Chapter 21
Lifting, Grading, Packaging, and Storing
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Abstract
While being lifted, tree seedlings are subject to mechanical damage. At the same time, their foliage may be inoculated with soil-borne spores of storage-mold fungi. During subsequent handling and storage, stock condition may change rapidly as a result of desiccation, molding, metabolic activity, or developmental processes. Damage to or deterioration of stock during and after harvest may be minimized through: choice of the method and date of lifting; prelift root pruning, fungicide application, and physiological conditioning; and post-lift control of stock water potential and temperature. Grading can improve stock quality either by identifying inferior seedlings or batches of stock for culling or by revealing deficiencies in quality that can be avoided in the future through changes in stock-production techniques. To be useful, grading must be in accordance with standards which reflect the stock characteristics necessary for satisfactory field performance. To improve stock quality through changes in cultural and handling practices, nursery managers must investigate the effects of alternative practices on the field-performance potential of the stock they produce.

21.1 Introduction
The quality of bareroot nursery stock depends greatly on the way it is lifted, graded, packaged, and stored. During lifting, delicate absorbing roots are easily lost, while larger roots may be stripped of bark or fractured. once out of the ground, trees can become desiccated rapidly if not protected. Grading can improve stock quality by eliminating inferior seedlings or batches of stock; but it can be detrimental if seedlings are desiccated or physically damaged in the process or if culling standards are inappropriate. During storage, stock condition can change greatly due to metabolic (e.g., respiration) and developmental (e.g., loss of bud dormancy) processes or to the action of pathogenic or saprophytic fungi. The rate of change is strongly influenced by the storage environment (e.g., temperature and relative humidity).

How, and to what extent, the quality of bareroot stock is affected by methods of handling and storage depends on the condition of trees at the time they are lifted. This, in turn, depends on the cultural regime under which stock has been raised and the time of year at which lifting occurs. Thus, to develop the best procedures for harvesting and storing bareroot stock, the following questions must be answered:

(1) What cultural regime should be used to prepare or condition stock for lifting?

(2) What is the optimum lifting date?

(3) How can mechanical damage to stock during lifting and subsequent handling be minimized?

(4) By what means and within what ranges should the temperature and water potential of lifted stock be maintained?

(5) What criteria should be used for grading stock?

(6) How can molding of stored stock be prevented?

This chapter discusses each of these questions [see chapter 15 and chapters 23 and 24 for detailed treatment of questions (1) and (5), respectively]. Variation in treatment effect on stock quality due to differences in species, seed source, and nursery environment is too great, however, to allow specific recommendations on many points. Here, the emphasis will be on general principles and the kind of nursery trials needed to develop optimum procedures for particular circumstances.

In Duryea. Mary L., and Thomas D. Landis (eds.). 1984. Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr W. Junk Publishers. The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University. Corvallis. 386 p.

21.2 Preparing Stock for Lifting

21.2.1 Physiological conditioning

The ability of stock to withstand transplanting and storage varies seasonally, and this has led to the belief that stock should be dormant when lifted. Aside from the vagueness of the term **dormant** in this context (see 21.3.3.1), this is a misleading proposition. Bareroot stock can be transplanted successfully at almost any time of year, provided that conditions at the planting site are favorable. It can also be stored, at least briefly, at almost any time of year. Thus, it is by no means essential that stock be "dormant" when lifted.

Nevertheless, it is true that stock is best able to withstand transplanting and storage when it is adapted to winter conditions. Furthermore, cultural treatments applied during the summer or fall which promote the adaptation of stock to winter conditions tend to increase the success with which stock can be transplanted and stored. For example, moisture- or nutrient-stress treatments which increase frost hardiness or induce bud dormancy have been observed to improve the ability of stock to withstand transplanting and storage [2, 10].

It is far from clear, however, why winter-adapted stock is best able to withstand transplanting and storage. Many seedling characteristics change both seasonally and in response to cultural treatments which condition stock for lifting. Care must be taken, therefore, to avoid unjustified assumptions about the causal connection between readiness for lifting and particular seedling characteristics such as frost hardiness or bud dormancy.

Until more is known about the physiology underlying the ability of stock to withstand transplanting and storage, the approach to conditioning stock for lifting must remain largely empirical. Knowing the way in which cultural treatments affect seedling physiology may indicate their value as conditioning treatments. But the only conclusive evidence of the value of a conditioning regime is a demonstration that, for a particular species raised at a particular nursery, it does improve stock quality. For a detailed discussion of conditioning treatments, see chapter 15, this volume.

21.2.2 Undercutting and lateral root pruning

Tree seedlings must have a compact root system if they are to be planted properly. This means that the root system of field-grown seedlings should be pruned. Though roots can be pruned after stock has been lifted (table pruning; see 21.8), it is advantageous to prune before lifting: this may not only modify seedling morphology and physiology in a beneficial way (see chapter 15, this volume) but also reduce the amount of stretching and stripping of roots that occurs during lifting.

Root pruning in the nursery bed may be restricted to undercutting. Drill-sown stock is often root-pruned laterally, however, by passing tractor-mounted knives (colters) through the soil between the drill rows. By preventing intermeshing of roots of trees in adjacent rows, this type of pruning reduces the extent of root stripping that occurs when lifted seedlings are separated from one another.

Two-way root pruning of grid-spaced seedlings entirely prevents intermeshing of roots of adjacent trees [8]. This technique, sometimes referred to as box pruning, is still only experimental, however.

21.2.3 Fungicide treatment

Stock that is to be stored for any length of time is prone to damage by mold. The extent of molding depends on a number of factors including the length and duration of storage, the physiological condition of the stock, and the degree to which the stock has been inoculated with spores of mold fungi such as *Botrytis cinerea* and *Rhizoctonia solani*. It may be possible to reduce mold damage by treating stock with a fungicide immediately before lifting (see chapter 19, this volume). Benomyl is reported to be effective against many of the soil-borne pathogens responsible for molding on bareroot stock [18].

21.3 Choosing a Lifting Date

If cold-storage facilities are not available, the nursery manager has little discretion in choosing a lifting date. Trees must be lifted when conditions at the planting site favor plantation establishment. Stock must be adapted to site conditions, but this should be ensured by adjusting the cultural regime (i.e., conditioning; see chapter 15, this volume) rather than by waiting for seasonal changes in stock condition. Otherwise, the optimum planting date will be missed.

if, however, cold-storage facilities are available, then lifting date is an important independent variable affecting stock quality because cold storage modifies the normal pattern of seasonal changes in stock physiology. For example, if stock is placed in cold storage in late winter or early spring, budbreak and the loss of cold hardiness are delayed [29]. The seasonal decline in root-growth capacity may also be delayed [25]. Depending on circumstances, such effects can greatly enhance the ability of stock to survive and grow when planted. Deteriorative changes in stock condition may also occur during cold storage (see 21.5), however, and the nature and extent of these are influenced by lifting date. Often, therefore, the optimum date for lifting stock is not readily apparent. Alternative approaches to estimating optimum lifting date are considered in the following paragraphs.

21.3.1 Past experience

One way of estimating optimum lifting date is the purely empirical. Stock is lifted on different dates and stored until the normal planting season. Its condition is then assessed by field testing or other means of predicting field performance (e.g., root-growth capacity testing).

Studies by Stone and Jenkinson [25] and Jenkinson and Nelson [19] with Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco) raised at nurseries in California illustrate both the benefits and limitations of this approach. They show that, in the case of stock for late winter or spring planting, root-growth capacity is highest (at the time of planting) if lifting occurs considerably before the planting date. They also indicate, however, that the optimum time of year for lifting stock (i.e., lifting window) varies with provenance and nursery and from one year to another. It also can be expected to vary according to the cultural regime used to condition the stock for lifting.

Thus, if the past is to be of use as a guide to when stock should be lifted, experience must be gained over several years for each combination of seed source, cultural regime, and nursery. This is both costly and time consuming. Moreover, because optimum lifting date varies from year to year, it can never be predicted by the calendar with complete certainty. Nevertheless, nursery managers should not abandon past experience as a basis for choosing lifting dates until the superiority of an alternative guide has been demonstrated under the particular circumstances of their own nursery.

21.3.2 Prelift chilling

Seasonal changes in the ability of stock to withstand transplanting and storage seem due, at least in part, to seasonal changes in temperature [22]. Thus, it may be possible to obtain a good indication of the optimum date for lifting stock by monitoring temperature in the nursery.

Support for this idea was gained by Stone and Jenkinson [25] in a study with Douglas-fir in California. They found that stock for late winter or early spring planting had the highest root-growth capacity (at the time of planting) if lifted after 1,500 to 1,800 hours of exposure to temperatures below 10°C (after August I). They also found that, in one nursery, the date by which 1,500 hours of chilling occurred varied by 2 months during a 3-year period. This seems to demonstrate the superiority of prelift chilling over the calendar as a guide to the optimum date for lifting stock that is to be cold stored.

However, the relationship between prelift chilling and prestorage stock quality cannot be assumed the same for all species or even for all provenances of a single species. It can be expected to vary with cultural regime and may vary from one nursery to another.

Furthermore, the value of prelift chilling as an estimator of optimum lifting date will depend on how it is measured. As suggested by our observations in nurseries in interior British Columbia, the best index of chilling may not be the same for all species. We found that, in Douglas-fir that was fall lifted and cold stored until spring, root-growth capacity was more closely related to prelift chilling below a threshold of 10°C than of 5°C. In lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and white spruce [*Picea glauca* (Moench) Voss], however, prelift chilling below 5°C seemed a better estimator of post-storage root-growth capacity than chilling below 10°C (Table 1).

Table 1. Relationship between the root-growth capacity and prelift chilling of fall-lifted, cold-stored stock in three species of 2+0 stock. The trees were lifted on five dates from September 12 to November 6 and stored at -2°C until May 15. The coefficient of determination (r^2) is for the best-fit regression line. Because different formulas were used to fit curves to the different sets of data, r^2 values followed by different letters are not strictly comparable.

Hours after August 1 below:	r^2		
	Douglas-fir	Lodgepole pine	White spruce
10°C	0.86a	0.52b	0.58a
5°C	0.77a	0.74b	0.71a

Methods of measuring prelift chilling which might prove superior to summation of hours when nursery air temperature is below a threshold include summation of hours when: air temperature is within a certain range (e.g., 0 to 10°C); when soil temperature is either below a threshold or within a certain range; and when both air and soil temperatures fall within specified bounds (used successfully in eastern Canada to estimate readiness for lifting in several conifers [24]).

Thus, before prelift chilling can be adopted as a guide to the optimum date for lifting stock, calibration data must be obtained for each nursery, species, cultural regime, and, even perhaps, seed source. At the same time, different methods of measuring prelift chilling must be evaluated.

But even with adequate calibration data, prelift chilling may not always provide a reliable indication of readiness for lifting—it has been shown that a warm period can negate the effect of earlier chilling [26]. Possibly, the effects of alternating warm and cool weather can be integrated in some way. But this remains to be demonstrated.

21.3.3 Seedling physiology

The effect of lifting date on post-storage stock quality must reflect seasonal changes in seedling physiology (see chapters 14 and 23 for more information on seedling physiology and quality assessment). The nature of the relevant changes is unknown. Nevertheless, if the causal variable or one of its close correlates were identified, it would be possible to measure directly whether stock is in a condition to be lifted and stored. A number of the physiological attributes of tree seedlings are known to vary seasonally, and a relationship between certain of these changes and readiness for lifting has been demonstrated or assumed.

21.3.3.1 Dormancy

It is commonly asserted that the ability of tree seedlings to withstand transplanting and storage depends on their dormancy [e.g., 11, 17]. The meaning of this is obscure, however, because the meaning of dormancy in this context is quite unclear. In the broadest sense, dormancy is a state of growth inactivity in the absence of environmental constraints to growth. Dormancy, therefore, pertains only to meristematic tissue and not to the whole plant. Tree seedlings have three meristematic zones: the shoot apex, the root apex, and the vascular cambium. Growth potential in these tissues is not normally correlated. The maximum degree of bud dormancy occurs during fall, when root dormancy (if defined as the inverse of root-growth capacity) may be at a minimum [25]. In the vascular cambium, rest, or dormancy, may not occur at all [33].

Whether a close relationship exists between some phase of bud dormancy and readiness for lifting is a possibility worth examining. As yet, however, no evidence of such a relationship has been reported in the literature. Moreover, if it does exist, its practical significance is questionable because a quick method of measuring bud dormancy remains to be developed. The possibility of a relationship between root dormancy and readiness for lifting is discussed in the following section.

21.3.3.2 Root-growth capacity

In a study with Douglas-fir in California, Stone and Jenkinson [25] found that the root-growth capacity of fresh-lifted stock increased during fall, reached a peak in late fall or early winter, and then declined to a low level by late winter. Paralleling these changes were changes in the ability of stock to maintain its root-growth capacity during 3 months of storage. Stock lifted early in the fall underwent a sharp decline in root-growth capacity during storage, whereas stock lifted later on—just before the root-growth capacity of the fresh-lifted stock reached its peak-maintained or increased its root-growth capacity during storage. As lifting date was delayed further, the ability of stock to maintain its root-growth capacity during storage declined.

We did not find a similar relationship between storability and root-growth capacity at lifting in Douglas-fir, white spruce, or lodgepole pine raised at nurseries in interior British Columbia. In all cases, the root-growth capacity of fresh-lifted stock was relatively constant throughout the fall, although storability, as measured by the ability of stock to maintain root-growth capacity during 6 months of cold storage, increased sharply from early September until freeze-up in early November (Fig. 1). Evidently, the value of root-growth capacity as a guide to the storability of tree seedlings is limited.

21.3.3.3 Frost hardiness

In an experiment with white spruce and lodgepole pine, we observed a close relationship between frost hardiness at lifting and the ability of 2+0 seedlings to maintain their root-growth capacity during storage (Fig. 2). The method we used for measuring frost hardiness took too long (4 weeks) to provide a signal as to when stock should be lifted. There are, however, a number of quick tests for estimating frost hardiness (see chapter 23, this volume) which may be suitable for this purpose. For example, measuring stem electrical impedance provides a rapid means of estimating relative frost hardiness; the closest correlation between stem impedance and seedling frost hardiness is observed when impedance is measured after trees have been subjected to overnight freezing at a standard temperature [30].

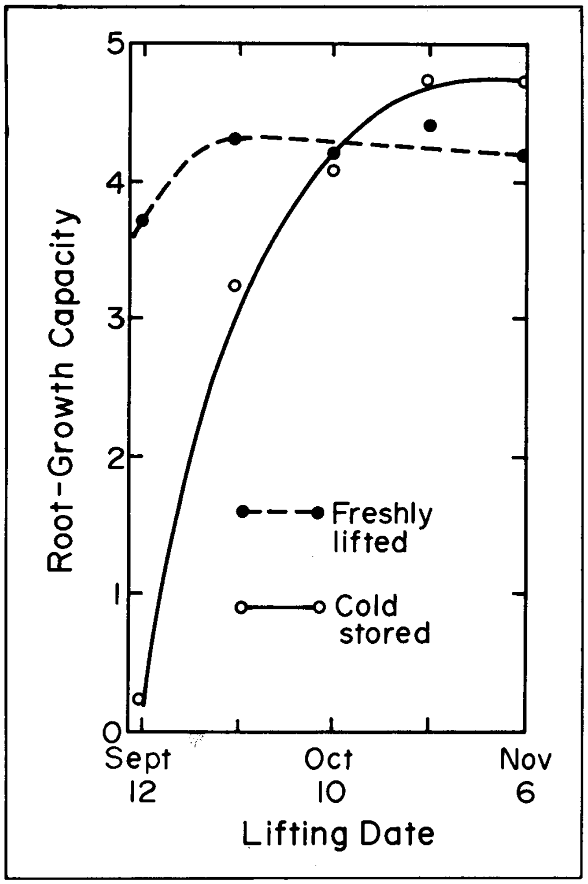

Figure 1. Effect of lifting date on the root-growth capacity of 2+0 bareroot lodgepole pine before and after 6 months of storage at -2°C. Root-growth capacity was measured with a 1-week test, described by Burdett [5], In which the scale for measuring root growth was: 0 = no new roots; 1 = no new roots > 1 cm long; 2 = 1 to 3 new roots > 1 cm; 3 = 4 to 10 new roots > 1 cm; 4 = 11 to 30 new roots > 1 cm; -5 = > 30 new roots > 1 cm.

A high correlation between the stem impedance of freshly lifted stock measured after overnight freezing at - 10°C and post-storage survival has been observed in Douglas-fir [32]. Working with 2 + 0 Douglas-fir, lodgepole pine, and white spruce, we observed a close correlation between stem impedance of freshly lifted seedlings measured after overnight freezing and the ability of the stock to maintain its root-growth capacity during 6 months of cold storage. Apparently, therefore, frost hardiness and its correlates (e.g., stem impedance) have promise as estimators of readiness for lifting. However, these estimators should not be implemented until calibration data have been gathered. Ideally, the data should indicate the consistency of the relationship between frost hardiness at lifting and post-storage stock quality from year to year, from nursery to nursery, and with different species, provenances, and cultural regimes.

21.3.3.4 Electrical wave-form modification

An electrical square-wave signal applied to the stem of a tree seedling is modified in various ways depending on the seedling's condition. It has been suggested that this wave-form modification (oscilloscope technique) may indicate whether stock is ready to lift. This hypothesis seems to have been refuted, however, by Askren and Hermann [1], who found no consistent relationship between wave-form modification of freshly lifted Douglas-fir seedlings and their ability to survive when planted after cold storage.

21.3.4 Weather and soil conditions

Weather and soil conditions must also be taken into account when choosing a lifting date. If stock is not watered after lifting, its ability to survive and grow when planted may be related to its water potential at the time of lifting [13]. The best time to lift stock, therefore, is when plant moisture stress is low. This occurs early in the morning, or-when the weather is cool and humid. These conditions also favor lifting because they minimize the potentially harmful rise in plant moisture stress during field handling.

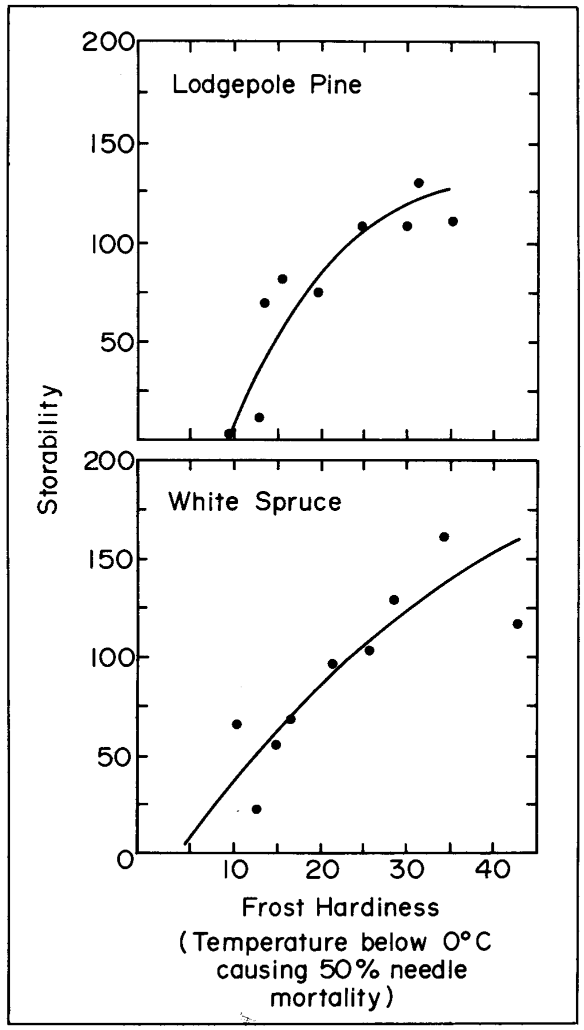

Figure 2. Relationship between storability (estimated by root-growth capacity after 6 months of storage at -2°C as a percentage of root-growth capacity at lifting) and frost hardiness in 2+0 bareroot lodgepole pine and white spruce. Test for measuring root-growth capacity and scale for scoring root growth are described in Figure 1 caption. Frost hardiness of trees was estimated by subjecting samples of stock to one of a range of subfreezing temperatures and observing the temperature causing 50% needle mortality after 4 weeks in a warm greenhouse.

To reduce mechanical damage, lifting should be restricted to occasions when the ground is not frozen. If soil is even lightly crusted with frost, severe root damage is likely during lifting. Lifting when the soil is wet, and therefore relatively heavy, should also be avoided. Another reason for not lifting when the soil is wet is to keep foliage clean and, hence, uncontaminated with soil-borne fungal spores.

21.4 Lifting

21.4.1 Minimizing mechanical damage

To minimize mechanical damage during lifting, roots can be pruned before lifting (see 21.2.2). Damage can also be controlled through the choice of lifting method. To select the best method for the prevailing conditions, trials are necessary. The degree of damage resulting from each method can be assessed visually (e.g., according to the number of stripped or broken roots). Physical symptoms of injury are not necessarily well correlated with functional damage, however. Thus, it is essential to assess effects on the functional integrity of the stock as indicated by, for example, its root-growth capacity or survival and growth after planting.

The importance of lifting method as a determinant of stock quality was demonstrated in experiments with 2+0 lodgepole pine at a government nursery in British Columbia. In eight trials, the root-growth capacity of stock lifted with an Egdal machine was consistently higher than that of stock lifted with a Grayco machine (Table 2) [unpubl. data, 4]. Survival tests on 1+0 Douglas-fir lifted with four types of machines at another British Columbia government nursery also indicated appreciable impacts of lifting machines on seedling quality [pers. commun., 3]. (Table 3). Methods of operating lifting machines also affect stock quality. Testing is, therefore, a prerequisite to developing satisfactory lifting procedures. Even if stock is hand lifted, care is essential if serious root damage is to be avoided.

Table 2. Effect of lifting method on the root-growth capacity of freshly lifted 2+0 bareroot lodgepole pine. Root-growth capacity was estimated with a semiquantitative 1-week test described by Burdett [5]. The difference between treatment means was statistically significant at the 1% level [4].

Date of trial	Root-growth capacity as % hand-lifted stock[1]	
	Grayco	Egdal
September 14	61	78
September 20	65	134
October 5	68	99
October 5	78	92
October 26	72	93
October 26	86	103
November 7	79	100
November 7	85	92
Mean	74 (± 9)	99 (± 16)

[1]To eliminate bias due to between-plot differences in stock quality, the root-growth capacity of the machine-lifted stock is shown as a percentage of that of a sample of trees carefully lifted from the same plot by hand immediately before machine lifting took place.

Table 3. Survival of 1+0 bareroot Douglas-fir seedlings lifted with four machines at Surrey Nursery, in British Columbia, and planted in 50-tree plots established In the nursery at the time stock was shipped [pers. commun., 3].

Lifting machine	Number of seedlots lifted	Mean 1st-year mortality, %
Löve	3	0.7
Egdal	147	1.1
Fobro	32	6.3
Grayco	5	11.2

21.4.2 Minimizing desiccation

Desiccation of stock during lifting can be reduced in several ways. These include: protecting lifted stock from direct exposure to the sun (e.g., with a canopy over the lifting machine); reducing to a minimum the time required to transfer lifted stock into field containers; misting stock in the field immediately after lifting; and limiting lifting operations to times when the evapotranspiration rate is low (see 21.3.4).

21.5 Presort Storage

Once stock has been lifted, its condition can change rapidly as a result of desiccation, molding, metabolic activity (e.g., respiration), or developmental processes (e.g., bud flushing) (see also chapter 22, this volume). Of these, the last three are highly temperature dependent. Although there are certain exceptions (e.g., loss of bud dormancy in fall-lifted stock stored for spring planting [31]), most changes in stock condition resulting from these processes are deleterious. Success in minimizing the deterioration of stored stock depends primarily, therefore, on controlling plant water potential and temperature.

21.5.1 Controlling water potential

Tree seedling roots, especially the fine roots [12], can become desiccated rapidly when exposed to air. Lifted stock should, therefore, be placed in field containers as soon as possible. Containers must be covered to prevent moisture loss. Damp burlap, canvas, or felt is often used for this purpose. An advantage of this method of covering is that it results in some evaporative cooling. A disadvantage is that the covering material may dry quickly and thus require constant rewetting. For this reason, it may be better to use a field container with a tight-fitting lid (e.g., as commonly used with waxed cardboard or plastic tote boxes) or a polyethylene liner. Some moisture may be lost even from containers with lids, in which case trees should also be covered with damp burlap or some other moisture-holding material.

Sometimes it is necessary to lift trees which have relatively low water potential (i.e., below - 10 bars). Daniels [13] found that this reduced survival and growth in Douglas-fir planted after 55 days of cold storage. He found, however, that adverse effects of low water potential at lifting were eliminated by spraying the trees with water immediately after lifting. This is consistent with, though not necessarily explained by, Hopkins' report [18] that molding in stored bareroot Douglas-fir is reduced by dipping the stock in water before placing it in storage.

Adding water to stock that is to be stored may not always be beneficial, however. According to Eliason [15], excess moisture promotes molding of cold-stored white spruce. Moreover, several studies have shown no relationship between moisture potential and field performance of cold-stored Douglas-fir [16, 32]. Clearly, more information about the relationship between planting-stock water potential and field performance is essential.

In practice, many nurseries in the Northwest do water lifted stock. Sometimes, plants are-watered according to need, as judged from plant water potential measured with the "pressure bomb." This appears to be a sound approach, but plant moisture-stress levels do not remain constant in lifted stock even if the stock is protected from desiccation. Experiments with Douglas-fir have shown that the water potential of stock in field containers can rise, without the addition of water, from - 10 to - 1 bars within 3 days of lifting, the rate of increase depending on storage conditions [pers. commun., 14]. Evidently, if water potential is to be monitored, the time of measurement in relation to both time of lifting and post-lift storage conditions must be standardized.

The distribution of moisture within the containers of stored stock also must be considered. Unless stock is frozen, metabolic heat production will create a temperature gradient from the middle of the container to the container wall. Convection in the container will take warm, moisture-laden air from within the mass of trees to the container wall, where the moisture will condense [6]. Through this process, stock at the center of the container may become dehydrated. To minimize this effect, the temperature gradient across a container of stock must be kept small. Means of doing this include refrigeration (to reduce metabolic heat production) and use of small containers.

21.5.2 Controlling temperature

in sunny weather, solar heating of tree seedlings in field containers can be rapid. Field containers should, therefore, be placed in the shade as soon as they have been filled. The length of time during which stock can withstand storage at temperatures much above 0°C varies with stock condition. As a general rule, however, trees should not be stored without refrigeration for more than a few hours.

If an exception to this rule is contemplated, the consequences should be evaluated experimentally. There is no adequate theoretical basis for predicting how a particular species, raised at a particular nursery and lifted at a particular time of year, will be affected by a period of warm storage. Any attempt to provide general guidelines would simply be misleading.

Even when stock is held without refrigeration only briefly (up to 24 hours), care should be taken to keep it cool. In large containers (e.g., field bins), metabolic heating can occur rapidly. This may be controlled through evaporative cooling of the ambient air (e.g., with a mist system) or, even more effectively, by watering the trees thoroughly (i.e., hydrocooling).

Once stock is placed under refrigeration, it should cool quickly to storage temperature. Temperature within containers should be monitored and appropriate action taken when necessary to hasten cooling.

A number of factors influence the rate at which stock cools. One is rate of air circulation around containers. For good air circulation; the containers must be adequately spaced. If gravity convection is relied upon for air movement, wider spacing is required than for forced air movement.

Container size has a major influence on the rate at which stock cools. The upper limit to the size of a cubical container in which stock will cool rapidly from 20°C or less to an ambient temperature of 0°C (i.e., to within 1 or 2°C of ambient in 48 hours) is approximately 1 m^3 [6]. The limit will vary considerably, however, depending on factors such as thermal conductivity of the container wall, metabolic activity of the stock, and density with which the stock is packed.

The density of packing affects not only the amount of heat to be removed, but also the freedom of air movement within the container. Convection is important in transferring heat from the contents of the container to the container wall. Its effectiveness is enhanced by the movement of moisture, with the circulating air, from the warm trees to the cool container wall (see 21.5.1). This results in evaporative cooling of trees without moisture loss from the container [6]. Condensation of moisture on the container wall transfers to the container wall the heat lost by the trees.

Stock is usually stored for only a short time before sorting. To freeze stock and thaw it again, without exposing it to extremes of temperature, can take many days. Consequently, stock is not normally frozen during presort storage. The risk of stock deterioration during storage increases with temperature, however. The optimum temperature for holding stock before sorting is, therefore, no higher than is necessary to prevent freezing. With a well-designed and properly loaded cooler, stock can be held below 1 °C without risk of freezing it.

21.6 Grading

Grading is intended to improve stock quality either by identifying inferior stock for culling or by revealing deficiencies in quality to be avoided in the future through changes in stock-production techniques. Tree seedlings can be graded individually, according to certain morphological standards, or batch graded in accordance with tests and measurements on only a sample of each batch of stock. Batch grading permits the use of both destructive and relatively expensive (compared with visual grading) evaluation techniques, including tests for physiological as well as morphological characteristics (see chapter 23, this volume).

21.6.1 Grading standards

Ideally, a grading (stock quality) standard should specify the type of stock able to perform satisfactorily under conditions of normal use. In reality, stock standards are often somewhat arbitrary. They may be based on little more than the knowledge of what a nursery has produced in the past, or they may originate in very questionable assumptions about the relationship between stock characteristics and plantation performance.

Great benefit can be gained from applying recently acquired knowledge about the physiology of plantation establishment to the definition of stock-quality standards. Physiological characteristics to which particular attention should be paid include root-growth capacity, drought and frost hardiness, and bud dormancy [27]. Important morphological and anatomical characteristics include stem unit number in resting buds [28], height:diameter ratio [9], foliage anatomy (e.g., whether sun- or shade-adapted), and root form [7].

21.6.2 Single-tree grading

Traditionally, stock is graded by hand according to a visual assessment of characteristics such as height, stem diameter, root and shoot form, root and bud damage, frost, or desiccation injury (i.e., foliage discoloration). Trees may be graded in the field as soon as they have been lifted. Usually, however, unsorted stock is moved in containers to a sorting building, where it is distributed to graders either in field containers or from field containers by way of a moving belt. Most often, a moving belt is used to take the graded stock from the sorters to a packing station. The period during which trees are exposed while being graded is usually brief (less than 2 minutes). Sorting sheds are kept cool, and a high humidity is sometimes maintained by watering the floor.

The cost of single-tree grading is high in terms both of labor and of trees discarded on the basis of morphological characteristics that may have only a tenuous relationship with field performance. In the future, the cost of single-tree grading may be reduced by using labor-saving grading machinery [23]. More desirable, however, is the development of cultural techniques which make possible the production of stock of such uniform quality that the need for single-tree grading is eliminated [27].

21.6.3 Batch grading

Batch grading serves two purposes. One is to identify inferior batches of stock for culling. The other is to obtain information about the seedlings currently produced as a basis for directing research and development to improve the quality of future nursery stock.

At present, batch culling is not widely practiced. Its potential is illustrated, however, by a program in British Columbia government nurseries to grade stock according to its root-growth capacity. On one occasion, many batches of bareroot lodgepole pine, totaling several million trees, were discarded because of their low root-growth capacity. A small quantity of the culled stock was trial planted. First-season survival was only 2% [pers. commun., 20].

21.7 Bundling

Graded stock is often tied in counted bundles. This makes it easier to inventory the stock and to measure planter productivity. Various materials are used for tying bundles, including jute, masking tape, and elastic bands. Plastic stretch film is probably best, however, because it is least likely to cause stem abrasion.

Because bundling costs money and may damage seedlings, other methods of quantity control may be preferable. For example, seedling numbers can be estimated by weight, the number of trees per unit weight being determined by sampling. Alternatively, seedlings can be counted directly into shipping cartons. If the shipping carton is designed to be carried by the planter, planter productivity is easily monitored.

21.8 Table Root Pruning

Lateral root pruning of drill-sown stock only severs roots growing more or less perpendicular to the drills. Roots growing parallel to the drills cannot be pruned until stock has been lifted (table pruning). Stock is table-pruned at most Northwest nurseries to make trees easier to plant. Roots are trimmed with a variety of saws and other cutting tools, usually to a length of 20 to 25 cm, after trees have been bundled. The customer may specify a different length, however. A longer root system may be needed for auger planting on dry sites and a shorter one needed for planting in shallow soils.

21.9 Packaging and Post-Sort Storage

The principles that apply to the storage of unsorted stock (see 21.5) apply equally to the storage of sorted stock. Trees must be protected from desiccation, and they must be kept cool.

21.9.1 Packaging and moisture retention

The simplest way of protecting stock from desiccation is to package it in bags or cartons with a vapor barrier. One such container is the multiwall kraft/polyethylene bag. Another is a cardboard carton with a polyethylene liner. These are the most commonly used containers for storing and shipping tree seedlings. Such containers limit gas exchange by the stock (although polyethylene is permeable to some gases, including carbon dioxide); however, there is no evidence that this has harmful consequences (see review by Hocking and Nyland [17]).

If, for some reason, stock must be packaged in unsealed cartons, bales, or crates, it can be protected from moisture loss by the maintenance of a high ambient humidity (> 98%) or packaged with a water-saturated material such as peat moss or wood shavings. Cedar shavings should be avoided, however, because they release compounds that are toxic to seedlings [21].

21.9.2 Packaging and temperature control

The largest container in which seedlings will cool rapidly to ambient air temperature is around 1 m^3 (see 21.5.2). Most storage and shipping containers are an order of magnitude smaller than this and so allow rapid equilibration between seedling temperature and that of the ambient air. Controlling stock temperature may be difficult, however, if storage containers are placed tightly together. Containers are usually stored on pallets with provision for good air circulation around the pallets. Nevertheless, warm spots may occur within the stack of containers on a pallet unless there is room for air movement (i.e., 2 to 5 cm) between the containers.

21.9.3 Storage duration and temperature

Storage duration—not an independent variable—is determined by the interval between the optimum lifting date and the optimum planting date (see 21.3).

The most favorable storage temperature appears to be either just above or just below 0°C [17]. Frozen storage prevents molding [17]. But if molding does not occur, the performance of stock held just above 0°C may be as good as or superior to that of frozen stock [31]; this may be because, at temperatures below 0°C, respiration is too slow for adequate cellular maintenance.

While stock is frozen or thawed, a temperature gradient must be maintained from the edge to the center of the storage container. The gradient should be no more than 1 or 2° C, otherwise seedlings near the edge of the container will be subjected to unacceptably low (during freezing) or high (during thawing) temperatures. Thus, while stock is thawed or frozen, the ambient air temperature should be no more than 1 or 2°C above or below freezing, respectively. Under these conditions, freezing or thawing will take days or even weeks. Care must be taken, therefore, to allow adequate time to thaw frozen stock before it is needed for planting.

21.10 Conclusions

The opportunities for damage to stock while it is being lifted, graded, packaged, and stored are numerous. Many causes of stock damage can be guarded against by applying elementary physical and biological principles. Much remains to be learned, however, about the relationship between nursery cultural regimes and stock handling practices, on the one hand, and plantation performance, on the other. Nursery managers must strive, therefore, to determine how alternative handling and storage treatments affect the field-performance potential of the stock they produce. This will often require nursery-specific trials because, in its combination of soil, climate, species and provenances grown, cultural regimes, and handling practices, every bareroot nursery is unique.

References

1. Askren, C. A., and R. K. Hermann. 1979. Is the oscilloscope technique suitable for predicting survival of planting stock? Tree Planters' Notes 72:7-11.
2. Blake, J., J. Zaerr, and S. Hee. 1979. Controlled moisture stress to improve cold hardiness and morphology of Douglas-fir seedlings. Forest Sci. 2 5:576-582.
3. Brazier, A. L. 1982. Personal communication, B. C. Ministry of Forests, Victoria.
4. Burdett, A. N. 1978. Unpublished data, B. C. Ministry of Forests, Victoria.
5. Burdett, A. N. 1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine stock quality. Can. J. Forest Res. 9:63-67.
6. Burdett, A. N. 1981. Bin storage of unsorted bare root stock. Page 18 *in* Research review 1980-81. B. C. Ministry of Forests, Victoria.
7. Burdett, A. N., D. G. Simpson, and C. F. Thompson. 1983. Root development and plantation establishment success. Plant and Soil 71:103-110.
8. Chavasse, C. G. R. 1978. The root form and stability of planted trees, with special reference to nursery and establishment practice. Pages 54-62 *in* Proc., Symp. on root form of planted trees (E. Van Eerden and J. M. Kinghom, eds.). B. C. Ministry of Forests/Can. Forestry Serv., Victoria. Joint Rep. 8.
9. Chavasse, C. G. R. 1981. Planting stock quality: a review of factors affecting performance. New Zealand J. Forestry 25:144-171.

10. Cheung, K. 1973. Induction of dormancy in container-grown western hemlock [*Tsuga heterophylla* (Raf.) Sarg.]. B. C. Forest Serv., Victoria. Res. Note 59. 5 p.
11. Cleary, B. D. 1978. Seedlings. Pages 63-97 in Regenerating Oregon's forests (B. D. Cleary, R. D. Greaves, and R. K. Hermann, eds.). Oregon State Univ. Ext. Serv., Corvallis.
12. Coutts. M. P. 1981. Effects of root or shoot exposure before planting on the water relations, growth, and survival of Sitka spruce. Can. J. Forest Res. l I :703-709.
13. Daniels, T. G. 1978. The effects of winter plant moisture stress on survival and growth of 2+0 Douglas-fir seedlings. M.S. thesis, Oregon State Univ., Corvallis. 86 p.
14. Darbyshire. R. 1982. Personal communication, School of Forestry, Oregon State Univ., Corvallis.
15. Eliason, E. J. 1962. Damage in overwinter storage checked by reduced moisture. Tree Planters' Notes 55:5-7.
16. Hermann, R. K., D. P. Lavender, and J. B. Zaerr. 1972. Lifting and storing western conifer seedlings. Oregon State Univ., Forest Res. Lab.. Corvallis. Unpubl. rep. 8 p.
17. Hocking. D., and R. D. Nyland. 1971. Cold storage of coniferous seedlings. Applied Forestry Res. Institute, New York State Univ., Coll. Environ. Sci. and Forestry, Syracuse. Rep. 6. 70 p.
18. Hopkins, J. C. 1980. Storage molds. Page 58 *in* Proc., Western forestry conf. Western Forestry and Conservation Assoc., Portland, Oregon.
19. Jenkinson, J. L., and J. A. Nelson. 1978. Seed source lifting windows for Douglas-fir in the Humboldt nursery. Pages B-75-B-77 *in* Proc., Western Forest Nursery Council and Intermountain Nurserymen's Assoc., Eureka, California, Aug. 7-11.
20. Kooistra, C. M. 1978. Personal communication, B. C. Ministry of Forests, Victoria.
21. Kreuger, K. W. 1963. Compounds leached from western red cedar shingle tow found toxic to Douglas-fir seedlings. U.S.D.A. Forest Serv., Pacific NW Forest and Range Exp. Sta., Portland, Oregon. Res. Note PNW-7.
22. Lavender, D. P., and P. F. Wareing. 1972. Effects of daylength and chilling on the responses of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] seedlings to root damage and storage. New Phytologist 71:1055-1067.
23. Lawyer, J. N. 1981. Mechanization of nursery production of bare root deciduous planting stock. Pages 30-37 *in* Proc., Symp. on engineering systems for forest regeneration. American Society of Agric. Engineers, St. Joseph, Michigan.
24. Mullin, R. E., and R. E. Hutchinson. 1978. Fall lifting dates, overwinter storage, and white pine seedling performance. Forestry Chronicle 54:261-264.
25. Stone, E. C., and J. L. lenkinsom 1971. Physiological grading of ponderosa pine nursery stock. J. Forestry 679:31-33.
26. Stone, E. C., and E. A. Norberg. 1979. Root growth capacity: one key to bare-root seedling survival. California Agric. (May): 14-15.
27. Sutton, R. F. 1979. Planting stock quality and grading. Forest Ecology and Management 2:123-132.
28. Thompson, S. 1981. Shoot morphology and shoot growth potential in 1-year-old Scots pine seedlings. Can. J. Forest Res. 11:789-795.
29. van den Driessche, R. 1968. Measurement of frost hardiness in two-year-old Douglas-fir seedlings. Can. J. Plant Sci. 49:159-172.
30. van den Driessche, R. 1973. Prediction of frost hardiness in Douglas-fir seedlings by measuring electrical impedance in stems at different frequencies. Can. J. Forest Res. 3:2 56-264.
31. van den Driessche, R. 1977. Survival of coastal and interior Douglas-fir seedlings after storage at different temperatures and effectiveness of cold storage in satisfying chilling requirements. Can. J. Forest Res. 7:125-131.
32. van den Driessche, R., and K. Cheung. 1979. Relationship of stem electrical impedance and water potential of Douglas-fir seedlings to survival after cold storage. Forest Sci. 25: 507-517.
33. Worrall, J. 1971. Absence of "rest" in the cambium of Douglas-fir. Can. J. Forest Res. 1:84-89.