relationships found show that the hazardous plantation establishment period can be shortened considerably if larger stock, produced over longer greenhouse rearing periods, or larger containers are used. However, seedlings from small-volume containers (e.g. 40 cc) have shown adequate growth on a wide range of sites in British Columbia (Vyse, 1982).

Induction of Cold Hardiness for Cold Storage for Overwintering Outdoors

Winter damage to lodgepole pine container seedlings overwintered outside, usually at the nursery site, adversely affects the seedlings and reduces the quality of stock. The conditioning process to induce adequate hardiness of lodgepole pine seedlings prior to extracting and packaging for cold storage is described by Matthews (1982). Cold hardiness can be enhanced by exposure to long-night (short-day) treatments developed for lodgepole pine by Rosvall-Ahnebrink (1982) and for other species (e.g. Colombo *et al.*, 1982). Zalasky (1983*a*, *b*) has designed a complete system for rearing, conditioning, and overwintering lodgepole pine container seedlings, and has also provided the structural specifications and operational procedures for a simple unheated storage facility. Further progress in this area is hindered by the lack of a rapid test for cold hardiness.

Enriched CO_2 Environment

Lodgepole pine responds positively to enriched CO_2 levels, and the enhancement of CO_2 concentrations appears to be a viable treatment for reducing the time needed to produce a seedling of targeted size. The CO_2 concentrations most often used in greenhouses range from 800 to 1500 ppm compared to the ambient level of 330 ppm. Enrichment of CO_2 to a concentration of approximately 1320 ppm reduced the length of growing time for lodgepole pine in greenhouses from 16 weeks to 14 weeks, based on time required to attain a target average height (Canham and McCavish, 1981). The effect was enhanced by increased nutrition. In another study, after 20 weeks of growth under controlled environment, total biomass was approximately five times greater in seedlings grown at 1000 ppm CO_2, than for seedlings grown at 330 ppm CO_2 (Higginbotham *et al.*, in press). Root biomass increased 15 times in the same seedlings. A further increase in CO_2 concentration to 2000 ppm reduced growth of seedlings.

Accelerated Growth by Extended Photoperiod

Lodgepole pine seedlings grown for six months under continuous photoperiod were ten times taller, and 200 times heavier than the control after six months of initial growing period (Wheeler, 1979). The excellent root system developed on treated seedlings and the resultant low shoot/root ratios were correlated with improved growth and survival after outplanting, and treated seedlings maintained an accelerated growth during the two growth seasons following outplanting. The immediate application of continuous photoperiod treatment may be hindered by large intraspecific variations in response to the treatment (Perry and Lotan, 1978).

Use of Growth Inhibitors and Retardants

The potential use of growth inhibitors and retardants for altering shoot/root ratios of containerized lodgepole pine, and thus enhancing survival after outplanting, and for reducing the root-bound effect of held-over container seedlings has been suggested by Weston *et al.*, 1980). Ancymidol and Phosphon could be used to reduce the shoot/root ratio, and Ethrel and CCC (Cycocel) treatments are recommended for use on held-over plants.

Mycorrhizal Inoculations

Another possible method for improving survival and growth of lodgepole pine after outplanting is to inoculate seedlings with mycorrhizal fungi. Techniques are now available for artificially inoculating containerized seedlings with pure cultures of selected mycorrhizal fungi. Twenty-two different fungi, indigenous in soils of the Pacific Northwest, were shown to have the ability to form ectomycorrhizae on lodgepole pine (Molina and Trappe, 1982). Lodgepole pine seedlings in containers have been successfully inoculated with several ectomycorrhizal fungi (table 5).

Table 5.—Successful ectomycorrhizal inoculations of container-grown lodgepole pine seedlings

FUNGUS	Evidence for Seed Source Variability
Pisolithus tinctorius (Molina, 1979; Grossnickle and Reid, 1982)	Alberta[1] Colorado (Cline and Reid, 1982)
Suillus granulatus (Grossnickle and Reid, 1982)	Colorado (Cline and Reid, 1982)
Rhizopogon luteolus	Colorado (Cline and Reid, 1982)
Laccaria laccata (Molina, 1980)	Alberta[2]
Cenococcum geophilum (Molina, 1980; Grossnickle and Reid, 1982)	Not known
Hebeloma crustuliniforme	Alberta[2]

[1] J. Dangerfield, Research Branch, Ministry of Forests, Victoria, B.C., pers. Comm.

[2] S. Navratil, unpublished data.

Both host seedling genotype and fungal species ecotype influence the degree of ectomycorrhizae formation, as well as the host seedling growth response. These results emphasize that consideration must be given to seed source, fungal species and different isolates of the fungus used for inoculation to insure optimal mycorrhizal development and seedling growth.

Seedling growth response to mycorrhizal inoculation in the rearing phase is highly variable: inoculation may increase or reduce the biomass of seedlings shoots and/or roots. In the study by Cline and Reid (1982) the amount of ectomycorrhizal infection with *Pisolithus tinctorius* and *Suillus granulatus* was positively correlated with dry weight and shoot/root ratios of lodgepole pine seedlings. The effects of mycorrhizal inoculations on growth and survival of lodgepole pine after outplanting on reforestation sites are not yet known, but on a high-elevation mining site lodgepole pine seedlings inoculated with *S. granulatus* had greater growth rates than seedlings inoculated with other fungi or control (Grossnickle and Reid, 1982).

Frequent applications of concentrated soluble fertilizers in containerized production may inhibit mycorrhizae development of seedlings, and low fertility schedules or slow-release fertilizers may be needed for inoculations with sensitive fungi such as *P. tinctorius.*

Improved Quality of Bareroot Stock Production

In recent years much has been done to speed production of bareroot planting stock and, at the same time, to improve the quality of that stock.

Van den Driessche (1982) investigated the effects of different seedbed spacing on lodgepole pine growth in the nursery and after outplanting, and examined the relation of spacing to nitrogen supply. Treatments consisted of spacing the germinated seedlings (1, 2, 4, 8, and 12 cm in drills 15 cm apart) and using three levels of nitrogen supply (60, 140, and 235 kg/ha). Spacing of 2 cm and more in drills 15 cm apart increased root collar diameter and dry weight of 2-0 year seedlings, but shoot length was only significantly increased at the 8- and 12-cm spacing. Each increase in nitrogen fertilization increased the size of seedlings as well as the amount of new shoot growth after outplanting. Much of the improved growth after planting was explained in terms of increased seedling size. At the highest level of N supply (235 kg/ha), increased spacing to 4 cm did not greatly reduce total yield of seedlings with root collar diameter greater than the minimum acceptable size of 3 mm. Thus, the combination of fertilization plus increased spacing improved quality without materially reducing yield of seedlings per unit area of nursery.

A new technique for enhancing production of bareroot seedlings has been tested in the United Kingdom. Polyethelene tunnel cloches with buried edges to cover seedbeds effectively reduced the time for producing planting stock by one year. The results show that it is possible to consistently produce one-year-old lodgepole pine seedlings sufficiently tall and sturdy for outplanting (Thompson and Biggin, 1980; Biggin, 1983).

The survival of planted bareroot lodgepole pine has been found to be strongly related to root growth capacity (Burdett, 1979*b*). Accordingly, a method for measuring root growth capacity of bareroot lodgepole pine seedlings has been adopted by the British Columbia Forest Service as the basis for nursery quality control. The method is a modification of the procedure reported by Stone and Jenkinson (1971); however, it requires less time and less labor to complete. Test seedlings are grown for no more than a week under conditions that are considered optimal for root growth, and are then assessed for new root growth.

Careful assessment of seedling morphology can be a useful criterion for estimating the potential of a plant for shoot growth and biomass production in the following year. Thompson (1976) suggests that it may be advantageous to modify the growing conditions to produce one-year-old plants that are short, but have a rosette containing a large number of primary leaves, and that have the potential to produce a large shoot after planting.

Comparisons of storage regimes of bareroot stock show that overwinter storage of fall-lifted lodgepole pine at a sub-freezing temperature results in survival and growth rates equal to or better than those obtained with conventional spring lift and cold storage procedures. Operationally, the frozen storage technique has many advantages for nursery operations and has been widely adopted in Canada and the U.S. Best results are achieved if the seedlings are lifted and preconditioned at above-freezing temperatures for 3-4 weeks prior to overwinter frozen storage[1] (McDonald *et al.*, 1983). However, the relationship between time of lifting and post-planting performance is critical. New methods for determining the physiological readiness of lodgepole pine for fall lifting, such as frost hardiness tests [2] and root growth curves (Navratil, 1984), are becoming available.

Planting freshly lifted stock late in the planting season after most stem elongation had taken place is biologically feasible and may give survival rates well above those of trees coming out of long-term storage (McDonald *et al.*, 1983). The biological potential for late summer planting is suggested by the bimodal pattern of seedling root growth (figure 2). However, the hot planting is operationally difficult because stock must be treated delicately and replanted very soon after lifting (1-2 days) to avoid severe mortality.

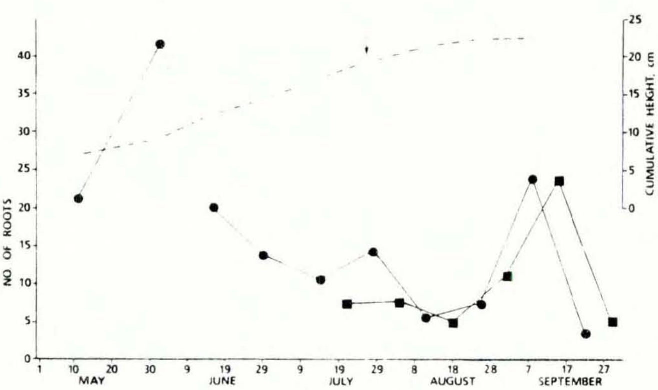

Figure 2. – Root regeneration (number of 3-10 mm long root tips) and height growth of rising 2-0 lodgepole pine seedlings in Pine Ridge Forest Nursery, Alberta

[1]S. Navratil, unpublished data.

[2]D. Simpson, Kalamalka Research Centre, B.C. Ministry of Forests, Vernon, B.C., pers. comm.

Performance of Container and Bareroot Seedlings

A number of studies of the field performance of container-grown and bareroot lodgepole pine seedlings have been completed in the interior of British Columbia. Evaluations of 6- to 10-year-old plantations planted under operational and research conditions reached the same overall conclusion: lodgepole pine container-grown seedlings survived and grew at least as well as bareroot seedlings (Gardner, 1982; Vyse, 1982). In fact, the data indicate the potential biological superiority of the container-planting systems over the bareroot method in achieving a high survival rate. Under operational conditions, the probability of achieving a survival rate higher than 90% was greater for container (styroplug) seedlings (Vyse, 1982) than for bareroot seedlings. Container seedlings produced the highest survival ratio of any of the stock tested in a research study reported by Gardner (1982). The initial height advantage of bareroot stock was maintained or increased (figure 3), but the similarity in growth rate of both types of stock suggests that this difference may be decreasingly significant with advancing age of plantations.

Three- and five-year results from field performance trials in Alberta confirm the British Columbia results that container-grown (styroplug) seedlings have higher survival rates than bareroot, and growth rates are comparable (Walker and Johnson, 1980). Growth curves from lodgepole pine plantations in west central Alberta attest to the similarity of height growth rate of container or bareroot stock and wildlings of the same age (Hellum, 1979).

From these field trials it appears that the commonly held view about superiority of bareroot stock may not be valid. The Canadian results support the conclusion that lodgepole pine seedlings grown in small-volume (40 cc) containers are capable of equaling the performance of 2-0 bareroot stock over a wide range of sites.

Improved Mechanical Site Preparation for Planting

Many research studies have shown that the method of mechanical site preparation and the resulting quality of planting microsite can considerably affect survival and growth of seedlings. Soil temperature, soil moisture and aeration, light, supply of nutrients, and availability of microbial symbionts vary with microsite and have been shown to directly influence seedling performance. These results have been adopted in practice wherever lodgepole pine is planted. Swedish spot scarifiers are currently preferred for light scarification. The normal objective is to create between 1250 and 1600 plantable spots per hectare (Ferdinand, 1983). On areas with significant amounts of brush, dense grass, or heavy slash a more intensive site preparation is required. For highest probability of success, individual planting spots are hand-scarified; however, a proper placement of scalps may be important on droughty sites and steep slopes (Lotan and Perry, 1983).

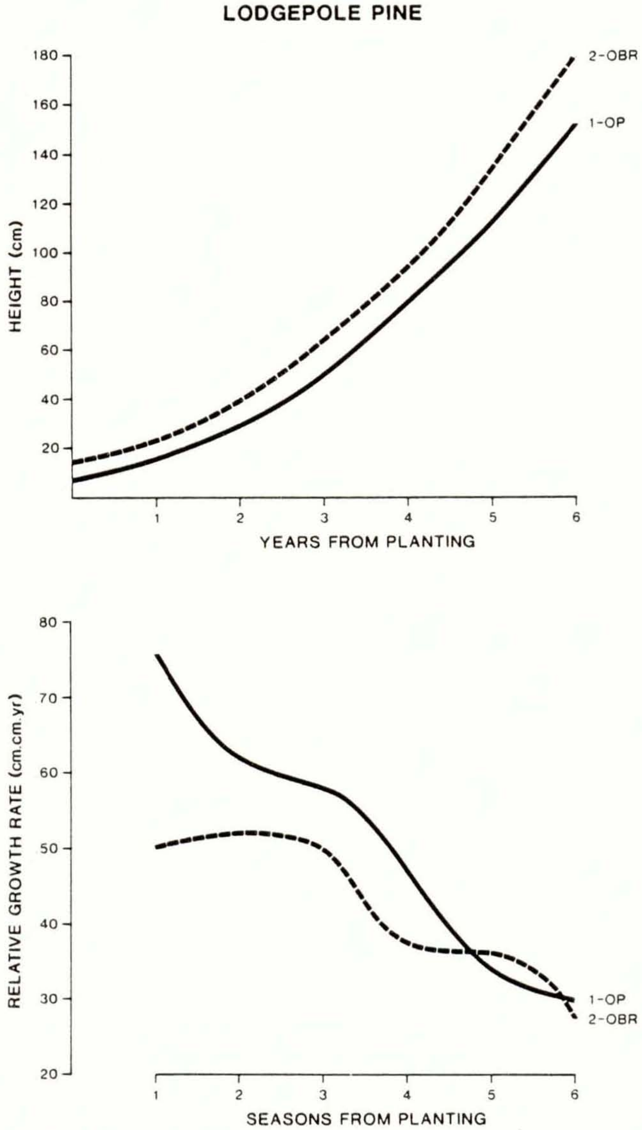

Figure 3. – Performance of operational planted seedlings in central interior of British Columbia (Vyse, 1982).

Trials with lodgepole pine and other pine species demonstrated the advantage of planting on mounds, inverted patches, and capped inverted patches, all of which increase soil temperature and favor the root growth and initial establishment of seedlings (Soderstrom, 1981; McMinn, 1982; Sutton, 1983). A new generation of site preparation equipment that produces planting spots which are responsive to the biological needs of seedlings (such as active topsoil agitators and mounding units), is becoming available. Still, if progress with mechanical site preparation is to continue, more information is needed on the interactions between microsite factors and survival and growth of lodgepole pine.

FUTURE PROGRESS IN REGENERATION

Although our survey of advances in the last ten years has revealed a number of instances where research work and innovative operations have overcome, or promise to overcome, biological and managerial obstacles to regeneration success, we think that further progress is always possible. Lodgepole pine planting can be expected to increase and a number of initiatives could be pursued in efforts to improve stock production. We anticipate that there will be substantial benefits gained with the production of stock of a higher growth capacity, a shaped root system, and with site specific mycorrhizal symbionts. More effective control of natural regeneration would reduce the overstocking problem. On sites of low productivity spot seeding offers potential benefits. However, it would be wrong to emphasize these essentially minor modifications to existing systems without drawing attention to a major deficiency in lodgepole pine regeneration programs.

As regeneration efforts expand and the system of interconnected activities becomes more complex, the need for systematic reviews of performance becomes more pressing. Managers need an improved flow of information to ensure that performance, in terms of goal attainment and resource expenditure, meets objectives. Unfortunately, most regeneration programs that we know of suffer from insufficient information feedback, and the western lodgepole pine programs are no exception. As an example, consider the current controversy over planting lodgepole pine in north central British Columbia. Proponents of planting argue that the benefits of increased control over early spacing and uniformly rapid growth offset extra costs. Natural regeneration advocates claim better early growth and reduced costs, and point to juvenile instability in plantations. No resolution of the argument is in sight because the background performance data is not available, either from operational programs or from research studies.

In order to upgrade natural regeneration programs, researchers and managers should concentrate on obtaining better information about the relationship between estimates of regeneration potential, seedbed conditions, and measured regeneration success by site. Faster and more complete monitoring of planting programs would help us learn from past mistakes and successes. Systematic efforts should be made to relate performance of various stock types to measures of stock quality at various stages from nursery to planting site, and to measures of environmental stress on those sites. Such initiatives, we submit, will provide the foundation needed for continued progress in the regeneration of lodgepole pine.

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ADVANCES IN LODGEPOLE PINE REGENERATION

Alan Vyse
and
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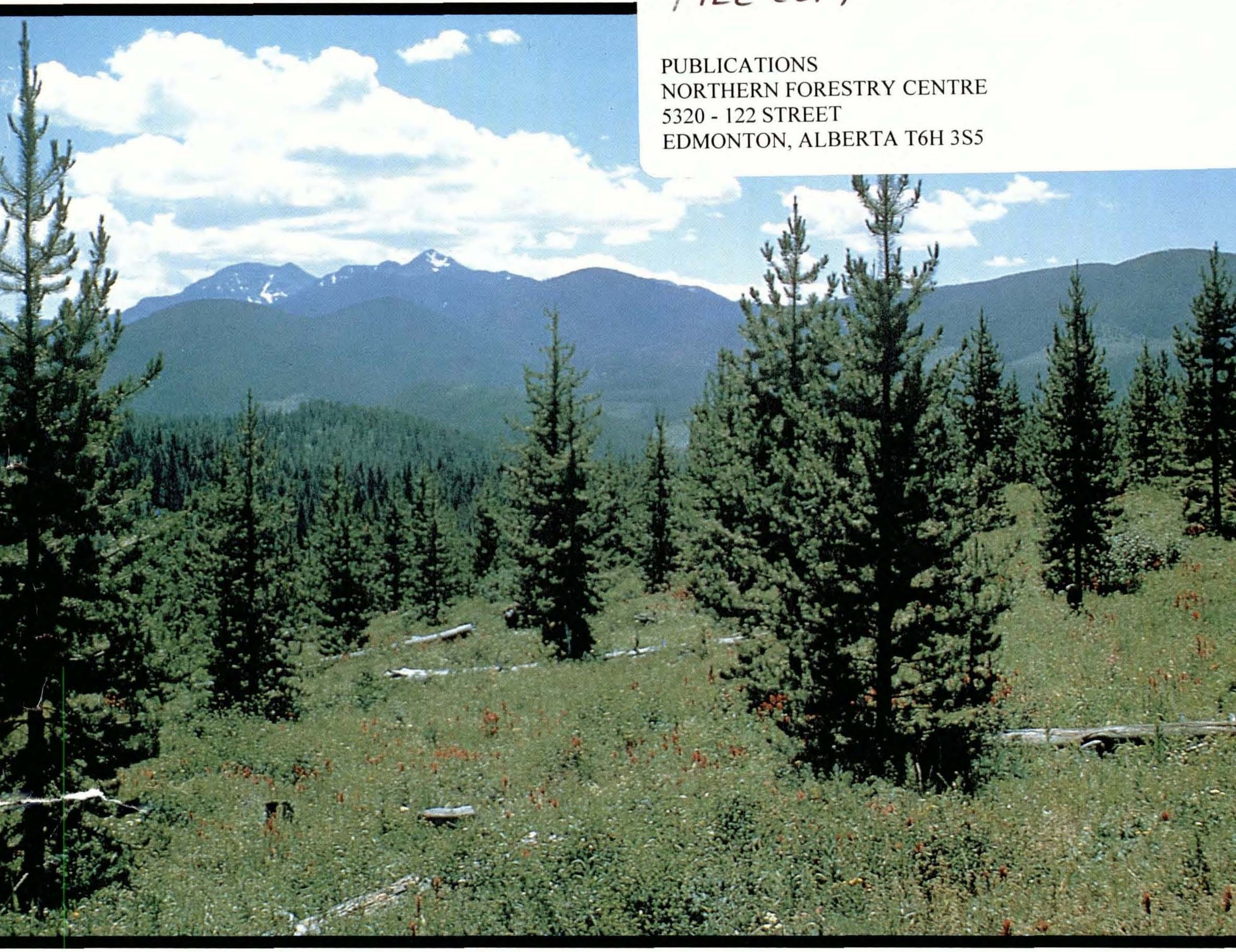

Lodgepole Pine
the species and its management
SYMPOSIUM PROCEEDINGS

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