The Effects of Seedling Quality and Forest Site Weather on Field Survival of Ponderosa Pine

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In this study, we report field survival results of an analysis of the USDA Forest Service Reforestation Improvement Program. The field survival of 3 test plantings of ponderosa pine (*Pinus* ponderosa Laws. *var.* ponderosa) were *modeled with* regression *analysis using a modified logit transformation. The initial* predictor *variables tested included nursery seedling morphological traits such as height, diameter, and stem and root weights; several performance attributes such as root growth potential, cold hardiness, and root exposure stress tests; and days since planting of the seedlings. Forest site weather variables measured during the first growing season reduced confounding between seedling quality tests and field survival measurements. Root growth potential was consistently important as a performance attribute in explaining survival* of *three field tests of ponderosa pine. The root exposure stress test was a useful measure for predicting survival* of *seedlings planted on warm sites, and the mean initial height* of *seedlings was an important predictor for survival on warm and very dry sites.* Tree Planters' Notes 47(1):16–23; 1996.

The importance of seedling survival monitoring became widely recognized with the creation of the National Forest Management Act in 1976, which mandates that the USDA Forest Service submit an annual report to Congress on the plantation survival of seedlings. During the early 1980's, when the Forest Service was experiencing failures rates of 18% for the 270,000 acres planted annually, the Reforestation improvement Program (RIP) was created in an effort to stem the high cost of plantation mortality (USDA Forest Service 1985). The RIP relies upon the extensive use of monitoring and seedling testing in the nursery to improve the quality of bareroot seedlings, and a systematic recording of forest site weather conditions and survival in the field to make reforestation more predictable and successful (Owston and others 1990). The RIP objectives were focused on increasing knowledge of seedling biology by nursery personnel and enhancing the consistent production of high-quality stock, resulting in lower reforestation costs by avoiding the occasional need for replanting.

The program was directed at identifying whether planting success or failure was a result of seedling quality or other postshipment factors (Rietveld and others 1987). The RIP did not constitute a controlled research experiment. Despite the lack of a rigorous statistical design of RIP, the program was begun in 1986 with the intention that it would eventually provide sufficient information for correlation and regression analvsis between planting stock quality variables with field performance variables. A significant difference between the RIP effort and most seedling survival studies, was that the RIP contained both nursery and field weather stations that monitored surface and other ambient meteorological attributes of the beds or planting sites. This paper discusses how seedling quality tests and measures of forest site weather conditions can be used to determine if nursery or post-planting conditions have been the major factor in poor seedling survival.

The ease with which most seedling morphological parameters can be measured makes them the most popular method for measuring seedling quality (Thompson 1986). The morphological measurements reported in this program include: height, stem diameter, bud length, shoot weight, and root weight. Thompson (1986) notes that as the planting site becomes more arid, the optimum seedling height for survival probably decreases. Larsen and others (1986), Tuttle and others (1987), Wilder-Ayers and Tolliver (1987), and Mexal and South (1991) reported a negative correlation between seedling survival and seedling height. Mexal and Landis (1990) state that shorter stockier seedlings are preferred for arid sites and taller seedlings are superior for sites where vegetative competition or animal damage is severe. Shiver and others (1990) however, reported a strong positive relationship between loblolly pine (*Pinus taeda* L.) survival and initial seedling height on sites where the survival was less than or equal to 75% and essentially no relationship on sites where the survival exceeded 75%.

Seedling root collar diameter is generally accepted as better than height as a positively correlated morphological measure of field survival and growth (Thompson 1986, Mexal and Landis 1990). Root weight is often correlated with seedling diameter; but height, diameter, and stem weight have been found to be better predictors of field survival.

Thompson (1986) speculated that bud length could potentially be a useful indicator of field height between seed lots rather than within a lot. A longer bud length is indicative of a more vigorous seedling as it becomes dormant. Mexal and Landis (1990) disagree and state that cultural practices late in the growing season can impact bud size with no appreciable effect on seedling height.

Root growth potential (RGP) represents the ability to regenerate new roots and is closely linked to the seedling's ability to avoid water stress after planting (Duryea and McClain 1984). High RGP is often correlated with high field survival (Feret and Kreh 1985, Barden and others 1987). The best results occur if measurement is taken immediately before planting (Ritchie 1984). Mexal and South (1991) state that if either survival or RGP is uniformly high, there will likely be poor correlation between RGP and survival. Ritchie and Tanaka (1990) have provided a matrix diagram that partially justifies why on 25% of occasions there is a poor correlation between RGP and field survival. Their figure depicts the interaction of RGP with the uncontrolled factors of site and weather conditions in the field. They state that the performance of poor stock on harsh sites or good stock on good sites is predictable, whereas the performance of good stock on harsh sites or poor stock on mild sites is less so.

Ritchie (1985) proposed that RGP was a good predictor of seedling survival and growth because of RGP's correlation with cold hardiness and stress resistance. Studies reported by Burr (1990) support Ritchie's hypothesis; however, she recommended that cold hardiness be monitored at the time of lifting and that RGP be measured immediately before planting. Cold hardiness is the ability of a seedling to survive or resist injury from exposure to freezing temperatures. It is frequently expressed as the minimum temperature at which 50% of the seedlings are killed, which is expressed as lethal temperature 50 (LT_{50}) (Glerum 1985).

Root-exposure or vigor testing attempts to simulate the normal stresses encountered during planting and first year establishment by exposing the seedling to artificial stress (McCreary and Duryea 1985). Such testing has been used to predict potential rather than actual field survival, because site conditions and yearly weather patterns can confound the ability to predict field performance of lots of varying quality.

Materials and Methods

We analyzed the data of the 4 USDA Forest Service bareroot nurseries that were responsible for the production of ponderosa pine (*Pinus ponderosa* Laws. var. *ponderosa*). Each nursery tested at least 2 seed sources. Standard Forest Service practices for matching seed source to outplanted forest sites, together with nursery production methods and cultural regimes were followed (Duryea and Landis 1984). Two forest sites were selected for outplanting the test seedlings from each nursery.

Consistent with a RIP objective of training operational personnel in monitoring, the nursery staff conducted frequent tests of seedling performance attributes and morphological measurements. Nursery staff or ranger district personnel measured field performance and maintained the forest weather stations. The added and new responsibilities in scientific testing, measuring, monitoring, and reporting were accomplished with mixed success. Several of the key nursery tests such as RGP, cold hardiness, or root exposure test (heat stress test) were not consistently repeated over the 3 outplanting years. Exchanges of seedlots, conflicting survival records, dearth of regular scheduled measurements, and the downtime of forest site weather stations made the analysis of the RIP problematic. As a result, only the results of 2 of the 4 pine nurseries are reported here: 1+0 stock of the Placerville Nursery, Camino, California, and 2+0 stock of the Bend Nursery, Bend, Oregon.

Stock quality tests. For the purpose of maintaining consistency among test years and nurseries, we used the RGP, root exposure, and cold hardiness test results that were collected at the time of shipping. These tests were initiated on average 30 days and 23 days before outplanting of the Placerville and Bend nursery stocks, respectively The RGP tests were conducted by suspending 15 seedlings in mist chambers at 27 °C and 100% relative humidity and counting the mean number of new roots (Burr and others 1987, Rietveld and Tinus 1987). The seedlings were left in the mist chambers for 26 days at the Placerville nursery and 15 days at the Bend nursery before the count was made. The root exposure test (heat stress test) consisted of taking 30 seedlings, removing all moisture-holding media from the roots, blotting dry the roots, and exposing them to 30 minutes of forced air at 30 “C. The seedlings were then potted and grown in a greenhouse for 60 days with temperatures between 15 to 27 °C and relative humidities between 40 to 80%, at which time the percentage mortality was recorded (McCreary and Duryea 1985). The root exposure test data were only partially complete for the Bend nursery.

Cold hardiness was determined by placing 2 pots with 5 seedlings each in a freezer and cooling them until a target temperature was reached, removing the pot, and after 14 days of growing the seedlings in the greenhouse **with conditions identical to the root exposure test, slicing the stem to compute the percentage dead area. The target temperatures were -5, -10, – 15, -20, and -25 “C. The** LT, was computed by interpolating between target temperatures to find a value that represented 50% mortality (Bun and others 1990). The cold hardiness test data were only partially complete for the Bend nursery. Plant moisture stress tests were conducted at the time of lifting. Lifting occurred on average 79 days before outplanting at the Placerville nursery and 24 days before outplanting at the Bend nursery. Plant moisture stress was determined by the pressure chamber technique with a sample of 10 seedlings and measured to the nearest 0.1 bar. Plant moisture test data were only partially complete for the Placerville nursery.

The morphological measurements of the test seedlok were conducted just before packaging. Seedling height was measured to the tip of the visible stem to the nearest centimeter, and diameter was measured with calipers to the nearest 0.1 mm. Dry weight was measured by removing soil and severing the seedling into 2 parts at the cotyledon scar. Dry shoot and root weights were recorded to the nearest 0.01 g. Bud length was measured to the nearest millimeter.

Planting site conditions. A planting site for each seed lot was selected that had at least a IO-acre opening with a relatively uniform in slope and aspect. Over a span of approximately 3 years, one-third of the planting area was randomly selected for planting each year. Site preparation for each planting sub-area was completed in the year before spring planting using the best local practices for the site. An automated weather station was located at the center of each planting site. Information recorded at the weather station included air temperature, wind speed and direction, relative humidity, precipitation, and solar radiation. In addition, soil moisture was monitored with gypsum blocks at the field site.

The 2 ponderosa pine seedlok grown at the Placerville nursery were outplanted during a span of 3 years (1988–90) at 2 locations on the Pacific Ranger District of the Eldorado National Forest and Weaverville Ranger District of the Shasta-Trinity National Forest, both in California. Both were considered typical good planting sites (table 1). Each year, about 400 seedlings/seedlot were outplanted at a spacing of 3 by 3 m. Only 1 seedlot was planted at each location. The planting tools (auger, hoedad, and shovel) varied from year to year, as did the contract planting crews. The seedlok planted in 1988 were monitored for 4.4 years for field survival, whereas those planted in 1990 were monitored for 2.4 years. A total of 51 observations was available for modeling survival at the Eldorado location, while 41 observations were available at Shasta-Trinity location.

The 2 ponderosa pine seedlok grown at the Bend nursery were outplanted during a span of 4 years (1988-91) at 2 locations on the Sisters Ranger District of the Deschutes National Forest, Oregon. All the seedlings outplanted in 1988 failed, so that we began the experiment again in 1989. The seedlots planted in 1989 were monitored for 4.4 years for field survival, and those planted in 1991 were monitored for 2.4 years. A forest weather station at 1 location did not function during the 1991 growing season, and after consultation with local ranger district staff, we decided to pool the seedlot and weather station information. A total of 24 observations were available for modeling survival of the pooled locations. Other attributes, such as elevation, aspect, percentage slope, habitat type, and soil type for each of the planting sites are presented in table 1.

Table 1— *Physical attributes and habitat type of forest planting sites*

	Location		
	Pacific **RD,** Eldorado **NF**, CA	Weaverville RD, Shasta-Trinty **NF**, CA	Sisters RD. Deschutes **NF**, OR
Elevation (ft)	5,000	3600	**3300, 5000**
Aspect	North	Southwest	West, flat
Slope (%)	15	35	30, 0
Habitat type	Mixed conifer	Mixed conifer	Mixed conifer
Soil type	Deep granitic loam	Forbes loam	Pacific pumy

RD = ranger district, NF = national forest, and ZIP code abbreviations for states.

The daily climatic variables that we utilized in our study were average surface temperature and average percentage relative humidity. The variables of surface temperature and wet and dry air temperature at a height of 1.5 m were scanned every 5 minutes by weather sensors and stored in an automatic data logging system. Every 60 minutes, an average surface temperature and relative humidity were calculated and recorded. We used daily values of surface temperature and relative humidity or the average of the 24-hourly values.

Results

The monitoring of forest site weather was a critical element in this study, because the Reforestation Improvement Program was not a controlled experiment, and there were only small measured morphological and physiological differences within seedlok during the 3 years of out-planting. The differences in seedling quality from year to year reflected the normal yearly variation that occurs in the weather and timing of bareroot nursery operations of Large nurseries (Burdett and Simpson 1984, Landis 1984). The inclusion of forest-site–weather-related variables in the statistical analysis was essential for reducing the unexplained variation and confounding between seedling quality and meteorological conditions on seedling survival.

Temperature extremes have considerably more influence on seedling survival than weekly or monthly averages (McCreary and Duryea 19851. We analyzed daily surface temperature and relative humidity readings for each seedlot during the first growing season (day of outplanting until September 15) because it is the most critical year in explaining survival performance. Table 2 presents, by location and year, the key weather attributes that were demonstrated by statistical analysis to influence seedling survival.

We selected the linear transformation of the logistic curve, or logit, for modeling survival. Barden and others (1987) modeled survival as a function of RGP, and found that the logit provided the best fitting linear model. Following a technique of Wonnacott and Wonnacott (19811, the modified dependent variable of the logit is

$$\ln\left[\frac{\frac{(S+1/2)}{n}}{1-\frac{(S-1/2)}{n}}\right]$$

where
S = number of surviving seedlings per plot
n = total number of seedlings planted per plot
ln = natural logarithm

The modified logit remains defined when $S=n$, and permitted us to use more field observations than if we had used the logit definition of $\ln[P/(1-P)]$, where $P = S/n$. Our estimated model for seedling survival for ponderosa pine on the Eldorado National Forest

$$\ln\left[\frac{\frac{(S+1/2)}{n}}{1-\frac{(S-1/2)}{n}}\right] =$$

$3.031 - 0.0043A + 0.000002A^2 + 0.\ .58RGP -$ 0.01127-G,,

where

A = age in days since planting
RGP = root growth potential
TG_{21} = number of days in the first growing season (from planting day until September 15) where the average daily surface temperature exceeded 21 °C

All coefficients were significant at the a=0.05 level, the number of observations n=51, and the $R^2=0.86$. In the presence of A, RGP, and TG_{21}, all other variables for this planting site including the morphological variables of height, diameter, weight, Dickson quality index*, and performance attributes such as cold hardiness and root exposure failed to enter the model with significant coefficients. We did not use the weighted least squares technique, suggested by Neter and others (1985). We were largely interested in constructing an explanatory model, and the weighting technique drastically reduced the significance of the estimated coefficients. The model may be expressed in terms of the survival proportion (P) as:

Table 2— *Forest site weather data: number of days in growing season with temperature or relative humidity extremes*

		Days from planting until September 15		
Location	Year	Ave. surface temp. ≥ 21 °C	Ave. surface temp. ≥ 30 °C	Ave. rel. humidity < 30%
Eldorado NF, CA	1988	60	0	**29**
	1989	3	**0**	**9**
	1990	0	0	28
Shasta-Trinity NF, CA	***1988***	***98***	33	77
	1989	95	4	44
	1990	78	26	36
Deschutes NF, OR	1989	16	0	6
	1990	78	7	100
	1991	82	56	155

NF = national forest

$$P = \frac{S}{n} = \frac{1}{1+e^{-x}} + \frac{1-e^{-x}}{(1+e^{-x})\,2n} \qquad (1)$$

where

X = $3.031 - 0.0043A + 0.000002A^2 + 0.158RGP -$ 0.01127-G,,

If age (A) is set to 365, and TG_{21} (the number of days in the first growing season where the average daily surface temperature exceeds 21 “Cl is set to 30, this equation predicts that survival after 1 year decreases from 94% to 90% if RGP decreases from 9 to 5. The observed range of RGP at the Placerville nursery for the Eldorado outplanting was 5 to 9 new roots/ seedling/seedlot of 15 seedlings. The functional relationship between survival and age, RGP, and TG_{21} for the Eldorado National Forest is displayed in figure 1.

Our model for seedling survival for ponderosa pine on the Shasta-Trinity National Forest may be expressed

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'Dickson quality index = $\dfrac{\textit{Total seedling dry wt (g)}}{\dfrac{\textit{Hei ht (cm)}}{\textit{Diameter (cm)}} + \dfrac{\textit{Shoot wt (g)}}{\textit{Root wt (g)}}}$

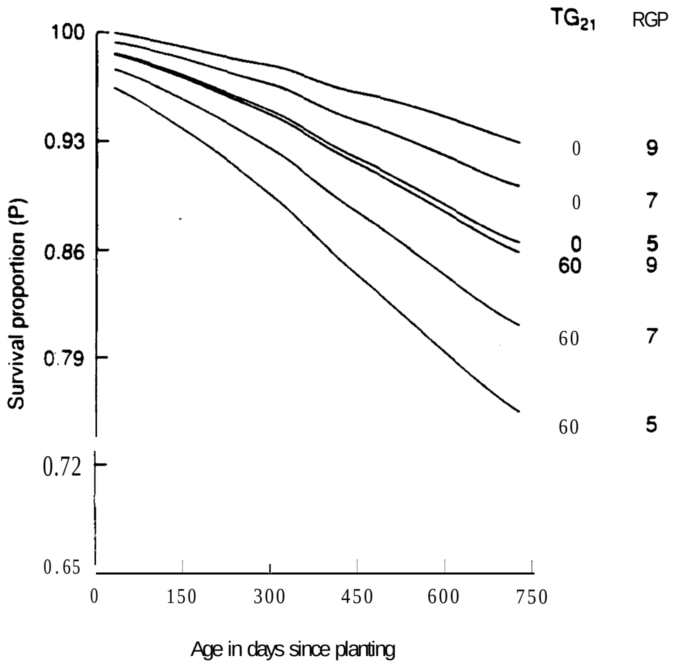

Figure 1— *Predicted survival proportion* **on the** *Eldorado National Forest. TG,, = the number* of days in the *first* ***growing season*** *when the average daily* ***surface*** *temperature exceeds 21 "C, and RGP = root growth potential.*

in terms of the survival proportion (*P*) by inserting the following value for X into equation (1):

$$X = -1.944 - 0.0035A + 0.000002A^2 + 0.824RGP - 0.02181$$

where

A = age in days since planting
RGP = root growth potential
I = interaction between the number of days in the first growing season (from planting day until September 15) where the average daily surface temperature exceeded 30 °C and the percentage mortality *from* the root exposure stress) test.

All coefficients, except for the intercept, were significant at the α=0.05 level, the number of observations n=41, and the R^2=0.85. The threshold surface temperature of 30 °C was chosen because it corresponds to the temperature used in the root exposure (heat stress) test. In the presence of *A*, *RGP*, and I, **all** other variables including the morphological variables of height, diameter, weight, Dickson quality index, the cold hardiness performance attribute and plant moisture stress failed to enter the model with significant coefficients. If age (*A*) is set to 365, and *I* (the product of the number of days in the first growing season where the average daily surface temperature exceeds 30 °C and percentage mortality of the root exposure test) is set to 20, this equation predicts that survival after 1 year decreases from 91% to 75% if *RGP* decreases from 7 to 5.5. The observed range of RGP at the Placerville nursery for the Shasta-Trinity out-planting was 5.5 to 7 new **roots/seedling/seedlot** of 15 seedlings. The observed range of percent mortality of the root exposure test at the Placerville nursery for the Shasta-Trinity outplanting was 0 to 3.5%. The functional relationship between survival and age, *RGP*, and *I* for the Shasta-Trinity National Forest is displayed in figure 2.

Our model for seedling survival for ponderosa pine on the Deschutes National Forest may be expressed in terms of the survival proportion (P) by inserting the following value for X into equation (1):

$$X = 6.883 - 0.0009A + 96.406/A - 498.706/A^2 + 2.850\ RGP/RHL_{30} - 0.3316HT$$

where

A = age in days since planting
RGP = root growth potential
RHL_{30} = number of days in the first growing season (from planting day until September 15) where the average relative humidity was below 30%
HT = average height to the tip of the stem in centimeters

All coefficients were significant at the α=0.05 level, the number of observations *n*=24, and the R^2=0.90. In the presence of *A*, *RGP*, RHL_{30}, and *HT*, **all** other variables including the morphological variables of diameter, weight, Dickson quality index, and performance attributes such as cold hardiness and root exposure stress failed to enter the model with significant coefficients. The model predicts **only** small changes in survival as a function of RGP, largely because the average observed range of RGP at the Bend Nursery was 0.8 to 3.5 new **roots/seedling/seedlot** of 15 seedlings. if age (A) is set to 365, RGP is set to 2.1, and RHL30 (the number of days in the first growing season where the average relative humidity is below 30%) is set to 120, this equation predicts that survival after 1 year decreases from 81% to 53% if HT increases from 16.4 cm to 20.3. The functional relationship between survival and age, RGP, RHL30, and seedling height for the **Deschutes** National Forest is displayed in figure 3.

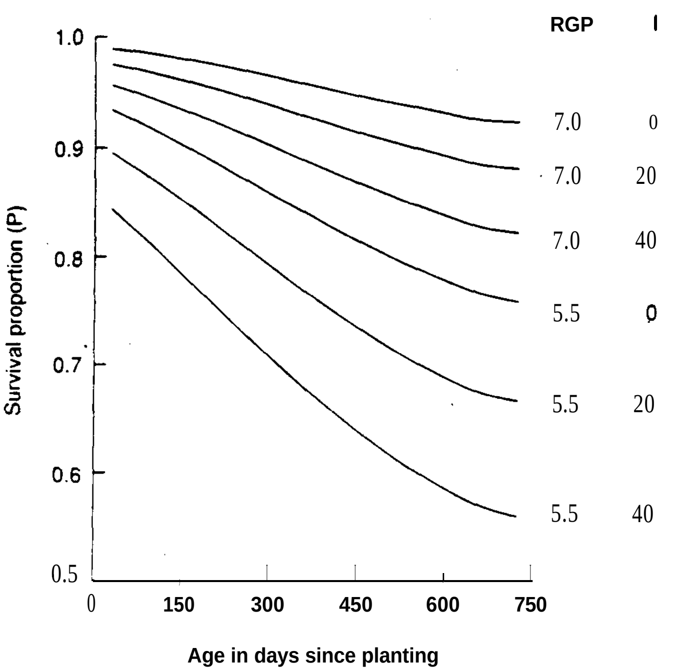

Figure 2— *Predicted survival proportion on the Shasta–Trinity National Forest. RGP = root growth potential and I = the product of* the number of *days* in *the first growing season when the average daily surface temperature exceeds 30 °C and the percentage mortality from the root exposure test.*

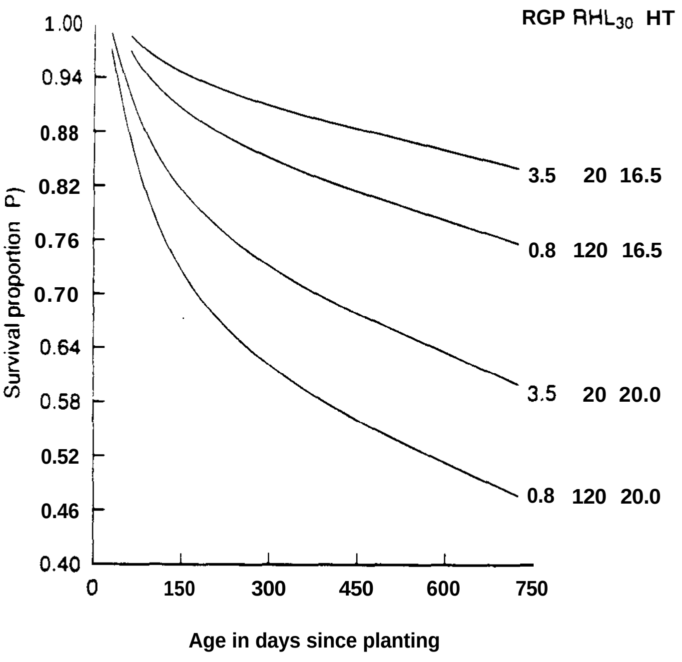

Figure 3— *Predicted survival proportion on the Deschutes National Forest. RGP = root growth potential, RHL_{30} = the number of days in the first growing season where the average relative humidity is below 30%, and HT = the average height to the tip of the stem in centimeters.*

Discussion

Ritchie *(1984)* states that the final test of a forest tree seedling is its performance after outplanting. It is widely acknowledged, however, that it is often difficult to assess the effect of seedling quality on field survival, given changes in yearly weather patterns. The RIP and the installation of forest site weather stations at the field sites overcomes this limitation. Given the lack of a designed experiment and the very small differences of morphological and performance attributes within seedlots from year to year of operational nurseries, the inclusion of weather variables in a survival model is imperative. Not only do weather variables reduce the confounding in the analysis data, but certain extremes, such as number of days where the average surface temperature exceeds 30 °C, or the number of days when the relative humidity is less than 30%, assist in indicating which performance test is useful in explaining field survival.

The results of the RIP are consistent with previous studies and reaffirm that several morphological and performance tests have site specific importance. The RIP analysis indicates the root exposure (heat stress) tes can be important for monitoring seedling quality on warm forest sites. For those forest sites that are warm and very dry, results indicate the average height of seedlings can be a critical morphological attribute. Although average daily surface temperature is a key weather attribute for monitoring on warm sites, relative humidity appears to be a critical meteorological variable for warm and very dry sites. In all 3 test sites, the root growth potential test was effective in predicting field survival of seedlings. The results also suggest that the cost and time involved in the routine testing of all morphological and performance tests may be unnecessary. Considerable savings in data collection and evaluation of the tests can be achieved by customizing site specific testing procedures.

When confronted with a plethora of morphological measurements, performance tests, meteorological variables, in addition to seedling age, it seems quite natural to first screen the variables in a survival model using a statistical stepwise regression technique. This approach can lead to some misleading results, if a forest site weather variable is not included in the model immediately following the inclusion of the independent variable of age or transformations of age. In the case of the Eldorado and Shasta-Trinity test sites, stepwise regression analysis included bud length as a predictor variable in either the first or first 3 steps, to the exclusion of any forest site weather variable or performance test attribute. The stepwise models predicted however, that field survival decreased as bud length (measured at the time of nursery lifting) increased. By ignoring the step wise results, and including a forest site weather variable in the survival model, we were able to obtain a logical survival model with goodness of fit statistics that equaled or **exceeded** the results provided by the stepwise regression analysis. The results of this study may be considered as the first step in providing better accountability toward identifying whether planting failure is a result of seedling quality or uncontrolable weather factors.

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