DEVELOPMENT OF INTERIM OAK ASSESSMENT GUIDELINES FOR THE SILVAH DECISION-SUPPORT SYSTEM

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Abstract—Updates to the SILVAH decision-support system make it more applicable to the mixed oak forests of Pennsylvania and other mid-Atlantic states. This update required establishing interim inventory guidelines for assessing the competitive ability of advance oak regeneration. This assessment was complicated by oak's growth strategy, emphasizing root development in lieu of stem development. Regression analysis of an oak height growth data set from the Piedmont region of Virginia was used to compare stem height, basal diameter, and root collar diameter over 3 years in shelterwood stands. If the oak stems were not top-killed, then there was no difference in the coefficients of determination among the three variables. Conversely, when the stems were top-killed, root collar diameter explained much more of the subsequent height growth than either basal diameter or stem height because many small oak stems produced tall vigorous sprouts. Examination of these sprouts revealed that they had large root systems and shared certain characteristics such as number of stems, number of full-sized leaves, and stem height. These findings indicate that root collar diameter should be examined when assessing oak regeneration in previously disturbed stands and should provide guidance as to what stem characteristics indicate small oak stems with large root systems.

INTRODUCTION

SILVAH is a quantitative and systematic approach to forest management developed following decades of research by personnel of the USDA Forest Service's Forestry Sciences Laboratory in northwestern Pennsylvania (Marquis and others 1992). SILVAH is geared primarily for the cherry-maple and northern hardwood stands of the Allegheny Plateau region and it has a documented record of prescribing appropriate treatments for these forest types in that part of Pennsylvania. SILVAH's oak component was less well developed and in late 1999, the Pennsylvania Bureau of Forestry (PA-BoF) encouraged the lab to remedy that deficiency.

In January 2000, representatives of the PA-BoF, USDA Forest Service's Northeastern Research Station and Allegheny National Forest, The Pennsylvania State University's School of Forest Resources, forest industry, and forest consulting firms met for 3 days in State College, PA to begin improving SILVAH's oak component. The meeting had three purposes: (1) to organize existing oak management knowledge into SILVAH's decision-making framework; (2) to develop interim guidelines for inventory procedures; and (3) to identify and prioritize knowledge gaps for future research. One of the first knowledge gaps encountered was how to identify competitive oak regeneration, i.e., a stem ready to compete for a dominant or co-dominant crown position in a regenerating stand.

Existing guidelines from the Ozarks use stem height to identify competitive oak reproduction. Ivan Sander and others (1976) determined that oak stems > 4.5 feet tall were the only ones large enough to reliably capture dominant or strong co-dominant crown positions after harvesting of the existing stand. The 4.5-foot stem height threshold fit well into SILVAH's "stocked plot" concept and prescriptive framework but the committee members felt, based on their collective experience, that it was too tall for most Pennsylvania oak forests so a 3-foot threshold was adopted as an interim height guideline.

There were three concerns regarding the use of oak regeneration guidelines developed elsewhere. The primary concern was the adequacy of stem height alone to indicate the competitiveness of oak regeneration given the fact that oak seedlings and seedling sprouts emphasize root development more

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than stem growth (Kelty 1989; Kolb and others 1990; Miller and others 2004). The concern over root development meant that assessing oak regeneration with stem height might be misleading because small oaks may actually have large enough root systems to compete following a harvest. This is especially true if the oak stem is broken during the harvesting operation resulting in a new, vigorously growing sprout or if prescribed fire is used during the regeneration process (Brose and others 1999a, 1999b).

Another concern was the dissimilarities between Pennsylvania and the Ozarks in terms of site quality, major competing species, disturbance regimes, and overstory density (full sunlight versus partial shade) and their influence on seedling growth. Most Pennsylvania oak forests are better quality than those of the Ozarks. Major species competing with oak in Pennsylvania include black birch (*Betula lenta* L.) and red maple (*Acer rubrum* L.). These two species are absent or not nearly as troublesome in the Ozarks.

Pennsylvania oak forests have been and are subject to defoliation by gypsy moth (*Lymantria dispar* L.) and subsequent salvage operations while the Ozarks still lack this pest. Consequently, oak regeneration in many Pennsylvania forests develop for years in partial shade while the Ozark guidelines assume complete canopy removal for their growth and survival projections.

Reanalyzing an existing data set (Brose 1997) offered a way to address the concern about which morphological attribute would effectively assess the competitive capacity of oak regeneration. That data set contained oak height growth data collected over 3 years and allowed direct comparisons of the ability of pre-treatment stem height, basal diameter, and root collar diameter (RCD) to post-treatment growth. Basal diameter was also part of Sander's research and was used by Loftis (1990) in his probabilistic regeneration model for the southern Appalachian Mountains. Basal diameter is usually measured where the stem emerges above the leaf litter. RCD is commonly used to measure root size in oak planting operations (Stroempl 1985; Johnson and others 1986; Kennedy 1993; Spetich and others 2002). The root collar is the transition point between stem and root and is identifiable by a ring of callous tissue and dormant buds. Generally, it is found in the upper 1-inch of soil. Because of oak's emphasis on root development, basal diameter or root collar diameter may be a better measure than stem height in explaining subsequent growth.

This paper reports the findings of the data reanalysis. The initial objective was to compare the ability of basal diameter, root collar diameter, and stem height to explain the variation in oak stem growth following top-kill and sprouting. Findings from that analysis spurred a second objective: to provide guidance for determining when root collar diameter should be included in the size assessment of oak regeneration.

METHODS

Site Description

The data set was compiled from a study that took place from 1994 to 1998 in three mixed-oak shelterwood stands at the Horsepen Wildlife Management Area in central Virginia. The stands ranged from 15 to 50 acres and were similar to each other in landform, soils, species composition, and structure. All were situated on the top and upper side slopes of gently rolling hills at elevations of 500-600 feet above sea level. Soil series for all three stands was a Cecil sandy loam with an oak site index of 70 feet (base age 50). The stands originated in the late 1890s, were even-aged, and had been partially harvested about 1990, reducing basal area from 120 to 60 square feet per acre. The resultant shelterwood had about 50 percent canopy closure. The most abundant canopy species were the upland oaks [black oak (*Quercus velutina* Lam.), chestnut oak (*Q. prinus* L.), northern red oak (*Q. rubra* L.), scarlet oak (*Q. coccinea* Muenchh.), and white oak (*Q. alba* L.)]. American beech (*Fagus grandifolia* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), flowering dogwood (*Cornus florida* L.), mockernut hickory (*Carya tomentosa* (Poir.) Nutt.), pignut hickory (*C. glabra* (Mill.) Sweet), red maple, and yellow-poplar (*Liriodendron tulipifera* L.) also were present, especially in the midstory. The heavy partial cut resulted in abundant, well-distributed, advance regeneration (> 20,000 stems per acre) with all canopy species represented. Red maple and yellow-poplar regeneration were the tallest stems, generally ranging from 8 to 10 feet in height, while oak reproduction was usually between 2 and 3 feet tall. Given these conditions, the study site was quite similar to Pennsylvania oak forests so the data set also satisfies the concerns of the committee about forest dissimilarity between Pennsylvania and the region of origin of the reanalyzed data set.

Study Design and Implementation

Each of the three stands was divided into four treatments (spring, summer, and winter burns, and an unburned control). In 1994, prior to the prescribed fires, 304 oak stems representing all five upland oak species were tagged for growth and height measurements. These stems were visually judged to represent the range in height of surrounding reproduction. For each tagged stem, species, basal diameter, number of stems, number of mature leaves, root collar diameter, and stem height were recorded.

Prescribed burns were conducted in February (winter), April (spring), and August (summer) 1995 by personnel of the Virginia Department of Game and Inland Fisheries. Drip torches were used to light the prescribed fires in a strip head-fire ignition pattern. The initial strip head-fire was lit along the uphill or downwind side of the treatment block and was about 10 feet wide. Once the initial strip was burned, subsequent strips were wider and systematically ignited moving in either a downhill or upwind direction until the entire treatment block was completely burned. Fire behavior was typical for the seasons, according to the experienced fire personnel conducting the burns. Spring fires produced flame lengths of 2 to 4 feet with rates of spread ranging from 5 to 10 feet per minute. Summer and winter burns were similar to each other and exhibited 1 to 2 feet flame lengths and rates of spreads from 1 to 5 feet per minute.

Tagged stems in the control, spring burn, and winter burn treatments were measured for height growth in fall 1995, 1996, and 1997. Tagged stems in the summer burn treatment were measured for height growth in fall 1996, 1997, and 1998 because many of the stems did not initially sprout until 1996.

Statistical Analysis

Earlier analysis of sprout growth rates found no significant differences among the oak species (Brose and Van Lear 1998), so height growth data were pooled to increase sample size and then separated by treatment. Stepwise regression was used to determine which of the three variables or combinations had the most influence on third-year stem height (SAS 2002). Simple linear regression was used to evaluate the ability of the three variables to explain third-year stem height by comparing their coefficients of determination. Each of these were rated as extremely poor (r^2<0.20), poor (r^2=0.20 – 0.39), fair (r^2=0.40 – 0.59), good (r^2=0.60 – 0.80), and excellent (r^2>0.80) predictors of third-year stem height.

The initial stepwise regression analysis showed the importance of RCD in predicting third-year stem height so stepwise regression was used to determine which aboveground stem characteristics best explained RCD size. Variables used in this analysis included basal diameter, number of stems per rootstock, number of mature leaves per stem, and stem height.

To develop field criteria for judging when to examine root collars, oak stems were sorted by pre-treatment and post-treatment heights into four groups. Small oaks were < 4.5 feet before and at the end of the study. Small-large oaks were < 4.5 feet to begin with but were > 4.5 feet by the third year. Large-small oaks were > 4.5 feet at the beginning of the study but did not attain that height by the end of the third growing season. Large oaks exceeded 4.5 feet before and after the study. Analysis of variance with Student-Keuls mean separation test was used to determine whether there were differences in the number of stems per rootstock and number of leaves per stem among the four groups. Residuals were examined for compliance with statistical assumptions and alpha was 0.05.

RESULTS

Of the 304 tagged oak stems, 83 were dropped from the reanalysis because they failed to sprout following the fires or were never top-killed by the fires. The remaining 221 stems were evenly distributed among the five oak species with 37 to 48 stems per species and among treatments with 48 to 66 oaks per treatment.

All four of the models derived from stepwise regression analysis explained between 64 and 71 percent of the variability in early height growth of sprouting oak stems, regardless of treatment (table 1). However, the models differed profoundly in their makeup. Root collar diameter was the major explanatory variable of early height growth in all the burn treatments. In fact, it was the only variable in the spring and winter burn models and accounted for over 90 percent of the coefficient of determination in the summer burn model. In the unburned control, stem height and basal diameter were the only components of the model.

Basal diameter, root collar diameter, and stem height all provided fair coefficients of determination ranging from 0.484 to 0.533 when oaks were not top-killed (table 2). However if they were forced to sprout, basal diameter and stem height produced poor and fair coefficients of determination ranging from 0.224 to 0.460, depending on season of burn, while root collar diameter had good coefficients of determination of 0.642 to 0.676.

Stepwise regression of the aboveground stem characteristics produced a model that explained about 67 percent of the variability in root collar diameter. Of the model's components, basal diameter and stem height were the two key variables, accounting for over 90 percent of the coefficient of determination.

Table 1—Models developed from stepwise regression analysis relating the total amount of height growth (stem height at age 3 minus initial stem height) of oak reproduction over 3 years to the pretreatment morphological attributes of basal diameter (BD), stem height (SH), and root collar diameter (RCD)

Treatment	n	Model	r^2
Control	66	Growth = 0.126 + 2.051(BD) + 0.342(SH)	0.664
Spring burn	55	Growth = 0.177 + 1.919(RCD)	0.642
Summer burn 1	48	Growth = 0.461 + 2.539(RCD)	0.665
Summer burn 2	48	Growth = 0.291 + 2.01(RCD) + 0.27(SH)	0.710
Winter burn	52	Growth = 0.400 + 2.089(RCD)	0.676

Table 2—Comparison of the coefficients of determination (r^2) of pre-burn basal diameter, root collar diameter, and stem height by treatment for explaining total height growth of sprouting oak stems through 3 years

Treatment	n	Basal diameter	Root collar diameter	Stem height
Control	66	0.509	0.484	0.553
Spring burn	55	0.460	0.642	0.224
Summer burn	48	0.344	0.665	0.454
Winter burn	52	0.301	0.676	0.326

Simple linear regression of these variables with root collar diameter showed that each explained about 50 percent of the variability in root collar diameter (figs. 1 and 2). Other variables that contributed significantly to the model were number of stems and number of leaves.

Analysis of variance indicated that small-large and large oak regeneration had significantly more stems per rootstock and leaves per stem than the other two size classes (fig 3).

DISCUSSION

Mixed-oak forests are tremendously important to Pennsylvania for a wide variety of ecological and economic reasons. They are declining in number and extent for numerous reasons and require active, scientifically sound management to stop this decline. Revising SILVAH to be more applicable in mixed-oak forests is an important step in that regard. Using collective knowledge from foresters and reanalyzing data sets from other regions accelerated this revision and produced interim guidelines in months, not years.

Sander (1971, 1972) set forth the 4.5-feet stem height as the threshold for identifying competitive oak regeneration. His regression equation had a low coefficient of determination (0.32), indicating that something else was influencing new sprout growth. He theorized the missing variable was root size and that it was probably better correlated with sprout growth than stem size.

These results support Sander's theory. In this study, coefficient of determination of basal diameter or stem height when the stem was top-killed and sprouted ranged from 0.22 to 0.46, comparable to that of Sander's work. However when root collar diameter was used, it provided a better model as indicated by an increase in coefficient of determination to between 0.64 and 0.68. RCD is the superior indicator of future early height growth in oak regeneration if top-kill and sprouting is likely to occur.

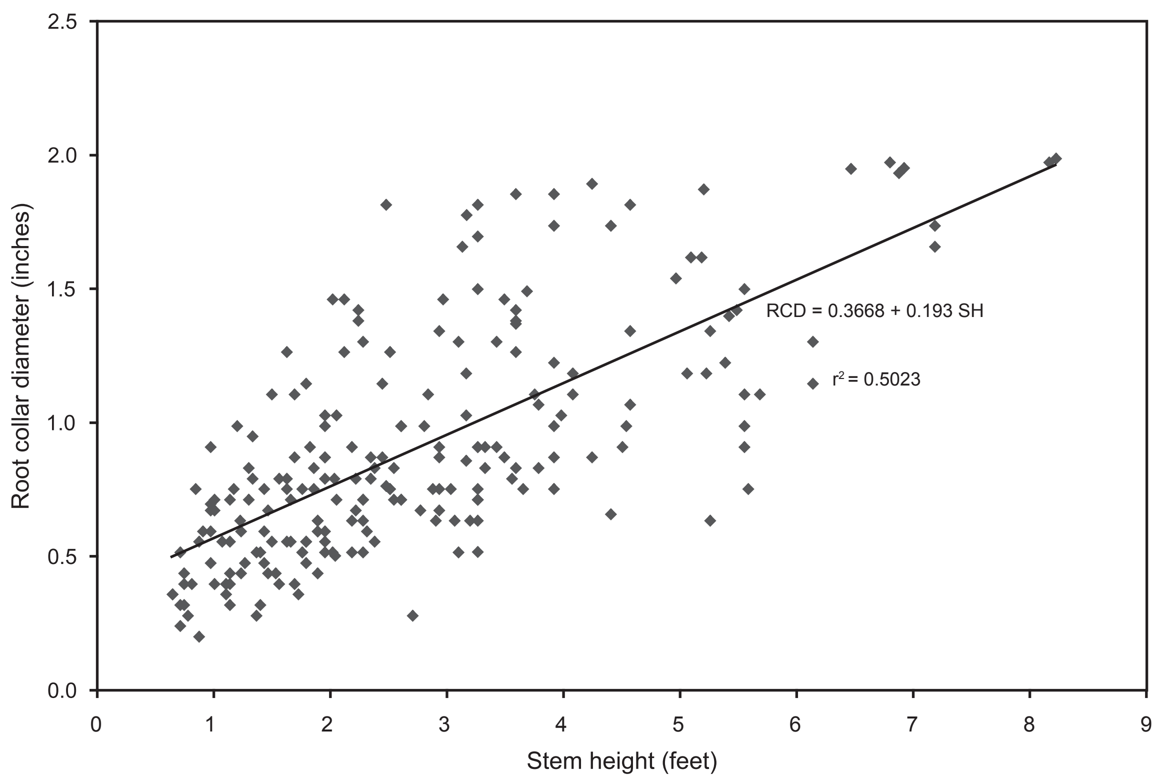

Figure 1—Simple linear regression of stem height (SH) and root collar diameter (RCD) for 221 mixed oak stems growing in shelterwood stands. The coefficient of determination (r^2) indicates that stem height explains approximately half the variation found in root collar diameter.

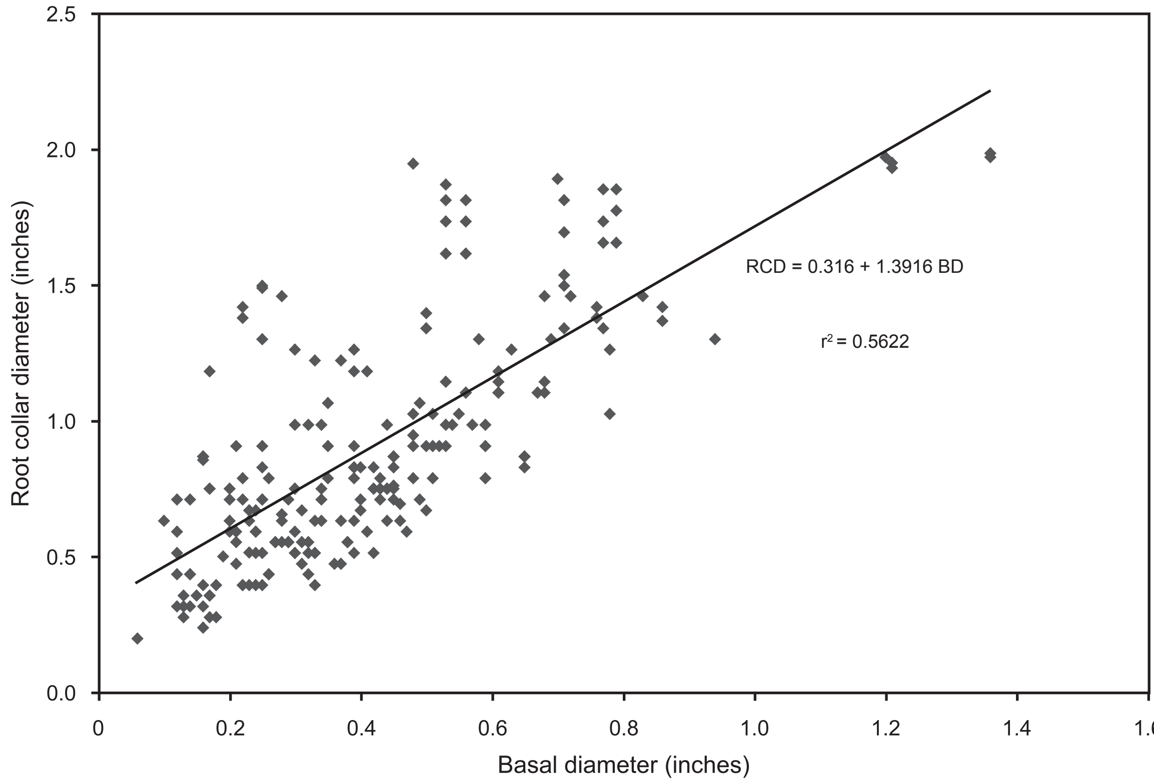

Figure 2—Simple linear regression of basal diameter (BD) and root collar diameter (RCD) for 221 mixed oak stems growing in shelterwood stands. The coefficient of determination (r^2) indicates that basal diameter explains a little more than half the variation found in root collar diameter.

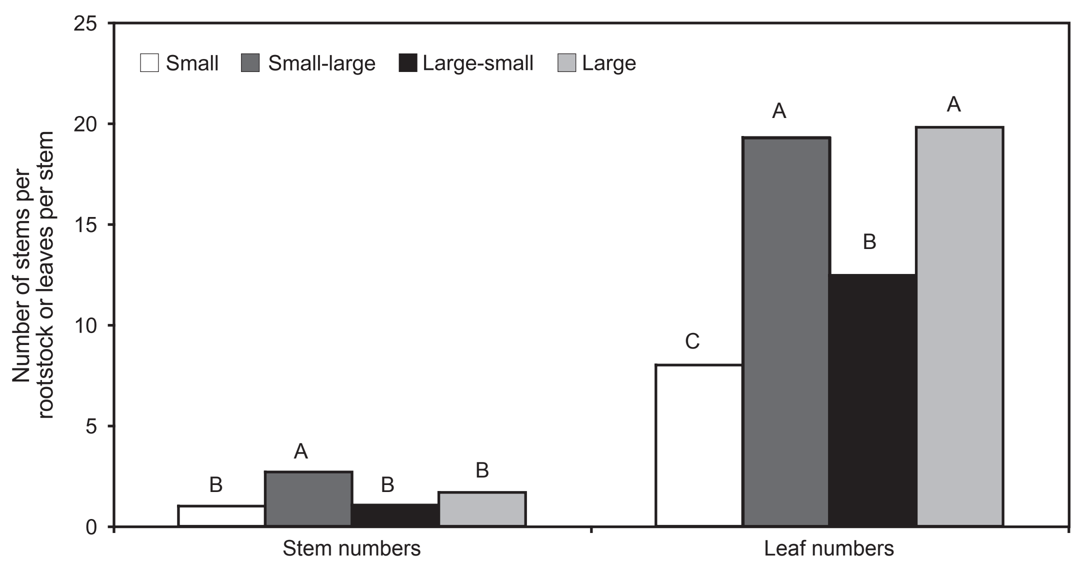

Figure 3—The mean numbers of stems per rootstock and leaves per stem for the four size classes of oak regeneration. Columns with different letters are significantly different for that stem characteristic at alpha = 0.05.

Conversely, if the oak reproduction is not forced to sprout, as in the control, then there appears to be no difference among the three stem characteristics in terms of their ability to explain subsequent height growth. In this setting, basal diameter, root collar diameter, and stem height all produced comparable models (coefficients of determination ranged from 0.48 to 0.53). Apparently in this scenario, it would not matter which stem characteristic was measured to assess size adequacy of the oak regeneration. However, avoiding top-kill of oak regeneration during timber harvests and prescribed burns is unlikely.

Sander also stated that root size would be difficult, if not impossible, to assess in the field, making stem size the preferred measurement. Obviously it is easy and quick to measure basal diameter or stem height but assessing root collar diameter requires the forester to do a little digging. Fortunately, this study provides some valuable clues as to which small oak stems have large root systems and are capable of rapid height growth, so digging to expose the root collar on every oak stem is unnecessary.

First, the relationship between stem size and root size is fairly linear despite oak's proclivity to emphasize root development in lieu of stem height growth. In this study the coefficients of determination for the basal diameter–root collar diameter and stem height–root collar diameter regressions were 0.56 and 0.50, respectively. In other words, larger oak stems will generally have larger root systems so usually oak regeneration can be assessed for its potential competitiveness based on stem height.

However, stem height may not always be the best criteria. In this study, 84 oak stems, or 38 percent of stems < 4.5-feet tall before the fires, produced sprouts that grew past the 4.5-foot mark within 3 years. This suggests that, at times, it is worthwhile to look at root collars. These stems, classified as small-large, had some other characteristics in common that help identify them. First, they were usually multiple stemmed, averaging nearly three stems per rootstock before they were top-killed. The other small oak stems seldom had more than one stem. Number of leaves also was related to number of stems. The small-large oak stems averaged almost 20 leaves, more than double that of the other small oaks. Minimum pre-burn basal diameter, root collar diameter, and stem height of the small-large oaks were 0.3 inches, 0.75 inches, and 2.0 feet, respectively. Species of oak does not appear to be a factor in determining which small oaks were capable of rapid sprout growth following top-kill by the prescribed fires.

Finally, stand history can help us identify when it is worthwhile to look at root collars. This study was done in 4-year-old shelterwood stands. The previous cut and the time between it and the study promoted root development by the oak reproduction (Miller and others 2004). Had this study been done in undisturbed, fully stocked stands, root development of the oak regeneration would have been retarded by the dense shade resulting in few, if any, oak stems capable of rapid height growth.

Users of the SILVAH decision-support system now have interim inventory guidelines for identifying competitive oak regeneration. They are:

1. Three foot is the minimum height to judge competitiveness of oak stems on medium-quality sites. This mark will vary some according to site quality and species composition, but overall, this is a safe, sound point of reference.

2. Shorter oak stems with root collar diameters > 0.75 inches can also be considered competitive. These are most likely found in previously disturbed stands and can be tentatively identified by height (> 2.0 feet tall), basal diameter (> 0.30 inches), multiple stems, and have > 20 normal-sized leaves.

3. Check root collars on oak stems in the first two or three plots. This will help develop a "stand-specific eye" for characteristics of oak stems that have large root systems capable of supporting rapid height growth upon release. After that, check only those stems exhibiting those characteristics.

Like all of SILVAH's guidelines, these oak inventory guidelines are a supplement and not a substitute to a forester's professional judgment. They are also interim in that two long-term oak regeneration studies now under way will supercede them in a few years.

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