# Stock quality assessment: Still an important component of operational reforestation programs[1]

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## Introduction

As early as 1954, the need to grade seedlings for morphological and physiological quality was recognized (Wakeley 1954). Over the last 50 years, and especially during the 80's and early 90's, scientists and foresters studied ways to produce better seedlings through improved nursery culture, and developed tests to assess seedling quality. This interest in seedling quality led to numerous reviews (Sutton 1979; Chavasse 1980; Jaramillo 1980; Timmis 1980; Schmidt-Vogt 1981; Ritchie 1984; Glerum 1988; Lavender 1988; Puttonen 1989; Hawkins and Binder 1990; Johnson and Cline 1991; Omi 1991; Grossnickle and Folk 1993; and Folk and Grossnickle 1997), several publications (Duryea and Brown 1984; Duryea 1985; Rose *et. al*. 1990), as well as special issues of periodicals (*New Zealand Journal of Forestry Science*, 1980, Vol. 10, no. 1, and recently *New Forests*, 1997, Vol. 13, no. 1-3). As a result, nursery cultural practices and field-planted seedling have survival has improved. In British Columbia, average survival for container stock is greater than 80% (Bowden 1993).

The achievement of better cultural practices and high survival rates has erroneously given rise to the impression that stock quality assessment is a tool of the past.

Consequently, actual assessment has often been confined to measures of height and diameter, a root growth capacity test for functional integrity, and a frost tolerance test to monitor stock for lifting. This view has been born out of a misunderstanding of the type of information that is provided by the different aspects of stock quality assessment.

Stock quality assessment is concerned with more than the achievement of high survival (Ritchie 1984; Grossnickle *et al*. 1991). Ritchie (1984) reported that seedlings could be measured for both material and performance attributes, and Grossnickle and Folk (1993) showed how these attributes could be used to determine both field performance potential and survival potential. The two measures are related but distinct from each other. Folk and Grossnickle (1997) demonstrated that field performance potential could be measured and related to actual performance on a reforestation site by measuring performance attributes under environmental conditions that better represented reforestation site conditions. This approach was first presented by Timmis (1980), and has only recently been adopted by operational seedling quality programs (Dunsworth 1997; Folk and Grossnickle 1997; Sampson et. al. 1997;. Tanaka *et. al*. 1997)

There is still a need for stock quality programs that determine survival and field performance potential. The high cost of reforestation and poor survival on some sites has led foresters to demand some kind of quantification of survival potential and functional integrity of their stock. Despite high survival rates on most sites, foresters are demanding better growth performance from their seedling stock. This has been accentuated by changes in policy which have placed the financial and labor burden of reforestation on private timber harvesting companies. Requirements to meet a free-to-grow status in a fixed period of time, associated with penalties of reduced annual allowable cuts and limited harvesting access to lands adjacent to sites without this status, has resulted in a free-to-grow obligation that is part of the financial liability of timber companies. Consequently, forest companies want to plant stock that will help them remove this liability as soon as possible.

Field performance forecasting is also being used by producers of forest seedlings. The increase in privately run nurseries in many regions in Canada has resulted in seedling producers using the tools of stock quality assessment to improve their competitive edge by producing better quality seedlings, or stock types that are unique to their product list. The assessment of field performance potential has allowed private nurseries to compare their unique stock types to conventional stock types, and provide a list of quantifiable material and performance attributes for the client.

The following is a case study that will describe how a timber harvesting company and a nursery seedling producer in British Columbia have made use of the Stock Quality Assessment Program at BCRI (Vancouver, BC).

**A case study of stock quality assessment in an operational reforestation program**
**Program objectives**
Rustad Bros. & Co. Ltd. and Northwood Pulp and Timber Ltd., located in Prince George, British Columbia, Canada, plant approximately 10 million seedlings a year (approximately 50 to 70 major key requests), requiring a substantial investment in reforestation. Stock types included 1+0 and 2+0 frozen-stored and summer-shipped seedlings, grown in various container sizes and types, and three major conifer species (interior spruce, *Picea glauca x engelmannii*; interior Douglas-fir, *Psuedotsuga menziesii*; and lodgepole pine, *Pinus contorta*). The company foresters recognized that little information was available on the quality and readiness of their stock for planting. They wanted to have their stock assessed while in the nursery, at time of planting and shortly after planting to obtain information that would aid them in responding to potential stock problems or strengths. Such information would allow silviculturists to determine and drive actions at the nursery and in the field. The foresters wanted to integrate and calibrate seedling quality information with data collected from the field, and from the stock performance testing program, to develop standards as a historical reference for yearly comparisons, and maintain the information in a database as a component of their seedling management system. A similar approach has been utilized by the Weyerhauser Forest Company since 1985 in their seedling testing program (Tanaka *et. al*. 1997).

**Two major objectives were identified by company silviculturists:**
1) Monitor development, forecast variability, recommend shifts in nursery culture or time of

lifting, and detect potential problems during the nursery production phase.
2) Determine the functional integrity (survival potential) and performance potential under defined environmental conditions.

**Species, seed lots, and stock-types tested**

Fourteen frozen-stored, and 15 summer-ship populations (key requests) were assessed. This included three species (lodgepole pine, Douglas-fir, and interior spruce), and seven stock-types (211A, 313B, 410, 415B, 415D, 515A, and 615A) (Table 1). A selection from both the frozen-stored and summer-ship populations are used to provide examples of the type of information that can be obtained from comprehensive testing in an operational program.

**Table 1. Break-down of seedling populations tested at BCRI for stock quality, representing 7 million seedlings from the reforestation programs of Rustad Bros. & Co. Ltd. and Northwood Pulp and Timber Ltd. in Prince George, British Columia. (Pl is lodgepole pine, Fd is Douglas-fir, and Sx is interior spruce)**

| Planting time | Number of Nurseries | Species | Stock-types | Number of Seed lots | Container Formats | Number of Key Requests | Range of Population Sizes |
|---|---|---|---|---|---|---|---|
| Spring Planting/Frozen Stored | 2 | Pl, Fd, Sx | 1+0, 2+0 | 12 | 211A, 313B, 410, 415B, 415D | 14 | 100,000 to 450,000 |
| Summer Planting | 1 | Pl, Sx | 1+0, 2+0 | 9 | 410, 415B, 415D, 515A 615A | 15 | 2,000 to 778,000 |

**Assessment of variability**

Early identification of height variability allows decisions to be made on how to best lift and package stock for planting. By assessing height variability, foresters are given information that aids in decision about the fate of populations or portions thereof. For example, efforts can be concentrated on planting small stock on sites with a low risk of vegetative competition, and vice versa. Populations that are candidates for this type of decision-making are those that are highly variable (i.e., coefficient of variation >20%), bimodal in height distribution, or below target. In the example given in Figure 1, all stock met the height targets set out by company silviculturists, but the S1 population had high height variability (>20%), and height was bimodal in distribution. By identifying this variability, silviculturists had the option of dividing the S1 population into two categories (e.g., 50% of stock at 14 to 22 cm and 50% at 22.1 to 34 cm), and planting on two sites differing in degree of competing vegetation.

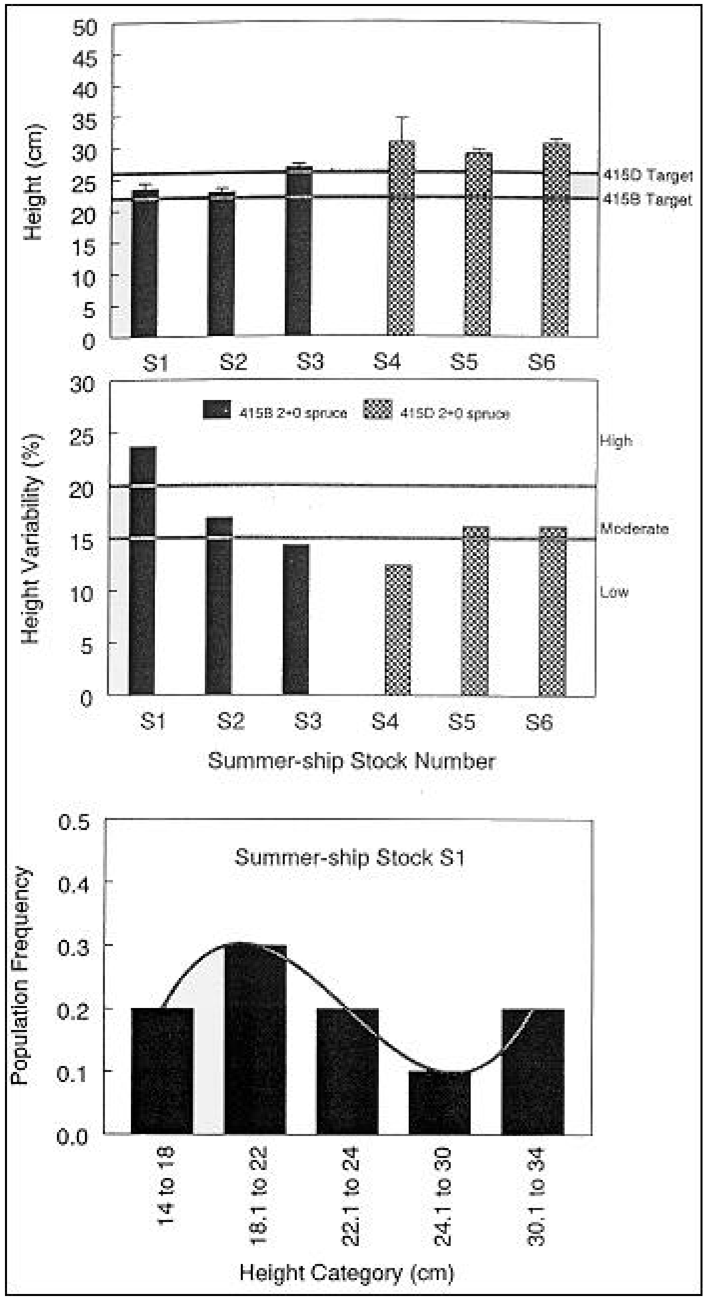


**Figure 1. Assessment of: 1) height and 2) height variability (coefficient of variation in %) of six summer-ship interior spruce seedling populations, and 3) distribution of 4-cm height classes in the S1 population at one week before the scheduled planting date.**

**Monitoring development in the nursery**

Adequate assessment of stock during the nursery phase requires the quantification of both visual observations and hidden attributes. Frozen-stored seedlings are often chosen as a stock type because they are ready for planting in the early spring and will grow in shoot height during the first year, compared to summer-ship stock which is planted after shoot growth in the nursery. Thus, it is important to determine the viability of the terminal bud in frozen-stored seedlings, and the developmental stage of terminal buds in summer-ship stock. This attribute should be assessed at the end of the storage period for frozen-stored stock, and after dormancy induction in summer ship stock.

Bud break characteristics of six frozen-stored stock types one month before the scheduled plant-date are described in Figure 2. Results indicated that only 70% of the F4 population broke their terminal bud. Reduced terminal bud viability indicated that the stock should not be planted on sites where first year height growth was important (i.e., on sites quickly invaded by competing vegetation). Loss of terminal bud viability coupled with the harsh environmental conditions of the planting site (e.g., frost), could result in first-year growth reductions. Tests can also be conducted to determine the rate of bud flush (Figure 2). Seedlings that have achieved an adequate chilling sum, either before lifting or during storage, will break bud rapidly under optimum environmental conditions (i.e., <12 days for 50% of interior spruce seedling populations). Seedlings that are slow in their bud break have been either lifted too soon for frozen-storage (i.e., not phenologically ready for lifting), or have been compromised in functional integrity.

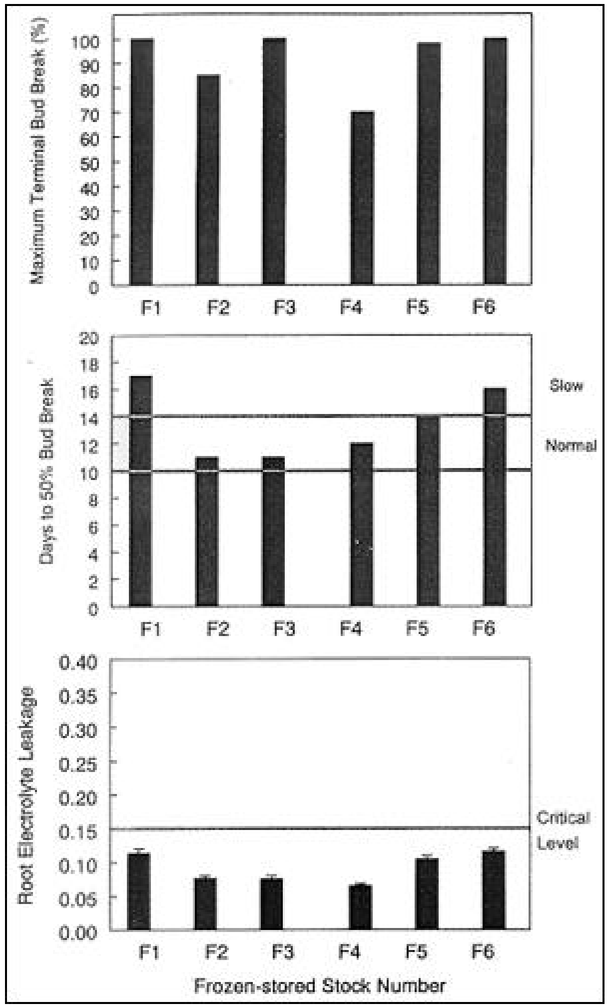

**Figure 2. Six frozen-stored stored interior spruce seedling populations one month before the scheduled planting date: 1) percent maximum terminal bud break, 2) number of days require for 50% of seedlings to break bud, and 3) root electrolyte leakage.**

Root electrolyte leakage can be measured on both frozen-stored and summer-ship stock at time of lifting. Identification of root damage in frozen-stored stock during fall lifting allows nursery personnel to avoid the cost of lifting and storage of populations, or portions thereof, that have been root damaged. Other tests for functional integrity (i.e., shoot integrity measured by photosynthetic capability, and root integrity plus overall physiological condition of the seedling measured by root growth capacity) can be conducted for similar purposes.

Measurements can also be made during storage to ensure that integrity is not reduced due to the storage environment. Testing for changes in seedling quality during lifting and storage allows both nursery personnel and foresters to monitor their seedling inventory for possible reductions in seedling quality that may require changes to their reforestation plans.

Summer-ship stock can be assessed for similar attributes, but in this case terminal bud retention is the useful attribute. Figure 3 is an example of six summer-ship stock populations measured one week before the scheduled plant-date. The S2, S4, and S5 populations had low terminal bud set, partly due to some breaking of previously set buds. As a result, at least half of each of these populations have terminal buds with less than 164 needle primordia. It was recommended that stock types in this condition be left in the nursery for further bud development before lifting, shipping and planting commenced. In contrast, population S1 had 100% bud set, 0% bud break, and more than 60% of the terminal buds had greater than 164 needle primordia developed. This stock was ready for the scheduled planting date. In contrast, planting the S2, S4, and S5 populations on their scheduled plant-date may have compromised future shoot development in the field.

During early testing, both frozen-stored and summer-ship stock can be assessed for anomalies, such as multiple leaders, crooked stems, disease, and other pests. Figure 3 provides the results of multiple leader tallies for the six summer-ship populations. Measurements indicated that 5% or more of the S4 and S5 seedlings had multiple leaders. Early detection of high levels of such anomalies allows foresters and nursery personnel to readjust anticipated seedling numbers by predicting cull rates based on attributes other than conventional height and diameter targets.

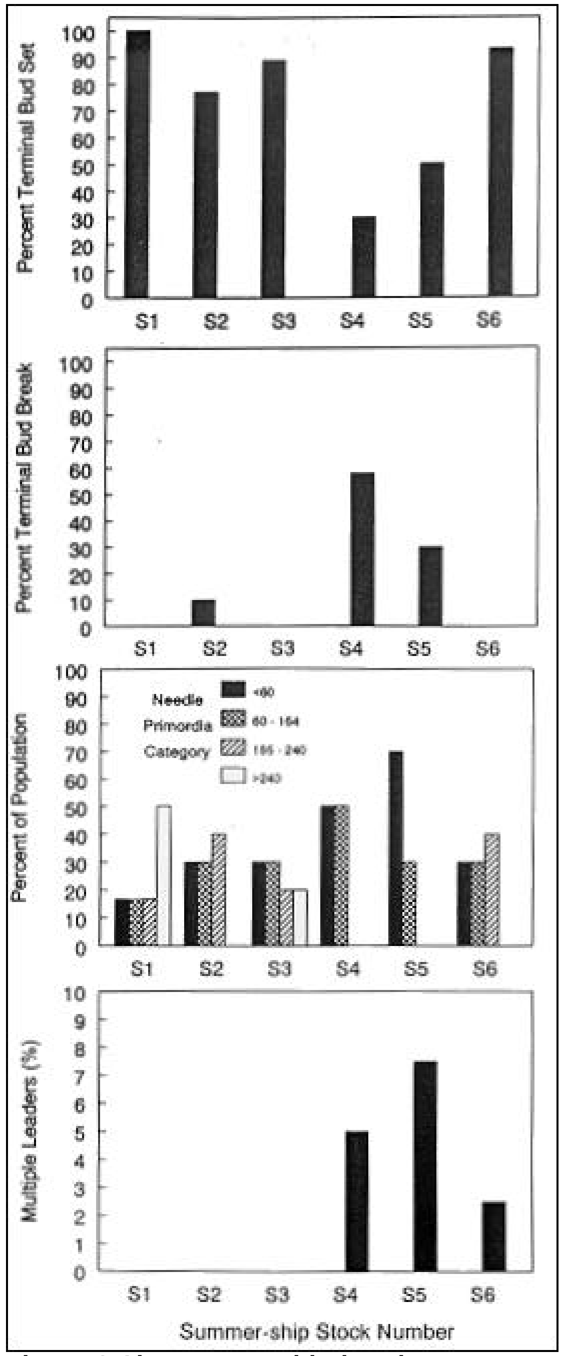


**Figure 3 Six summer-ship interior spruce populations at one week before the scheduled planting date; percent of: 1) terminal bud set, 2) terminal bud break after bud set, 3) terminal buds with i) <60, ii) 60 to 164, iii) 165 to 240, and iv) >240**

**needle primordia, and 4) seedlings with multiple leaders.**

## Forecasting optimum lift-date

Monitoring the development of seedlings is important for determining if stock will be ready for storage or planting. Determining the best time to lift seedlings for frozen-storage is important. Timing of fall lifting has been considered to be crucial for subsequent field performance of frozen-stored stock. A number of review articles have stated that seedlings can have poor field performance when the dormancy cycle has been interrupted (Ritchie and Dunlap 1980; Sutton 1990). Specific research with container interior spruce has found premature fall lifting can result in low root growth capacity and poor field performance after frozen storage (Simpson 1990). The timing of lifting is even more important for summer-ship stock. This stock is usually lifted, shipped, and planted within a three to six-week period after dormancy induction treatments that are used to stop shoot growth and initiate bud development (short-day or drought). Shortly after this treatment, stock produce a terminal bud and enter an exponential phase of needle primordia development (Figure 4). This stage is also associated with decreases in root growth capacity, slight increases in frost tolerance, dry weight fraction, and drought tolerance as seedling phenology changes. To forecast an optimum lift-date, these parameters are compared to historical trends. These trends allow an assessment of the approximate time required for stock to reach target levels of needle primordia, frost tolerance, drought tolerance, while maintaining an accept able level of root growth capacity (i.e., > 30 new roots) (Figure 4).

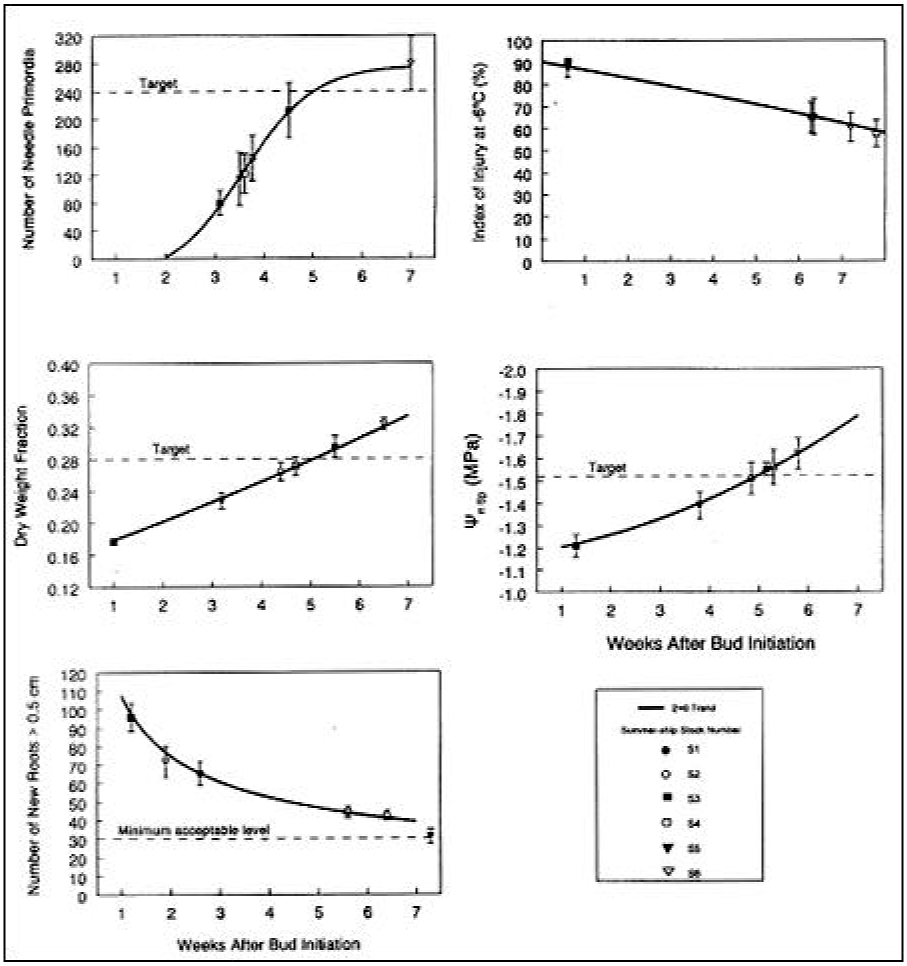


**Figure 4 Forecasting optimum lift-date for six interior spruce seedling populations two weeks before the scheduled plant date: 1) number of needle primordia, 2) dry weight fraction (shoot dry weight divided by saturated weight), 3) index of injury at -6°C (freeze-induced electrolyte leakage), 4) osmotic potential at turgor loss point (Yptlp), and 5) number of new roots >0.5cm after seven days. Lines are regression models describing the historical trend of these parameters in 2+0 interior spruce seedlings after bud initiation (short-day treatment).**

Targets are still under development, but are currently based on water relation parameters and frost tolerance levels associated with the end of the exponential phase of needle primordia development after dormancy induction. Historically, this has occurred on week 5 after bud initiation. However, the rate of development after dormancy induction may change from year to year according to annual fluctuations in the environmental conditions at the nursery. This can be assessed by comparing mean levels of needle primordia with those predicted by the historical trends. If the time of dormancy induction is known for the stock, an assessment of the rate of development can be made. Seedling populations, or portions thereof, can also set bud before scheduled dormancy induction treatments are to be applied, resulting in populations, or portions thereof, being shipped for planting after seedling dormancy is well advanced. Stock lifted too late will have low levels of root growth capacity, and field establishment capability may be reduced. In contrast, stock that is lifted too early will have low needle primordia development at time of lifting, and further development will have to occur under less than optimum conditions in the field.

In the example given in Figure 4, all populations were tested one week before their scheduled plant-date. The S1 and S9 populations are well advanced in needle primordia production, frost and drought tolerance, and cell development (i.e., dry weight fraction), and are ready for planting. In contrast, the S4 and S7 populations require at least two more weeks of development in the nursery before planting should occur.

**Assessment of survival potential**

Survival potential is a measure of seedling functional integrity (Grossnickle and Folk 1993). Seedlings in good physiological condition should survive in all but the most severe environmental conditions (Sutton 1988; Folk and Grossnickle 1997). Survival potential is determined by material attributes that measure the specific integrity of seedling systems (e.g., root electrolyte leakage (REL) for root system integrity), or by performance attributes measured under optimum conditions (e.g., root growth capacity (RGC), net photosynthesis, etc.) (Folk and Grossnickle 1997). Seedlings that are not compromised in integrity should have acceptable performance attribute levels under non-limiting conditions for their stage of phenological development (i.e., different for actively growing compared to dormant seedlings).

Information on functional integrity allows silviculturists to make effective decisions on stocking levels that will account for possible future losses from mortality. For instance, six summer-ship populations were assessed for one material attribute (root electrolyte leakage) and two performance attributes under optimum conditions to determine their functional integrity one week before their scheduled plant-date (Figure 5). Test results indicated that all six populations had acceptable mean levels of RGC (i.e., > 10 roots), and net photosynthesis (i.e., >1.5 mmol m-2 s-1), but portions of S1, S2, and S6 populations had reduced RGC, net photosynthesis, and or high REL. Twenty-three percent of the S2 population, and 13 % of the S6 population had seedlings that were below critical RGC levels. A portion of the S1 and S6 populations also had seedlings with low net photosynthesis. Information on reduced survival potential of populations, or a portion thereof, provides the forester with an option to increase stocking levels to account for a high potential rate of mortality. In the long-term, this should reduce the incidence of re-planting to improve stocking levels.

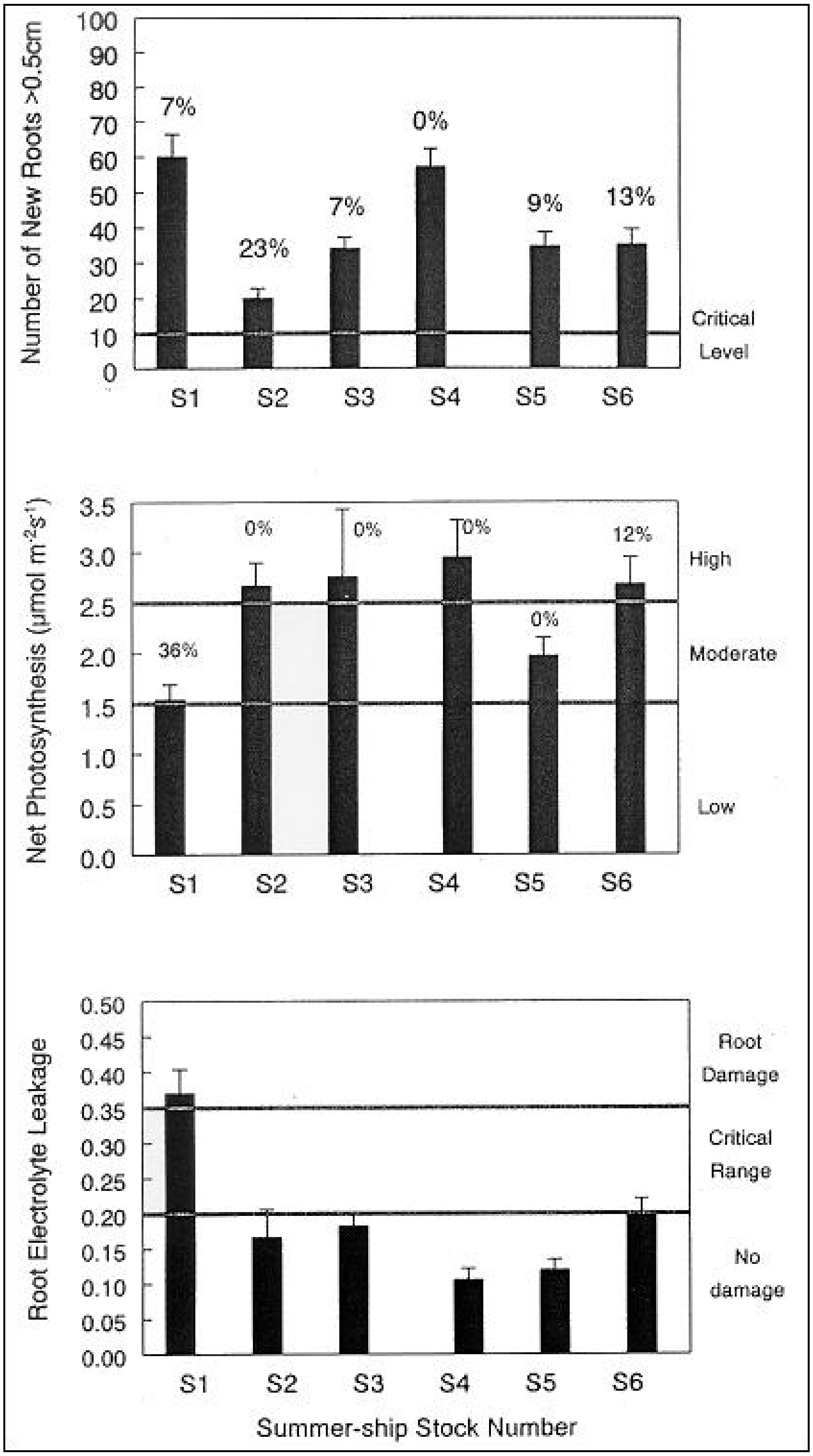


**Figure 5 Survival potential of six summer-ship interior spruce populations at time of planting: 1) number of new roots >0.5cm after seven days under optimum conditions, 2) net photosynthesis after four days under optimum conditions, and 3) root electrolyte leakage. Values above each bar indicate the percent of each population that fell below critical number of roots or moderate net photosynthesis levels.**

**Assessment of field performance potential**
Material attributes that measure stress tolerance, and performance attributes that are measured under conditions that reflect the planting site, provide information about field performance potential (Grossnickle et. al. 1991; Grossnickle and Folk 1993; Folk and Grossnickle 1997). Various standard environmental regimes can be used to represent different site conditions. For example, seedlings can be tested under low root temperature conditions for high elevation sites, or sites planted in early spring, where root temperature is low (< 10°C), or under low moisture conditions for dry sites where seedlings will undergo significant planting stress or drought.

Six frozen-stored interior spruce populations were tested under low root temperature (i.e., 10°C) and frost conditions at time of planting (Figure 6). Results indicated that three populations (F1, F5, and F6) had low RGC, and two (F1 and F6) also had low net photosynthesis under low root temperature conditions. Thus, populations F3, F4, and F5 may be better suited to cold-soil sites. However, sites with cold soils are also likely to experience frost events (e.g., northern ESSFwk subzone in British Columbia, see Farnden 1994). Tests for frost damage at -6°C indicated that all six populations had low frost tolerance (>70% index of injury) in new needles (of the elongating leader), but greater frost tolerance in old needles (developed in the previous season). Differences in the frost tolerance of old and new needles is important when frost events result in severe damage of new shoot growth. The old needles of population F5 had no measurable damage at -6°C, indicating a better ability to survive when new foliage is severely damage by frost. Planting the F5 population on the most frost-prone sites may increase the probability for survival on those

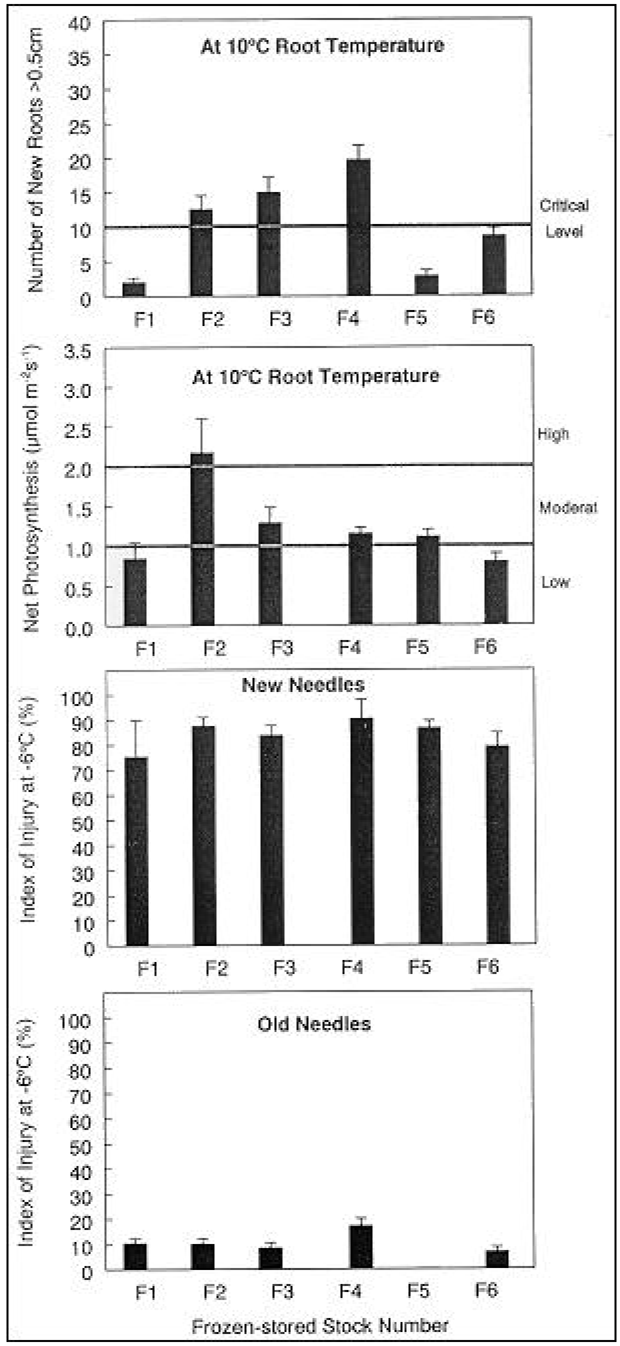


**Figure 6 Field performance potential of six frozen-stored interior spruce populations for cold sites, measured one month before planting: 1) number of new roots >0.5cm after fourteen days at 10°C root temperature, and 2) net photosynthesis after seven days at 10°C root temperature, and index of injury at -6°C for 3) new needles of the elongating leader, and 4) old needles produced the previous year in the nursery.**

sites. However, this would be done at the expense of reduced performance potential, since this population had poor root growth and low net photosynthetic capability under low root temperature conditions.

Field performance potential testing can also be conducted to determine the ability of stock to recover from planting or drought stress. For this testing, seedlings are exposed to drought until they reach -3.0 MPa mid-day shoot water potential, and re-measured for RGC and net photosynthesis under optimum conditions. Testing results of six summer-ship populations indicated that populations S3 and S6 had high RGC after drought, but RGC of S2 was below critical levels (Figure 7). Populations S1, S2, and S6 maintained high levels of net photosynthesis which were 60% or greater of optimum levels. Based on the combined results of RGC and photosynthesis, S3 and S6 appear to be the best suited populations for low-moisture sites. In contrast, the S2 population should not be planted on drought prone sites. A lower RGC for the S2 population also indicated a lower drought avoidance capability. Under continued low moisture conditions, all populations will eventually experience drought stress. For this reason it is important to also test for the ability to avoid further needle desiccation under severe drought stress. Seedlings with high cuticular transpiration will continue to loose water at greater rates after stomatal closure (severe drought stress) than seedlings with low cuticular transpiration. For the six summer-ship stock tested, S2 and S3 had highest mean levels of cuticular transpiration (Figure 7). Despite a greater ability to recovery from a brief drought stress, S3 may have the lowest ability to avoid further drought stress during a prolonged drought. On sites associated with prolonged droughts, population S1 may be more appropriate. This population had an acceptable RGC (>10 roots) and net

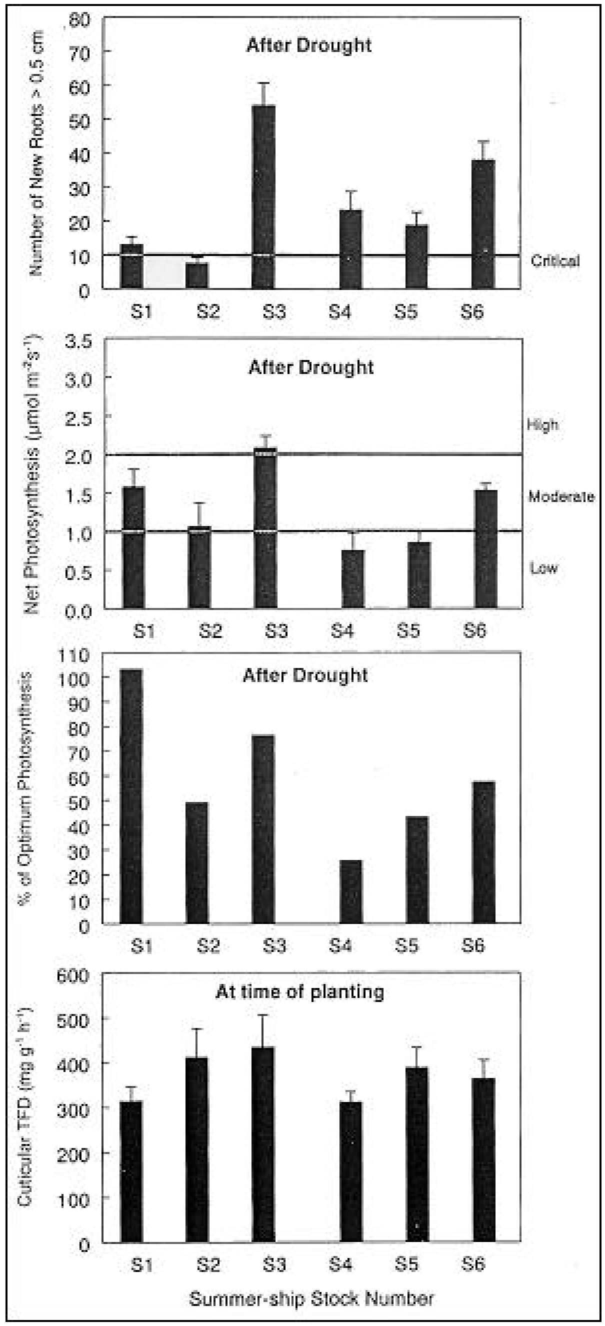


**Figure 7 Field performance potential of six summer-ship interior spruce populations, measured at time of planting and after a drought stress of -3.0 MPa mid-day shoot water potential: 1) number of new roots >0.5cm at seven days after drought stress, 2)**

photosynthesis level after drought, and a lower cuticular transpiration rate than S3.

**net photosynthesis and 3) percent of optimum levels of photosynthesis at four days after drought stress, and 4) cuticular transpiration (TFD) (mg H2O per g needle dry weight per hour) measured after turgor loss point.**

**Conclusions**

Stock quality assessment conducted for monitoring seedlings during the nursery phase, and determining survival and field performance potential, provides valuable information for decision making by both nursery personnel and reforestation silviculturists. Tests conducted to determine optimum lift-date, morphological variability, and performance for specific site conditions can result in decisions that will facilitate greater success in achieving stocking and free-to-grow standards. Costs of providing such information can be less than 3% of the total reforestation budget, and in the long-term, returns on this investment may be realized in terms of lower replanting costs and quicker elimination of free-to-grow liabilities. Stock quality assessment also provides an effective means of quantifying seedling populations for specific site conditions, and evaluates the final product with respect to the client's needs and objectives. This results in more effective communication between buyers (foresters) and producers (nurseries) of forest seedlings.

The tests described in the above case study are only an example of the many assessment procedures that can be used. Grossnickle and Folk (1993) give examples of others that are also useful. Similarly, the results of tests and their implications to nursery cultural practices and operational planting programs described in the case study are not an exhaustive discussion of all of the possible situations that can arise in reforestation programs. Each program will deal with different nursery and site conditions, resulting in different stock quality needs and problems. Stock quality assessment programs must be designed to define seedling performance with specific forest regeneration problems in mind.

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