Impact of Lift Date and Storage on Field Performance for Douglas-fir and Western Hemlock[1]

B.G. Dunsworth[2]

Abstract.--This study was established to assess the impact of changes in seedling morphology and physiology on outplant performance of western hemlock and Douglas-fir.

The six lift/store regimes in this experiment led to greater changes in seedling physiology than seedling morphology. The regimes created a wide range of dormancy intensities and frost hardiness for both species. Frost hardiness, as assessed by electrolyte leakage, was more closely related to dormancy intensity than was foliage browning. Storage regimes reduced the rate of dormancy release and maintained frost hardiness relative to no storage.

Field performance results from unwatered, raised beds indicate that early planting dates (Jan. 15) had the best relative volume growth. Storage maximized relative volume growth for both species for the March 15 and May 15 planting dates. Electrolyte leakage and dormancy intensity were the best predictors of volume growth.

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INTRODUCTION

For a number of years there has been a contentious debate among coastal nursery growers and field users about the appropriateness of winter lifting and storage of planting stock (Stone and Schubert 1959a, Hermann et al. 1972, Jenkinson and Nelson 1978, Krueger 1966, Nelson and Lavender 1979). Today, many foresters feel that cold storage is detrimental. They subsequently demand hot planting stock when they can, particularly for late spring planting.

This sentiment has been reinforced by erratic survival and poor growth in Douglas-fir, western red cedar, and ponderosa pine bareroot stock cold-stored for several months prior to planting (Stone and Schubert 1959b, Stone et al. 1961, Hocking and Nyland 1971, Curran and Dunsworth 1987, Van Den Driessche 1977).

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2 MacMillan Bloedel Limited, Woodlands Services Division, 65 Front Street, Nanaimo, B.C. Canada V9R 5H9

Cold storage has been associated with the following problems:

- molds,
  loss of carbohydrate reserves,
- reduction in root growth capacity,
- loss of dormancy intensity, and
  reduced frost hardiness and stress resistance.

Although the potential for physiological deterioration exists, the literature indicates that the rate of deterioration is accelerated without cold storage (Ritchie and Dunlap 1980, Burdett and Simpson 1984, Garber and Mexal 1980, MacDonald et al. 1983).

However, cold storage may create an acclimation problem, particularly with late spring planting. Investigations with boreal species in eastern Canada suggest that the stresses of acclimation may be greatest for cold-stored stock (Grossnickle and Blake 1987). Whether this is true in coastal species and whether the maintenance of a higher level of stress resistance is a compensating factor has yet to be determined.

Eliminating cold storage reduces nursery operating costs but creates a logistical problem. Persistent delays in handling the last season's crop leads to delays in starting the next season's crop. Coastal, container nursery growers need to determine if there is good biological foundation to the belief that cold storage is a detrimental practice. They also need to know if there is sufficient variation among seedlots to justify a range of winter lift regimes.

Our initial look at the problem focused on:

1. The predictive relationships among morpho logical and physiological characterizations at lift with subsequent field performance.
2. The progression and interrelationships among physiological characterizations from January to May under stored and non-stored conditions. 3. Potential optimum lift/store regimes.

METHODOLOGY

This experiment consists of two parts:

1. Seedling characterization.
2. Seedling performance.

The experimental approach is to create as wide a range of morphological and physiological kinds of seedlings using species, cavity size and lift/store regime as is practicable. These are then exposed to a simulated outplanting, under conditions where soil moisture and temperature can be measured and controlled. Seedlings able to maximize survival and growth under these conditions can then be associated with a specific cultural regime.

Seed Source and Lift/Store Treatments

The following species and stocktypes were grown at the Angus P. MacBean Nursery during 1985:

Table 1.--Seedlots and stocktypes used for Douglasfir and western hemlock.

Douglas Fir			Western Hemlock	
Seedlot/ Elevation	Stock Type		Seedlot/ Elevation	Stock Type
	PSB 313	PSB 415		PSB 313
4504/579	X		7311/150	X
7320/915	X		18752/416	X
4505/610	X	X		

The lift/store regimes shown in Table 2 were applied to each of the species and stocktypes shown in Table 1.

Seedling Characterization

Seedlings were characterized for morphology and physiology at lift and at the end of storage.

Morphology

Twenty-five trees per treatment (five trees for five replicates) were assessed for height, caliper, shoot and root dry weight.

Physiology

Seedlings from each treatment were assessed for Root Growth Capacity (in two environments),

Table 2.--Lift dates and storage duration treatments for Douglas-fir and western hemlock.

Lift Date	Storage Duration (months) at +2 C.		
	0	2	4
01/15/86	T1	T2	T3
03/15/86	T4	T5	
05/15/86	T6		

Dormancy Release Intensity, and Frost Hardiness (foliage browning and electrolyte leakage).

Root Growth Capacity.--Twenty-five seedlings (five trees from five replicates) per treatment were grown for one week in a peat/vermiculite/sand medium (2:1:1) in each of two environments (75% RH, 16 hr photoperiod, and 400 pmol/s/m^2 common to both):

1. 22 C/18 C (day/night) (D/N)
2. 30 C/25 C (D/N)

Seedlings were kept at field capacity for one week and assessed for root elongation using the index of root growth (IRG) (Burdett 1979).

Dormancy Release Index.--Twenty-five trees (five trees from five replicates) per treatment were assessed for number of days to budburst. The test environment was a 20 C D/N greenhouse with 16 hour photoperiod. Seedlings were kept at field capacity for the duration of the test. The index was calculated as:

DRI= 10/11 days to budburst (Ritchie 1984)

Frost Hardiness.--The risk of frost damage was assessed using foliage tissue in two ways:

1. Foliage Browning--qualitative (visual) assessment of the percent of foliage browned after exposure (-18 C) and one week of growth at room temperature and field capacity.
2. Electrolyte Leakage--quantitative assessment of cell membrane leakage of electrolytes due to stress or damage by frost (-18 C). Assessment consists of a comparison of conductivity measures for diffusate from frost damaged, undamaged, and heat killed foliage (Colombo and Cameron 1986).

Seedling Performance Study

The field study was designed as a completely randomized experiment consisting of six lift and store regimes and six species/stocktype treatments each replicated three times. Replicate plots consisted of twenty tree-row plots at 15 x 15 cm spacing. This test was planted into a 4 m x 8 m x 70 cm wooden soil box consisting of an alluvial, silty sand soil. The box was covered with a 6 mm, polyethylene sheet roof. This allowed rain to be excluded and still achieve approximately 75% full sunlight.

All seedlings were grown in the raised beds for one growing season. In December, all surviving seedlings were measured for height and caliper and carefully excavated. Shoot and root dry weights were determined for treatments; replicates were pooled.

The field performance results described here pertain to the dry moisture regime. This regime received no watering during the growing season. Soil tension at 20 cm exceeded -5 bars for greater than 100 days; soil temperature at 10 and 20 cm exceeded 20 C for up to 60 days.

RESULTS AND DISCUSSION

Seedling Characterization

Morphology At Lift

Height over all lift dates ranged from 16 to 23 cm. Western hemlock seedlings tended to be taller than Douglas-fir. Caliper ranged from 2.2 to 3.7 mm, with the latest lift having the largest calipers for all seedlots.

Shoot dry weight extended from 0.8 to 3.0 g, with a consistent trend of increasing weight from later lift dates. Western hemlock had consistently higher shoot weight than Douglas-fir for all lifts. Root dry weight varied from 0.6 to 1.6 g and exhibited a consistent increase with later lifts. This was less dramatic than increases in shoot dry weight.

Shoot to root ratios tended to increase with later lift dates. Western hemlock had larger ratios than Douglas-fir for the first two lifts, but by May 15 both species were comparable (Figure 1).

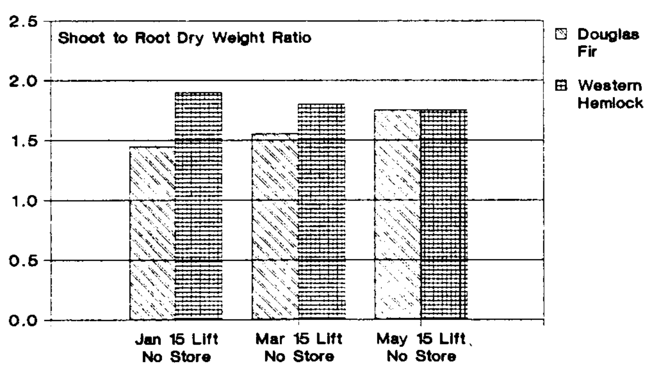

Figure 1.--Shoot to root ratio for three lift dates averaged by species.

The other measures of seedling balance (height:caliper and caliper:mass) tended to decrease with later lifts (Figure 2).

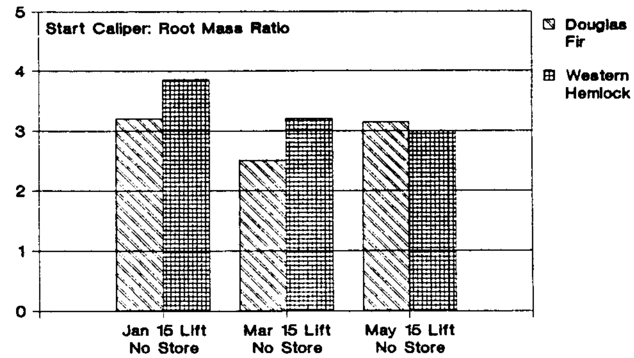

Figure 2.--Caliper to root mass ratios for three lift dates averaged by species.

Species differences in morphology were most pronounced for the earliest lift. Western hemlock was taller, thinner, and less balanced than Douglas-fir. These differences were negligible by the last lift.

Physiology At Lift and During Storage

Root growth capacity (index of root growth) was high for both hot (30/25 C, D/N) and cool (22/18 C, D/N) tests over all species and lift/store regimes. The cool test tended to have higher values and a slightly narrower range than the hot test (Figure 3). In both tests, western hemlock had higher RGCs than Douglas-fir for most lift/store regimes.

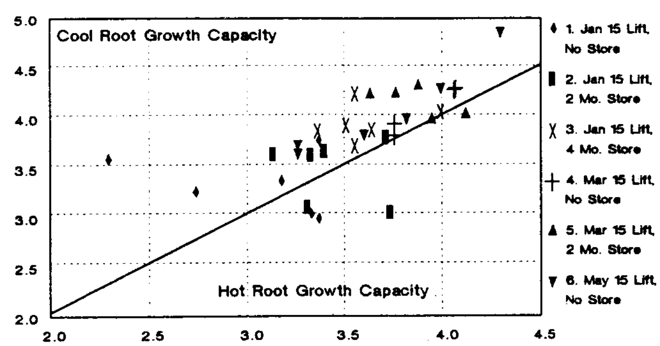

Figure 3.--Comparison of hot and cool root growth capacity test results (points are species/stocktype averages).

In assessing the progression of RGC over lift dates, Douglas-fir tended to increase RGC to March 15 and then decrease slightly to May 15. This was most pronounced in the hot test. Western hemlock, on the other hand, increased RGC consistently with later lift dates. Storage duration did not have a significant negative effect on RGC in either species.

Dormancy intensity consistently weakened (index values increased) with increasing lift date (Figure 4). The impact of storage at both January 15 and March 15 was to reduce the rate of dormancy release relative to unstored stock for the same planting date. Douglas-fir had slightly more rapid dormancy release than western hemlock for both stored and unstored comparisons.

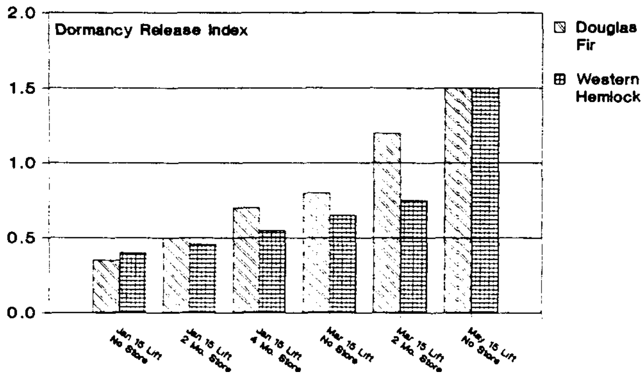

Figure 4.--Dormancy intensity averages for Douglasfir and western hemlock over the six lift/store treatments.

Frost hardiness (-18 C) weakened with later lifts. The largest difference occurred between January 15 and March 15 lifts (Figure 5). Differences between species were not pronounced or consistent. Cold storage sustained good frost hardiness. In several seedlots, the stored versus non-stored differences in foliage browning were as high as 70 to 80 percent.

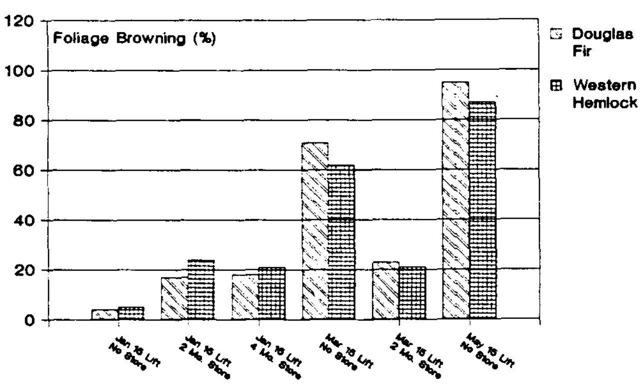

Figure 5.--Frost hardiness (foliage browning at -18 C) averages for Douglas-fir and western hemlock over the six lift/store treatments.

The conductivity test showed a more continuous pattern of change over the lift/store treatments and more consistent trends between species (Figure 6). Western hemlock was more frost tolerant than Douglas-fir with the odd exception of the last lift. From the March 15 lift to the May 15 lift, Douglas-fir showed a marked reduction and western hemlock an increase in index of injury.

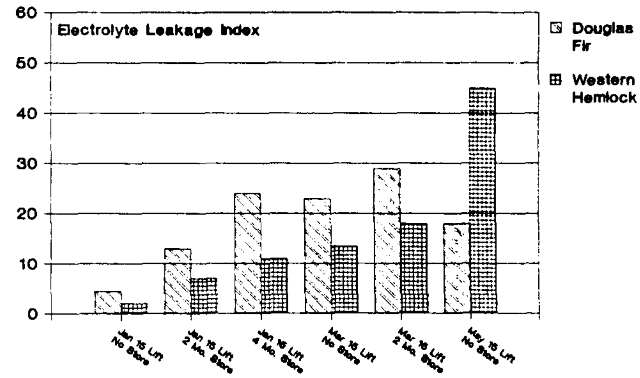

Figure 6.--Electrolyte leakage (Index of Injury) averages for Douglas-fir and western hemlock over the six lift/store treatments.

Comparison Among Physiological Tests

The physiological tests in this study each provide slightly different information about seedling function. RGC indicates the ability to initiate and elongate roots. Electrolyte leakage indicates the degree to which the foliage has been stressed or damaged from frost exposure. The foliage browning test is a qualitative measure of cellular damage resulting from exposure to frost.

The comparison of "hot" versus "cool" RGC test environments has been discussed previously. In general, the cool test raised the RGC relative to the hot test (Figure 3) suggesting that the hot environment is beyond the photosynthetic optimum (W. Binder, pers. comm.). Also, rankings changed within and among lift/store treatments, with the most pronounced changes within treatments. For the remaining discussion, the comparisons to RGC will refer to the cool test which is now the B.C. Ministry of Forests' standard.

RGC and electrolyte leakage (index of injury) exhibited a positive linear relationship with dormancy intensity (dormancy release index) over all treatments. This appears to be at odds with the hypothesis put forward by Ritchie (1985) which suggested a strong, alternate cyclic pattern in RGC and frost hardiness as dormancy intensity weakens.

In the foliage browning frost hardiness test, the relationship with dormancy intensity partitions into two distinct groups: cold-stored and nonstored (Figure 7). The cold-stored stock from either the January 15 lift or the March 15 lift all had less than 40 percent frost damage. The nonstored stock ranged up to 95 percent damage by May 15. As Ritchie (1984, 1985) has shown for bareroot Douglas-fir, the effect of cold storage in this study was to reduce the rate of dormancy release and markedly reduce the rate of loss of cold hardiness.

Electrolyte leakage does not exhibit the same tight, treatment clusters as foliage browning (Figure 8). This may be because the test integrates stress and damage as they effect cell membrane permeability and function. Subsequently, for the same level of foliage damage, we can have very different levels of electrolyte leakage within a given lift/store treatment.

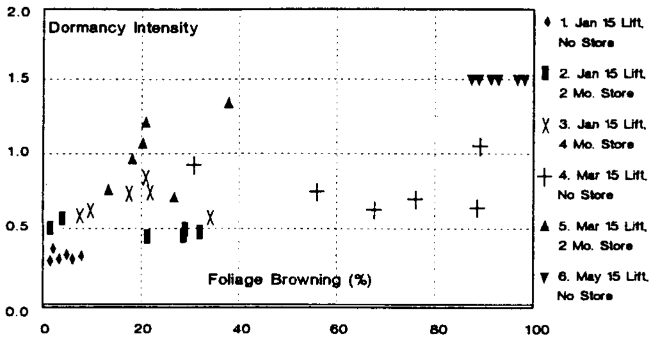

Figure 7.--Comparison of dormancy intensity and frost hardiness (foliage browning at 18 C) for Douglas-fir and western hemlock over the six lift/store treatments.

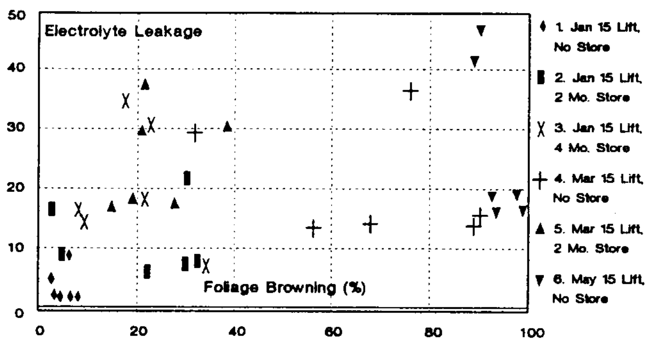

Figure 8.--Comparison of frost hardiness (foliage browning at -18 C) and electrolyte leakage (Index of Injury for Douglas-fir and western hemlock over the six lift/store treatments.

Field Performance

Survival

Survival ranged from 88 to 100 percent, indicating that all lift/store regimes resulted in stock with sufficient stress resistance to survive high seasonal root zone temperatures and persistent drought.

Growth

It should be realized that the nature of the lift/store and plant regimes is such that growing seasons may differ by as much as 120 days.

Height growth.--Relative height growth (growth/initial height) ranged from 0.35 to 0.80 (Figure 9). The trend was for later lifts to have greater height growth. Douglas-fir tended to have a narrower range than western hemlock and a much weaker tendency for later lifts to exhibit more growth. Storage appeared to have an indeterminate effect on Douglas-fir, but a marked negative effect on western hemlock.

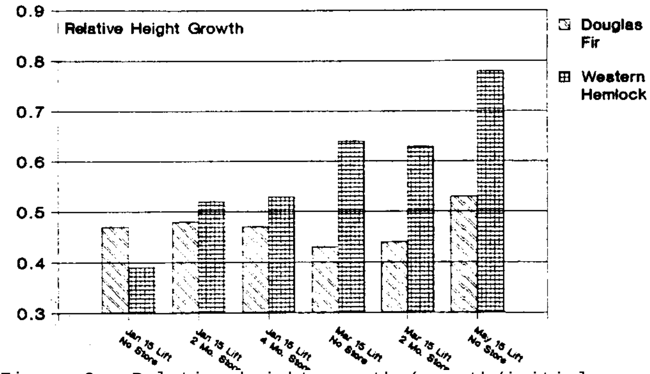

Figure 9.--Relative height growth (growth/initial height) averages for Douglas-fir and western hemlock over the six lift/store treatments.

Caliper growth--Caliper growth tended to show the reverse relationship to lift/store regimes that was evident with height growth. Early lifts had the best relative caliper growth. Stored stock had comparable or better caliper growth for March 15 or May 15 planting dates. The pattern of caliper growth over lift/store regimes tended to be more consistent between species than with height growth.

Volume growth--Relative volume growth (volume growth/initial volume) integrates height and caliper growth but with more emphasis on caliper than height. Subsequently, the pattern of volume growth over lift/store regimes mimics that of caliper growth.

Early lifts have the highest relative volume growth (Figure 10). Western hemlock and Douglas-fir tended to respond similarly to storage. Stored stock had comparable or better volume growth than non-stored stock for the same planting date. This was particularly evident for the May 15 planting date for both species where the January 15 lift with four months storage had 20 to 25 percent better relative volume growth than the March 15 lift with two months storage, and 50 to 75 percent better relative volume growth than non-stored stock.

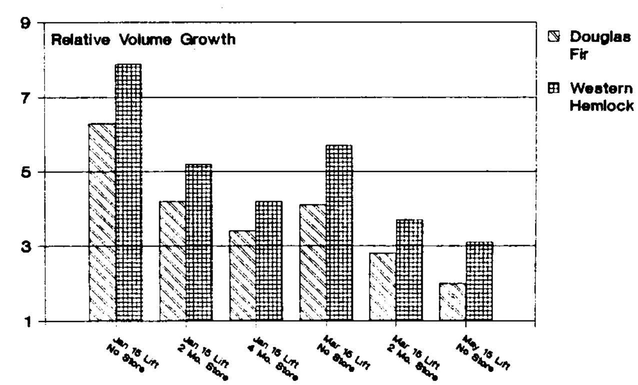

Figure 10.--Relative volume growth (growth/initial volume) averages for Douglas-fir and western hemlock over the six lift/store treatments.

These differences in height, caliper and volume growth are a function of length of growing season and of differing physiological responses to the outplanting environment. They result from changes in water relations and gas exchange which ultimately impact on photosynthesis, total biomass production, and the partitioning of biomass above and below ground.

Biomass Production and Partitioning

Total biomass growth for both species ranged from 3.5 to 5.5 g dry weight. Western hemlock tended to produce more biomass than Douglas-fir for any given lift/store combination. Storage resulted in comparable or greater biomass production for both species for either the March 15 or May 15 planting dates. Storage differences were more pronounced for Douglas-fir.

The more marked difference in biomass production came from the way in which seedlots and species partitioned their seasonal biomass above and below ground (Figure 11). The general tendency over all lift/store regimes was for biomass to be allocated more below ground with later lifts.

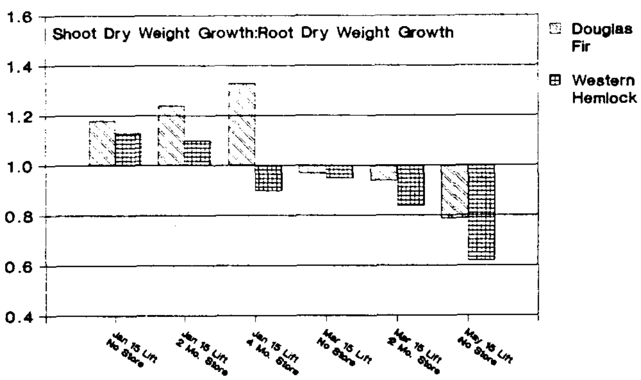

Figure 11.--Above and below ground biomass growth averages for Douglas-fir and western hemlock over the six lift/store treatments.

Storage tended to stimulate relatively more allocation to the shoot for both species in either the March 15 or May 15 planting dates. Species responded differently in the sense that western hemlock tended to be relatively more root-oriented in its partitioning than Douglas-fir for any lift/store combination. This may be a reflection of western hemlock's tendency to be a moisture stress avoider and Douglas-fir's tendency to be a moisture stress tolerator.

Western hemlock also favored the root over the shoot for the March 15, no storage and for the May 15 stored and non-stored regimes. Douglas-fir had root dominant partitioning for the March and May 15 lifts, no storage, and the March 15 lift with two months storage. The strongest shoot partitioning for Douglas-fir was for the January 15 lift, four months storage; for western hemlock, it was for the January 15 lift, no storage.

The most marked example of the differences in biomass partitioning between species was the latest planting date where, with stock stored for four months, Douglas-fir allocated about 58 percent and western hemlock about 48 percent of their total biomass growth above ground. Non-stored Douglas-fir and western hemlock, for the same planting date, allocated approximately 45 and 38 percent respectively of their biomass growth above ground.

The combination of total biomass production and allocation strategies for species and lift/ store regimes correspond well with both relative volume growth and changes evident in dormancy intensity, and frost hardiness with lift/store combinations. It appears that maintenance of a relatively high level of dormancy and frost hardiness may lead to less need for damage repair following outplanting, and more in-phase development of root and shoot over the growing season.

Seedlings able to put out roots during the first part of the growing season likely experience reduced seasonal moisture stress. Higher stress resistance, less stressful post-plant conditions, and a longer growing season, led to greater total biomass growth and a larger proportion of that biomass allocated to the shoot. This resulted in shorter, fatter seedlings than those which began the season with a heavier stress load, lower stress resistance, rapid budburst, and relatively little root production.

PREDICTION OF VOLUME GROWTH

Relative volume growth was significantly correlated with dormancy intensity (r^2=0.628) (Figure 12). RGC, electrolyte leakage, and foliage browning were less well correlated (r^2= 0.375, 0.358 and 0.269 respectively). Relative volume growth tended to decrease as dormancy intensity decreased, as electrolyte leakage and foliage browning increased, and as RGC increased.

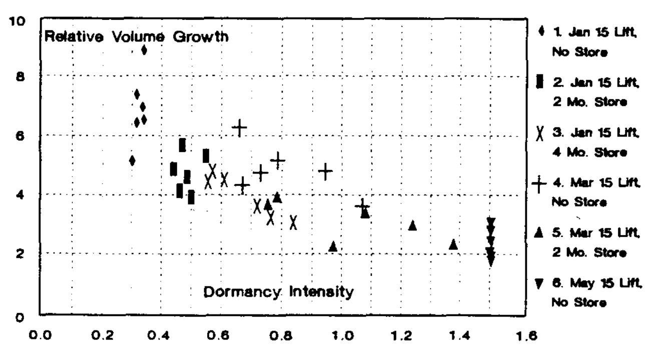

Figure 12.--Relationship between relative volume growth and dormancy intensity for Douglas-fir and western hemlock over the six lift/store treatments (points are species/stocktype averages).

It is evident that maintaining dormancy intensity in the 0.3 to 0.5 range will tend to maximize relative volume growth. This type of target would infer an electrolyte leakage (-18 C) target of less than 10, a foliage browning (-18 C) target of less than 30 percent, and an RGC target of 3.0 to 3.5.

In general, for any planting dates beyond January 15, early lifts and long storage periods maximize volume growth. The optimum lift/store regimes for both species were the January 15 lift and plant, and the January 15 lift with two months storage.

Earlier planting dates optimize stress resistance with the least stressful environmental conditions following planting. Root and shoot phenology are sufficiently "in-phase" to allow the greatest degree of drought avoidance during the first growing season. Volume growth increases as more photosynthate is produced and as less of that photosynthate is allocated to the roots of to repairing cellular damage.

CONCLUSIONS AND RECOMMENDATIONS

This preliminary investigation of the impact of lift and store regimes on the field performance of containerized Douglas-fir and western hemlock has indicated the following:

1. Lift date and storage duration can significantly effect seedling growth and the pattern of biomass allocation.
2. Early planting dates have the highest volume growth.
3. Cold storage maximized volume growth for both the March 15 and May 15 planting dates for both species.
4. Cold storage delayed the release from dormancy and the loss of frost hardiness relative to non-stored seedlings.
5. The best predictors of volume growth were dormancy intensity and the frost hardiness index (electrolyte leakage).

These results suggest that the following would be reasonable practices for nursery growers and seedling consumers to follow:

1. Douglas-fir and western hemlock should be lifted prior to January 15.
2. Cold storage should be used to minimize the rate of loss of dormancy and cold hardiness.
3. Planting should be done as soon as possible after lifting.
4. Targets for defining high quality stock would be:

   - dormancy release index of 0.3-0.5
   - frost hardiness (-18 C); index of injury <10 and foliage browning <30%
   - RGC >3.0.

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