Oak Regeneration Guidelines for the Central Appalachians

Kim C. Steiner, James C. Finley, Peter J. Gould, Songlin Fei, and Marc McDill

ABSTRACT

This article presents the first explicit guidelines for regenerating oaks in the central Appalachians. The objectives of this paper are (1) to describe the research foundation on which the guidelines are based and (2) to provide users with the instructions, data collection forms, supplementary tables, and decision charts needed to apply the guidelines in the field. The principal research foundation for the guidelines is a set of quantitative models that estimate, in advance of harvest, a stand's potential to regenerate oak stocking from advance regeneration and stump sprouts. Regeneration potential is measured by the predicted stocking by oak species, expressed as a percentage of full (100%) stocking, in the new stand in its third decade (21–30 years) after overstory removal. An understory classification system is used in conjunction with the models to help identify potential barriers to regeneration development. Model results and other data on current stand conditions are used in the decision charts to identify prescriptions for achieving a strong component of oak regeneration after stand harvest. Overstory removals are recommended when the stand's oak regeneration potential is adequate to meet management goals. Otherwise, prescriptions designed to enhance seedling-origin oak regeneration potential are recommended.

Keywords: oak, *Quercus*, regeneration, silviculture, guidelines

Oak-dominated forests occupy much of the forestland in the central Appalachian region (Johnson 1992, Alerich 1993, Griffith and Widmann 2003). Oaks have a long history of dominance in the region (Abrams 2002) and often are considered the best species for many sites because of their high value for timber and wildlife (Kirkpatrick and Pekins 2002). With this in mind, usually, the goal of regeneration treatments in oak-dominated stands is to regenerate new stands with a large oak component. Even-aged silvicultural systems that rely on natural regeneration generally are the best option for achieving this goal (Sander 1977). However, the regeneration of oaks is not assured after a final overstory removal unless a high potential for oak regeneration is already in place (Sander et al. 1984, Beck and Hooper 1986, Sander 1988). A stand's oak regeneration potential refers to the capacity for oak advance regeneration (oak seedlings less than 2 in. dbh) and stump sprouts (from stems 2 in. dbh or more) to capture and maintain growing space after an overstory removal.

Many oak stands in the central Appalachians have low oak regeneration potentials, and an oak regeneration problem is widely recognized in the region (McWilliams et al. 1995, Gould et al. 2003). Typically, oaks are replaced in new stands in part by red maple (*Acer rubrum* L.), a species that has increased in abundance in all states within the region in recent decades (Fei and Steiner 2007). In our long-term data set (described later), in 65 stands harvested between 1968 and 1978 that regenerated to at least 50% total stocking, the mean relative basal area of oak declined from a mean of 81.2% before harvest to just 30.1% 30 years after harvest, and red maple increased from 8.4 to 37.1% (K. Steiner and J. Finley, 2002, unpublished data). Although the long-term consequences of this shift are still under study, generally, it is considered to be undesirable by forest managers.

When regeneration treatments are planned in an oak-dominated stand, two very important questions are (1) What is the stand's current oak regeneration potential? and (2) If oak regeneration is found to be insufficient, what should be done to improve it? Regeneration models and guidelines are useful tools for addressing these questions. Such tools have been developed for regenerating oaks in the Missouri Ozarks (Sander et al. 1984, Dey 1991), the southern Appalachians (Loftis 1990a), New England (Hibbs and Bentley 1983), and in southern bottomland stands (Belli et al. 1999). Some of these guidelines simply prescribe a fixed density of oak advance regeneration (e.g., Hibbs and Bentley [1983]), and others use more elaborate research-based models (e.g., Sander et al. [1984]). Similarly, some guidelines indicate only whether oak regeneration potential is "adequate" for an overstory removal (e.g., Hibbs and Bentley [1983]), and others produce quantitative predictions of the importance of oak in the future stand (e.g., Dey [1991]).

In this article, we describe the development of the first explicit, model-based guidelines for regenerating oaks in the central Appalachians under even-aged silvicultural systems. The objectives of this article are to familiarize users with the research that contributed to the guidelines and to provide instructions, work forms, and decision charts. The work forms and decision charts incorporate models and emerging information on oak regeneration development in the region. The models are described in detail in other publications (Northrup 2003, Gould et al. 2006, Gould et al. 2007). Basic model

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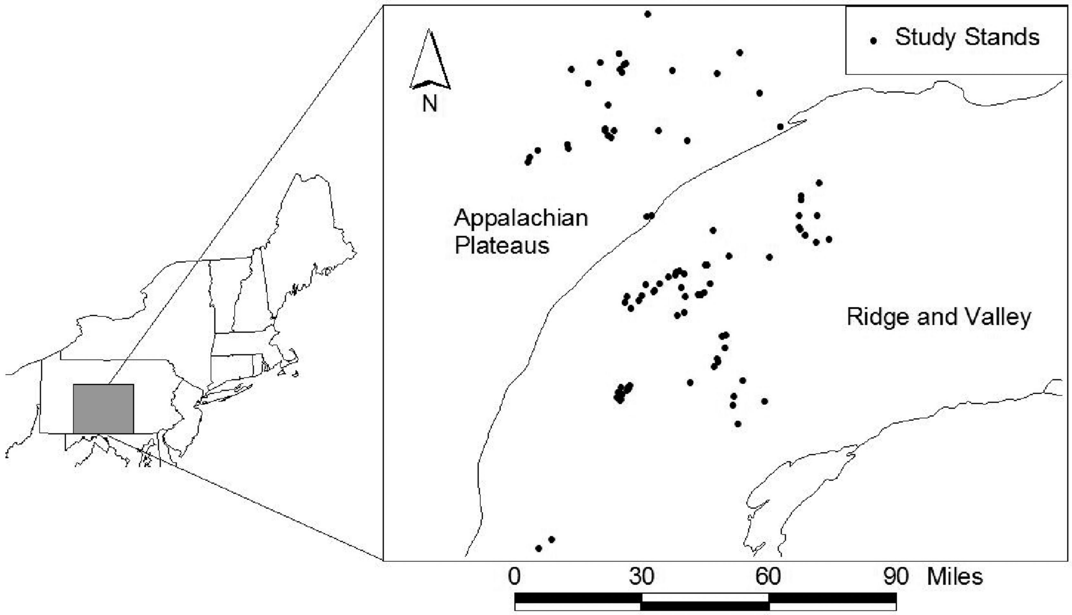

Figure 1. Map of the study stands used in developing the regeneration guidelines. The Appalachian Plateaus and Ridge and Valley physiographic provinces are labeled.

functions are described here to provide users with a better understanding of how stand measurements are used in the guidelines. The process undertaken to develop the decision charts is described to explain how emerging information and expert opinion were used to recommend prescriptions based on user goals and stand conditions.

Research Background

The guidelines were developed principally from studies of oak regeneration development on Pennsylvania State forestland. The studies are part of an ongoing research collaboration between the Pennsylvania Department of Natural Resources, Bureau of Forestry, and The Pennsylvania State University, School of Forest Resources, to further understanding of the regeneration process in upland, oak-dominated stands (often called mixed-oak stands) and to identify silvicultural treatments that improve regeneration when it is otherwise inadequate. The development of regional oak regeneration guidelines has been a principal objective of the research effort.

To help address this objective, a long-term data set (described by Gould et al. [2003, 2005]) was developed from operational (nonresearch) measurements in 90 stands that were regenerated by clearcutting and had reached the third decade of postharvest stand development. Of these 90 stands, 41 were measured more intensively to generate the seedling-origin regeneration model described later. The third decade of stand development (21–30 years after harvest) is significant because it is generally viewed as marking the end of the regeneration period (Sander et al. 1984, Loftis 1990a, Dey 1991), and the oak component in third-decade stands typically is well-established and not expected to decline because of competition with other species (Oliver 1975, Ward et al. 1999). This data set enabled a retrospective analysis of the link between (1) preharvest measurements of oak advance regeneration and (2) nonsprout-origin oak stocking during the third decade after harvest (Gould et al. 2006).

Aside from the aforementioned, our primary research effort is directed toward an ongoing longitudinal study, Oak-forest Regeneration Study in Pennsylvania (ORSPA), of stand development after silvicultural treatments designed to harvest and regenerate oak-dominated stands. The study was begun in 1996 and now encompasses 55 formerly oak-dominated stands, all of which were measured using a grid of permanent, fixed-area plots before regeneration treatments were conducted. The stands are presently at various stages of regeneration and have been remeasured periodically through as long as the 7th year after harvest. The study has provided detailed information on preharvest oak seedling populations, the short-term development of oak seedlings and stump sprouts, and understory and overstory conditions at the time of harvest. These data were used in the development of the regeneration models on which the guidelines are based. The study also has provided information on the effects of silvicultural treatments (e.g., shelterwood harvests, herbicide treatments, and deer exclosures) that was central to the development of the guideline's decision charts. Importantly, this study will continue to provide new information as stands are continuously monitored. The emerging information will be used to test and refine the guidelines.

Stands included in both studies described previously were dominated before harvest by northern red oak (*Quercus rubra* L.), chestnut oak (*Quercus montana* L.), white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), and scarlet oak (*Quercus coccinea* Muenchh.), in decreasing order by mean basal area. Other common overstory species included, again in decreasing order, red maple, blackgum (*Nyssa sylvatica* Marsh.), sweet birch (*Betula lenta* L.), eastern white pine (*Pinus strobus* L.), and hickory (*Carya* spp.). All other overstory species were present at less than 1.0 $ft^2\ ac^{-1}$ on average. Productivity in the study stands is typically poor to moderate, with most site index values between 60 and 75 ft at 50 years. Stand locations are shown in Figure 1. The study region includes parts of two physiographic regions, the Ridge and Valley and Appalachian Plateaus, which are characteristic of much of the central Appalachians. Soils in the study areas are weathered from sandstone, siltstone, and shale and typically are well drained (Cuff et al. 1989).

Stand elevations range from about 1,000 to 2,300 ft above msl. Mean annual precipitation in the region ranges from 38 to 45 in. and frost-free periods range from 140 to 160 days (Cuff et al. 1989). Oaks tend to dominate the vegetation in the Ridge and Valley province, and they transition to more mesophytic species in the Appalachian Plateaus, although oaks continue to be locally dominant (Stout 1991, Bailey et al. 1994). Most mature oak stands in our study area regenerated after turn-of-the-century logging (Rothrock 1915, Stout 2000).

The study area occupies approximately the northern 25% of Bailey's (1995) Central Appalachian ecological province, dominated at middle elevations by "Appalachian oak" forest in Bailey's terminology. This ecological province extends southward into North Carolina and Georgia and is geographically similar in configuration to Braun's (1950) oak-chestnut forest region. The stands and sites represented in our study resemble other Appalachian oak stands in much of this region, especially from Virginia and West Virginia northward into central Pennsylvania (i.e., the region conventionally regarded as "central" Appalachians). The central Appalachian province lies to the east of Bailey's (1995) Eastern Broadleaf province and Braun's (1950) mixed mesophytic forest region, in which oak-dominated stands tend to contain species such as *Acer saccharum* Marsh., *Liriodendron tulipifera* L., *Tilia americana* L., *Magnolia acuminata* L., *Fagus grandifolia* Ehrh., and *Fraxinus americana* L. These species occurred on our study sites at very low mean densities (although more abundantly in the Appalachian Plateaus physiographic region), and their prominence within a stand is evidence that the guidelines should be applied with caution.

Evaluation of Regeneration Potential and Understory Conditions

The first step in the application of the guidelines (Appendix) to a particular stand is to evaluate the potential of the stand to regenerate to oak and assess the potential for existing understory vegetation to inhibit the development of regeneration after harvest. Regeneration potential is evaluated using models based on the data sets described previously, one model for the expected contribution of oak seedlings to third-decade stocking by trees in the dominant, codominant, and intermediate crown classes (Gould et al. 2006), and a set of models (by species) for the expected contribution of oak sprouts to third-decade stocking (Gould et al. 2007). The seedling-origin model addresses the component of regeneration that begins as oak seedlings (or seedling sprouts) before removal of the former stand. It is a plot-level model that estimates the probability that a particular milacre (0.001 ac) plot will be occupied successfully by an oak at a time in the future when the average stand density is 1,000 stems ac^{-1} and the average dbh is 3.7 in., a state of 100% (A-level) stocking in upland hardwood forests (Gingrich 1967). In our data, the average stand reaches this state during the early part of its third decade of development, and all stands have transitioned out of this state by the end of the third decade (Gould 2006). We refer to this as a third-decade stand condition for convenience, but it is really a state defined by tree size and density, and some stands reach it before the age of 21 years.

The probability that a plot will be stocked successfully with a seedling-origin oak is calculated as a function of the size and number of oak seedlings present shortly before harvest. Seedling size and number are summarized by a single index of density, aggregate height per unit area (ft milacre^{-1} in our models), which is the sum of the individual oak seedling heights within a plot. Aggregate height is a convenient and predictive measure of density in seedling cohorts and can be regarded as analogous to basal area as used in older stands (Fei et al. 2006). The probability that a plot will be stocked successfully with an oak is expressed in the guidelines as a percentage stocking value. The mean stocking value for a stand represents the expected stocking by oak in the third decade of development as a percentage of full (100%) stocking (if the success probability were identical for all plots, e.g., 0.35, and then 35% of all plots would become stocked with oaks).

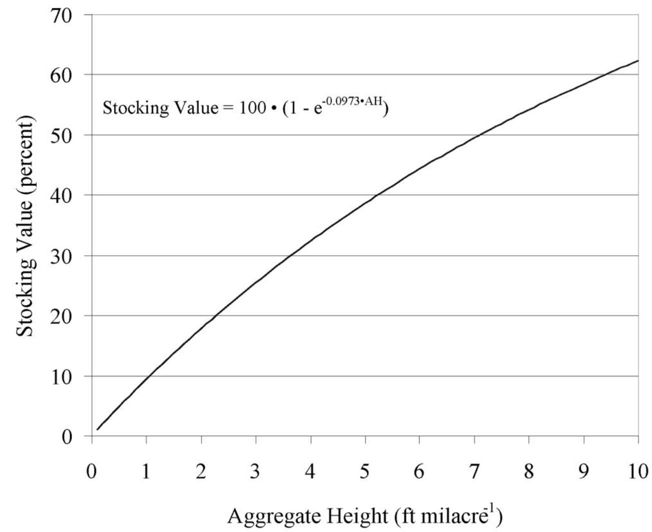

Figure 2. Seedling-origin regeneration model for assigning stocking values to milacre plots based on the sum of oak seedling heights (aggregate height/milacre) measured shortly before harvest.

The model is illustrated in Figure 2. About 9 of 100 milliacre plots that contain a single 1-ft oak seedling are expected to be occupied by an oak in the third decade after harvest, which corresponds to an expectation of 9% stocking from seedling-origin oaks. If the plot contains two 1-ft seedlings (or one 2-ft seedling) the probability of success increases to about 17%. The seedling-origin regeneration model is applied in the guidelines by using Appendix Form A to (1) tally oak seedlings by height class on a sample of milacre plots, (2) calculate aggregate height in feet per milacre, and (3) determine the corresponding plot stocking value from a lookup table (see Table A1). The expected third-decade, seedling-origin oak stocking for the stand is calculated as the mean of all plot stocking values.

The seedling-origin model used here predicts that small advance regeneration oak seedlings (less than 1 ft in height) can make a significant contribution to future stand development (Gould et al. 2006). This prediction is contrary to other recommendations for regenerating oak (Sander et al. 1984, Sander 1988), but the prediction appears to be borne out by our observations of stands through age 7 years after harvest in ORSPA (K. Steiner and J. Finley, 2006, unpublished data). The potential for small oak seedlings to contribute to regeneration also is supported by the observations of Ward and Stephens (1999) in Connecticut and Ross et al. (1986) in southwestern Virginia. In fact, our model closely fits the realized 20-year success of sample seedlings used in the Missouri study by Sander et al. (1984) and does so better than the authors' own projections, as shown by Gould et al. (2006). Our model is only slightly more optimistic about the fate of small seedlings than the model of Loftis (1990a) based on research in North Carolina. However, users should be cautious about applying these guidelines to stands on

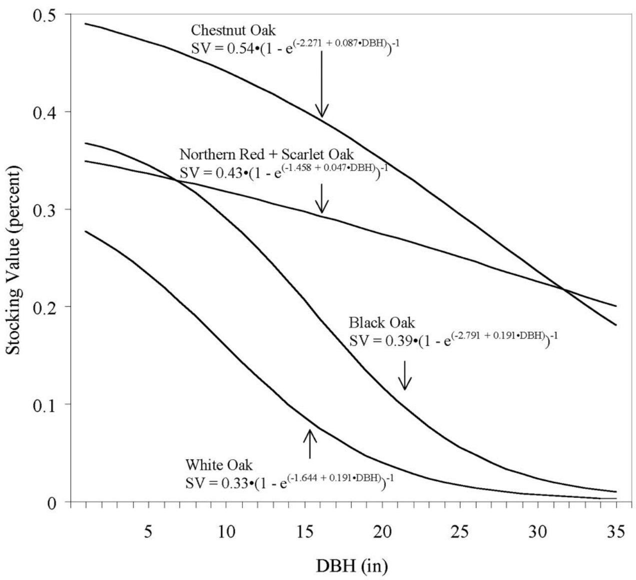

Figure 3. Sprout-origin regeneration models for individual oak parent trees according to species and dbh as measured shortly before harvest. Stocking values are the percentage of stand stocking in the third decade after harvest that each oak parent tree is expected to contribute.

higher-quality sites and with a different species composition than those used in our research, particularly those that contain a significant component of yellow-poplar. Yellow-poplar can regenerate in abundance from dormant seeds in the litter and humus and compete vigorously with oaks.

The sprout-origin oak regeneration models are similarly used to estimate third-decade oak stocking originating from stump sprouts. Models were developed to estimate the contribution of individual parent trees (as ortets) to third-decade stocking. The models include coefficients that reflect initial sprouting probabilities, sprout-group survival through the end of the regeneration period, and sprout-group size at the end of the regeneration period. Considering sprout-group size at the end of the regeneration period is important for accurately modeling the contribution of stump sprouts because sprout groups often are composed of several stems that produce a single contiguous crown (Gould et al. 2007). Parent tree dbh is the independent variable in the models, and model coefficients differ between oak species. The output unit (dependent variable) is expected third-decade sprout-origin oak stocking in the dominant, codominant, and intermediate crown classes expressed as a percentage of full (100%) stand stocking.

The individual tree sprout-origin oak regeneration models are shown in Figure 3. Because of insufficient data, the sprouting probability of scarlet oak could not be modeled, but other research shows that the species is similar to northern red oak in this respect, and the model for northern red oak is assumed to be a reasonable substitute (Gould et al. 2007). The expected contribution of all oak species decreases with increasing diameter because of a lower sprouting potential among larger parent trees. Chestnut oaks are expected to contribute more than the other oaks to third-decade sprout-origin stocking across most diameter classes because of superior sprouting potential and a larger mean sprout-group size. The expected contributions of white and black oaks, in contrast, are lower because of poorer initial sprouting and smaller sprout-group sizes.

The sprout-origin regeneration models are applied in the guidelines by using Appendix Form B to (1) tally overstory oaks by species and diameter class on 1/20th-ac sample plots and (2) calculate the expected contributions by their sprouts to future stocking using stocking values derived from the models depicted in Figure 3. The stocking values incorporate an expansion factor (20) appropriate to the plot size. Expected sprout-origin oak stocking in the third decade is the sum of stocking values for all species and diameter classes.

Understory vegetation can strongly influence oak regeneration success (Lorimer et al. 1994, George and Bazzaz 1999, Oswalt et al. 2004). The guidelines use an understory classification system (see Table A2) that is largely based on classes described by Northrup (2003) using ORSPA data. All classes in Table A2 are considered inhibitory except BB (blueberry and huckleberry) and NO (mostly bare soil or litter). Northrup (2003) found that an abundant ground cover of blueberry (*Vaccinium* spp.) and black huckleberry (*Gaylussacia baccata* [Wangenh.] K.Kock) tended to have a positive association with relatively large oak seedlings. The occurrence of blueberry and huckleberry may reflect underlying topographic and edaphic conditions that are relatively favorable for oak regeneration development (Fike 2002). Inhibiting vegetation cover of 30% or more is regarded as problematic for regeneration development in this region (Marquis et al. 1975). This threshold generally agrees with the mean values found for Northrup's (2003) cover classes, and it was incorporated into the guidelines, except that that a threshold of 15% was used for mountain-laurel (*Kalmia latifolia* L.). Rhizomatous ferns (especially hayscented fern, *Dennstaedtia punctilobula* [Michx.] T. Moore; New York fern, *Thelypteris noveboracensis* [L.] Nieuwl.; and northern bracken fern, *Pteridium aquilinum* [L.] Kuhn) are considered the most problematic sources of interfering vegetation if present.

Understory vegetation classes are applied in the guidelines by, first, visually estimating projected cover within 1⁄20-ac plots according to the categories defined in Appendix Table A2. Using Appendix Form A to tally the data, each plot is assigned to the first vegetation class that is applicable in the table (reading from top to bottom), and the stand is summarized by calculating the percentage of plots assigned to each class. The percentage values for F (fern), ML (mountain-laurel), LS (low shade), and OT (other vegetation) classes are summed to estimate the percentage of stand area where inhibiting vegetation is problematic.

Decision Charts

Information about regeneration potential and understory vegetation conditions gathered on Appendix Forms A and B is summarized in Appendix Form C, and this summary is used in Charts 1 and 2 to identify appropriate silvicultural prescriptions. The first question addressed in the decision charts (Chart 1) is whether expected total oak stocking (seedling origin + sprout origin) is sufficient to meet the user's goal. Because these guidelines typically will be used in stands in which the current stocking is dominated by oaks, an obvious goal is a future stand in which oaks compose at least 50% of the future stocking. However, the manager may choose to manage the stand for other species, in which case other guidelines (e.g., Marquis et al. [1992]) should be consulted. Our guidelines are not applicable when the choice is to manage for a future stand in which other species are considered more desirable and the oak component is expected to be negligible or regarded as unimportant.

In practice, we have found that a target of at least 50% predicted future stocking of oak often is not feasible, but stand conditions are frequently such that an oak stocking of at least 30–35% can be expected without further augmentation of the regeneration cohort.

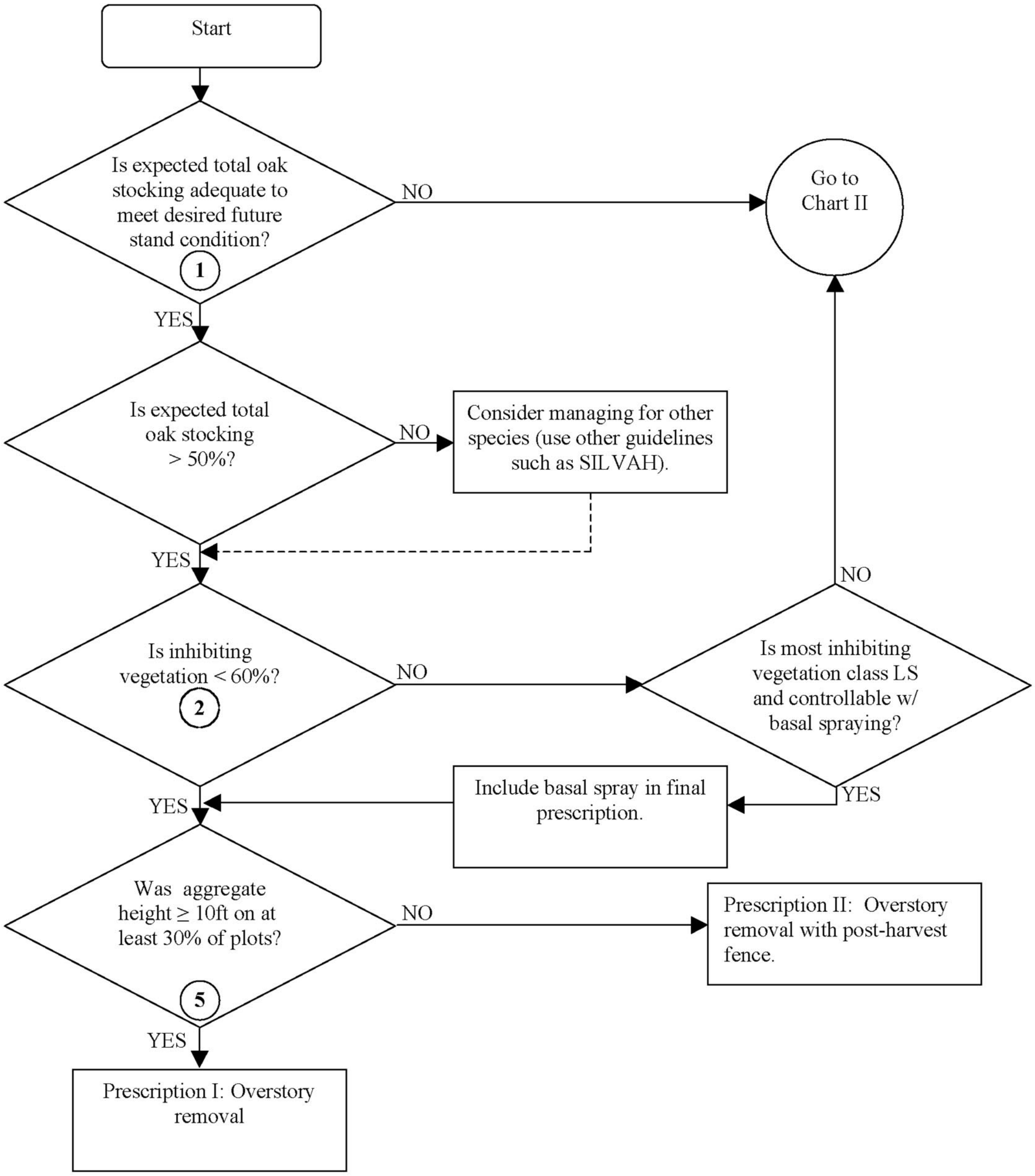

Chart 1. Regeneration treatment evaluation.

Whether this is sufficiently ambitious can only be answered by the manager. It should be borne in mind that our regeneration models address only third-decade stocking by oak, and the output is expressed as a percentage of Gingrich's (1967) A-level (100%) stocking. It is assumed that remaining growing space in the stand will be occupied by other species. Oak-dominated stands capable of regenerating to 30–35% oak stocking typically will regenerate other species in sufficient abundance to become fully stocked (assuming that protection from deer is provided if needed). However, stands may be fully stocked at somewhat less than 60% stocking, corresponding to Gingrich's (1967) B-level, which is the lowest level of stocking at which the stand of trees fully occupies the site. If projected levels of oak stocking materialize in the third decade, but third-decade stocking of *all* species is less than 100%, then the *relative* stocking by oak will be higher than suggested by model predictions. This circumstance, which will occur frequently, bodes well for an even stronger component of oak as the stand develops toward maturity. The manager may wish to factor this possibility into the determination of an acceptable target for oak regeneration.

The decision charts were developed using results from ORSPA stands that had undergone various treatments and were remeasured 1, 4, and 7 years after harvest. To our knowledge, these data provide the most extensive and comprehensive quantitative information available within this region on the efficacy of alternative silvicultural treatments. Decision charts drafted on the basis of these results were subsequently modified based on input from 17 silvicultural scientists and professionals convened in winter 2004 for the purpose of evaluating the draft guidelines. We also have tested the guidelines in two field workshops attended by a total of over 140 practitioners. In short, the decision charts reflect emerging information and expert opinion. Silvicultural treatments, and the rationales for assigning them, are described later.

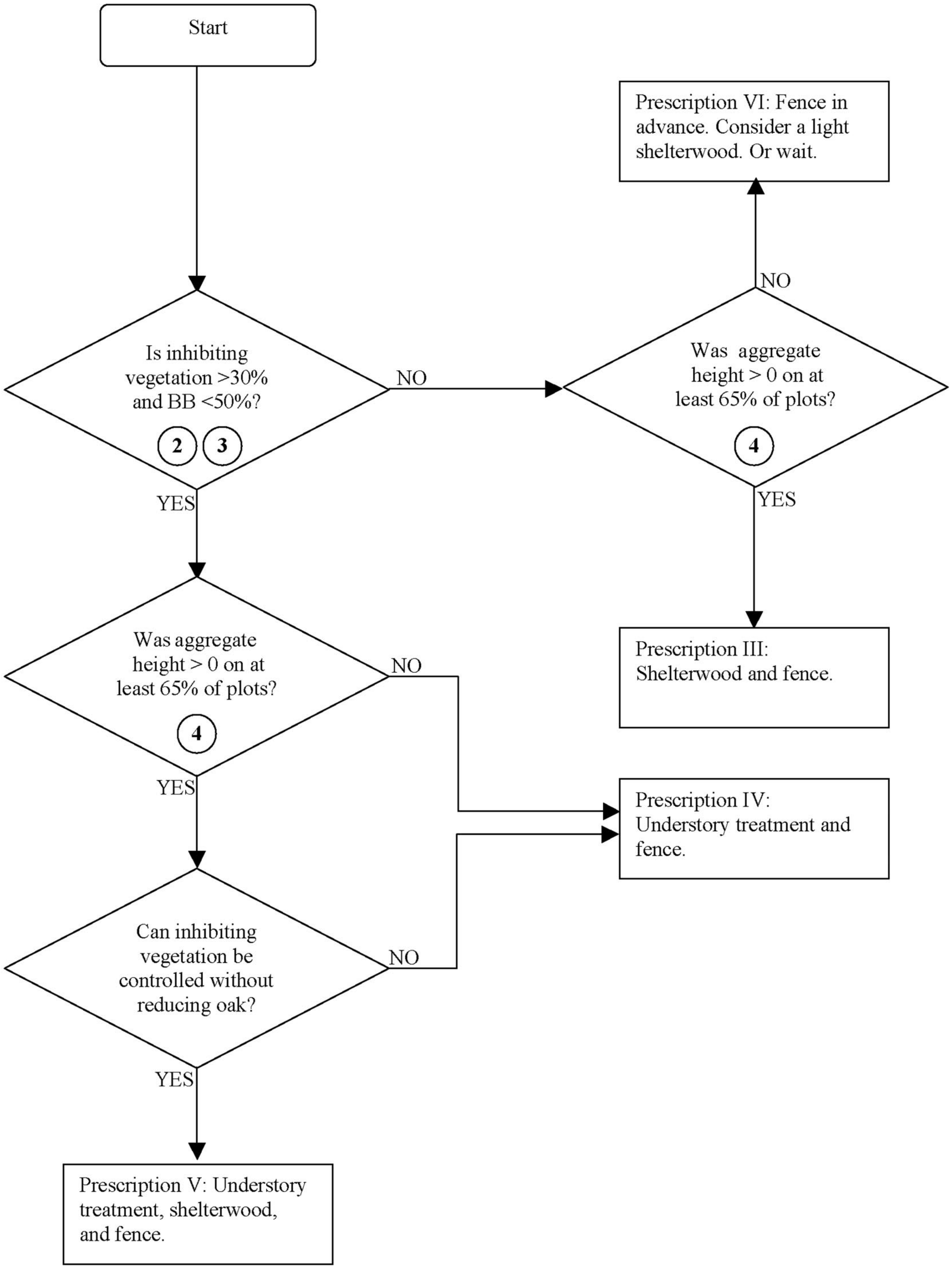

Chart 2. Regeneration problem diagnostics.

Complete Overstory Removal

A complete overstory removal (prescriptions I and II) is permissible when expected third-decade oak stocking exceeds 50% or otherwise meets the user's goal as discussed previously, except when inhibiting vegetation is very high (more than 60%) and is primarily *not* in the low shade class and controllable by basal spraying of herbicide. Very high levels of inhibiting vegetation may threaten regeneration success even when oak regeneration appears otherwise adequate. We recommend treating very high levels of inhibiting vegetation before proceeding with an overstory removal, and the stand should be reevaluated after treatment.

White-tailed deer browsing has major impacts on regeneration in the central Appalachians (Marquis and Brenneman 1981). Fencing to exclude deer often is necessary to reach regeneration goals. However, fencing is costly and it is important to recognize cases where fencing is unnecessary. Fencing is not recommended in conjunction with an overstory removal when a strong cohort of oak advance regeneration has developed without a fence, indicating that the deer population in the vicinity of the stand is in balance with the habitat. ORSPA results indicate that stands that have oak aggregate heights of 10 ft/milacre or more on at least 30% of sample plots are not strongly impacted by deer browsing after an overstory removal, and we suggest that fencing may be avoided when this criterion is met (prescription I). The criterion provides guidance to forest managers, but past experience in a particular area also should factor strongly into the decision of whether to fence after overstory removal.

Shelterwood

The shelterwood regeneration method is widely recommended for stands lacking sufficient oak regeneration potential (Sander et al. 1984, Loftis 1990b, Johnson et al. 2002). Oak regeneration potential may be improved by increasing the size of established oak seedlings in the more favorable growing environment created by the shelterwood cut and by increasing oak seedling density. Although the growth of established oak seedlings can be expected to accelerate after a shelterwood cut (when combined with fencing, if necessary), it is less clear whether managers can depend on periodic acorn crops to increase oak seedling densities (Graney 1999). ORSPA results indicate that, without a fortuitous acorn crop, less desirable species may benefit most from the improved growing conditions. In other words, experience shows that shelterwoods often fail to achieve the objective of enhancing oak regeneration. Ideally, shelterwoods should be scheduled to occur immediately after a heavy acorn crop.

To balance the potential benefits of shelterwood cuts with the risk of increased competition, the shelterwood regeneration method is recommended in stands where (1) expected third-decade oak stocking is too low to meet management goals, (2) oak regeneration is already established, and (3) inhibiting vegetation levels are low (less than 30%; prescription III) or it can be controlled without damaging oak advance regeneration (prescription V). Both prescriptions III and V include fencing to exclude deer because it is our experience that these stands also will typically fail to meet the 10 ft/milacre or more criterion for oak seedling aggregate height. However, this may not always be the case, and fencing may not always be required in conjunction with a shelterwood.

We recommend that shelterwoods be used only in stands in which 65% or more of sample milacre plots contain oak seedlings. Our long-term data set shows clearly that nonsprout regeneration of an oak component was always minimal in stands where this criterion was not met. Some participants who reviewed a draft of these guidelines believed that a light shelterwood cut could improve regeneration in stands that do not meet the 65% or more threshold. Again, our experience is that shelterwoods do little to supplement the oak regeneration cohort unless a heavy seed crop occurs within the 1st or (perhaps) 2nd year after harvest. We leave the possibility open in the guidelines (prescription VI). The ultimate selection of an appropriate prescription is, of course, at the manager's discretion.

Inhibiting Vegetation Treatment

Nontree understory vegetation and small undesirable trees can inhibit oak seedling establishment and growth (Lorimer et al. 1994, George and Bazzaz 1999, Oswalt et al. 2004). Guideline projections for future oak stocking may not be achieved if problematic levels of inhibiting vegetation are present and no control measures are imposed. We recommend treating understory vegetation when 30% or more of sample plots are occupied by inhibiting vegetation (prescriptions IV and V). The 30% threshold was adopted from regeneration guidelines for Allegheny hardwood stands (Marquis et al. 1992) and reflects expert opinion. The threshold is raised to 60% in stands where expected future oak stocking is expected to exceed 50%, an exceptional condition in our experience. Herbicide treatments are not recommended when 50% or more of sample plots are classified in the BB understory vegetation class. This understory class reflects generally favorable conditions for oak regeneration development (Northrup 2003). Methods for controlling inhibiting vegetation are described by de la Cretaz and Kelty (2006), Engelman and Nyland (2006), Jackson and Finley (2005), and Nyland et al. (2006).

Defer Treatment or Fence

We recommend deferring treatment, fencing, or considering a light shelterwood cut, in stands that (1) do not have enough oak advance regeneration to start a regular shelterwood sequence and (2) do not have high levels of inhibiting vegetation (less than 30% of plots; prescription VI). Deer browsing can be a serious detriment to oak seedling establishment and survival (Steiner 1995, Steiner and Joyce 1999), and fencing may be required before oak advance regeneration will successfully establish. Fencing in advance of harvest should be considered when it is a feasible management option, but it should be understood that a strong component of oak regeneration can not develop without an excellent acorn crop, which can be as infrequent as once in a decade (Smith 1993). Although fencing is necessary in some stands to accumulate a substantial population of oak seedlings, it may not always be sufficient. In heavily shaded stands, removal of up to 40% of the basal area may be necessary to give oak seedlings sufficient light to become established without giving too much encouragement to more light-demanding species (Kass and Boyette 1998; Loftis 1990b, 1993). This light shelterwood or heavy thinning should be administered to understory sources of shade and result in no canopy gaps, unless timed to occur with a heavy acorn crop. If the cause of the current lack of advance regeneration is removed by excluding deer or providing more light to the forest floor, the stand's regeneration potential will increase after the next large acorn crop, at which time a more aggressive harvesting regime can be contemplated.

Conclusion

These oak regeneration guidelines for the central Appalachians are based on the best available models of oak regeneration development within this region. We anticipate that continuing research will lead to refinements and revisions to the guidelines. The guidelines are meant to be a tool for adaptive management, and applying them thoughtfully and with care will enable forest managers to discover their strengths and limitations in the context of the manager's own understanding of local conditions. User feedback also is valuable and users are invited to contact us with suggestions for improvements. We intend to reevaluate periodically the guidelines to incorporate emerging information.

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Appendix: Instructions, Work Forms, Tables, and Decision Charts

Data Collection

Form A *(Seedling-Origin Regeneration and Vegetation Cover Class)*

1. Oak advance regeneration is measured on milacre plots (3.72-ft. radius), and the potential for sprouting by larger oaks is measured on 1⁄20-ac plots (26.3-ft radius). We recommend a minimum of 40-milacre plots, arranged on a grid over the full area of the stand, and one-half that number (centered on every other milacre plot) of the larger plots. If 40-milacre plots are measured per stand, and if x is the size of the stand in acres, the distance in feet (y) between milacre plot centers is calculated as $y = 33 \cdot \sqrt{x}$. Run transects along the azimuth of the main axis of the stand, turn corners at 90° to the main azimuth, and establish plots no closer than y ft from the edge of the stand.

Stand: ______________________ Date: ____________________ Collected by: ____

Form A. Understory Data Collection for Seedling-Origin Regeneration and Cover (milacre plots)

	Oak Seedling Height Class (feet)						Aggregate Height	Plot Stocking	Vegetation Cover Class[1] →					
	0.5 [< 1]	1 [1.0 - 1.5]	2 [1.6 - 2.5]	3 [2.6 - 3.5]	4 [3.6 - 4.5]	5+ [> 4.5]								
1.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
2.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
3.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
4.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
5.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
6.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
7.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
8.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
9.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
10.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
11.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
12.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
13.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
14.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
15.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
16.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
17.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
18.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
19.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
20.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
21.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
22.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
23.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
24.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
25.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
26.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
27.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
28.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
29.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
30.	0.5	1	2	3	4	5+			F	ML	LS	OT	BB	NO
Number of Plots						>0	≥ 10							
Percentage of Plots						>0	≥ 10							
Expected Seedling-Origin Oak Stocking (mean)														

[1]F = fern cover (≥30%); ML = mountain-laurel cover (≥15%); LS = low shade cover (≥30%); OT = vegetation cover other than oak, blueberry, or huckleberry (≥30%); BB = blueberry or huckleberry cover (≥30%); NO = <30% total vegetation cover; vegetation cover is estimated for 1/20th-acre plots

2. Use dot tallies on Form A to record the number of advance regeneration stems (less than 2 in. dbh) in each height class within milacre plots. Tally stems less than 1 ft tall in the 0.5-ft height class. Print the heights of stems more than 4.5 ft tall in the "5+" box. Add the heights together and record in Form A under "aggregate height." For example, if three oak seedlings are tallied in the 1-ft height class, two seedlings in the 2-ft class, and one seedling measured as 8 ft tall, then aggregate height = 1 + 1 + 1 + 2 + 2 + 8 = 15 ft.
3. Determine the "stocking value" from Table A1 that corresponds to the plot's aggregate height. Record the stocking value under "plot stocking" on Form A.
4. At each milacre plot center, sweep a 1⁄20-ac (26.3-ft radius) plot and visually estimate vegetative cover on the plot (assume a vertical projection) for the understory cover classes described in Table A2. Reading the table from top to bottom, find the first class that describes the plot. For example, a plot that meets the criteria for both the "F" class and the "ML" class is assigned to the "F" class. Circle the appropriate code under "vegetation cover class" on Form A. Except where stated otherwise in Table A2, estimate cover looking downward from 5ft above the plot. Note that OT may include fern and mountain-laurel in the event that these are present but not abundant enough to meet the thresholds for F and ML classes. At every other plot center, enter the data described below under Form B number 1.
5. Data summary. At the bottom of Form A, count and record the following: the number of plots where aggregate height was more than 0 (i.e., at least one stem of oak advance regeneration was present), the number of plots where aggregate height was 10 ft or more, and the number of plots in each vegetation cover class. Convert these values to percentages by dividing by the total number of sample plots measured and multiplying by 100%. Record these values in the "percentage of plots" row. Calculate the mean plot stocking value and record in the "expected seedling-origin oak stocking" box. This value represents the expected contribution made by oak seedlings to stocking in the third decade after harvest, as a percentage of full (100%) stand stocking.

Table A1. Expected oak stocking in the future stand in the third decade after harvest as a function of aggregate height of oak seedlings in advance regeneration.

Aggregate height (ft milacre^{-1})	Stocking value	Aggregate height (ft milacre^{-1})	Stocking value
0.0	0	7.5	52
0.5	5	8.0	54
1.0	9	8.5	56
1.5	14	9.0	58
2.0	18	9.5	60
2.5	22	10.0	62
3.0	25	10.5	64
3.5	29	11.0	66
4.0	32	11.5	67
4.5	35	12.0	69
5.0	39	12.5	70
5.5	41	13.0	72
6.0	44	13.5	73
6.5	47	>14.0	75
7.0	49		

Table A2. Understory cover classes tallied in Form A.

Class	Description
F	≥30% Cover by rhizomatous ferns (hayscented, New York, and northern bracken fern)
ML	≥15% Cover by mountain-laurel
LS	≥30% Cover 5–20 ft (low shade) by trees or shrubs other than oak.
OT	≥30% Cover below 5 ft by vegetation other than oak, blueberry, or huckleberry
BB	≥30% Cover by blueberry or huckleberry
NO	<30% total vegetation cover below 5 ft (i.e., mostly bare)

Categories in the table are not mutually exclusive, and care must be taken to assign a plot to the first class whose description it fits when the table is read from top to bottom.

Form B *(Sprout-Origin Regeneration)*

1. At every other plot center as established previously, measure the dbh for all oaks 2 in. dbh or more within an area of 1⁄20 ac (sweep a 26.3-ft radius with a tape measure) and tally the results under the appropriate species name and diameter class on Form B. For example, a 16-in. black oak would be tallied in the "black oak" row and the "15–18 (in.)" column. Tally oaks from all plots together.
2. Record the total number of overstory plots on Form B and divide this number into the total tally for each species and diameter class to calculate the mean number of trees per 1⁄20-ac plot. Enter these values in the "mean density" rows, rounding to one decimal place. For example, if 11 black oaks were tallied in the 15- to 18-in. diameter class on 30 plots, the mean density would be 11/30 = 0.37 = 0.4. Multiply mean densities by the respective "stocking factors" and enter the products in the "sprout stocking" rows. Sum the sprout stocking values for each species and record the sum at the far right of the row, under "species total." Sum species totals and record under "Expected Sprout-Origin Stocking." This value represents the expected contribution made by oak sprouts to stocking in the third decade after harvest, as a percentage of full (100%) stand stocking.

Form C *(Regeneration and Vegetation Cover Summary)*

Complete Form C using the appropriate values from Forms A and B. Calculate expected total oak stocking as the sum of seedling- and sprout-origin stocking. This represents total expected oak stocking in the dominant, codominant, and intermediate crown classes at some point in the third decade when average stand density is 1,000 stems ac^{-1} and the average dbh is 3.7 in. Calculate the percentage of plots on which inhibiting vegetation is expected to be problematic by summing percentages for fern (F), mountain-laurel (ML), low shade (LS), and other vegetation (OT). Circled data elements 1–5 will be used in the decision charts.

Determining a Prescription

Beginning at the top of Chart 1, use Charts 1 and 2 to identify the best prescription to meet your regeneration goal. Chart 1 is used exclusively if conditions are immediately suitable to an overstory removal, perhaps including postharvest fencing against deer and a basal herbicide spray to control problematic levels of low shade. Chart 2 is used if expected oak stocking is inadequate or if inhibiting vegetation (other than low shade) is at problematic levels.

First, consider whether "total oak stocking" is consistent with the desired future stand condition. As a guide, oak stocking of more than 50% represents an oak-dominated stand during the third decade after harvest. This is the kind of stand that provided the data for our regeneration models, and owners and managers of such stands

Stand: ____________________ Date: ________________ Collected by: ______________________________

Form B. Overstory Data Collection for Sprout-Origin Regeneration (1/20th-acre plots)

	Diameter Class (inches)									
	2-6	7-10	11-14	15-18	19-22	23-26	27-30	31-34	>34	
Chestnut Oak (count)[1]										
Number of Plots[2]										
Mean Density										Species Total
Stocking Factor	x 9.4	x 8.9	x 8.3	x 7.6	x 6.7	x 5.8	x 4.9	x 4.0	x 3.1	
Sprout Stocking										
Northern Red Oak and Scarlet Oak (count)[1]										
Number of Plots[2]										
Mean Density										Species Total
Stocking Factor	x 6.6	x 6.3	x 6.0	x 5.7	x 5.3	x 4.9	x 4.5	x 4.1	x 3.7	
Sprout Stocking										
Black Oak (count)[1]										
Number of Plots[2]										
Mean Density										Species Total
Stocking Factor	x 6.9	x 6.0	x 4.7	x 3.3	x 2.0	x 1.1	x 0.5	x 0.3	x 0.1	
Sprout Stocking										
White Oak (count)[1]										
Number of Plots[2]										
Mean Density										Species Total
Stocking Factor	x 4.7	x 3.4	x 2.2	x 1.2	x 0.6	x 0.3	x 0.2	x 0.1	0.0	
Sprout Stocking										
									Expected Sprout-Origin Oak Stocking	

[1]Counts are cumulative over all sample plots in stand.
[2]Total number of sample plots (identical for all cells).

usually prefer to retain that composition in the next rotation. However, that goal is often difficult or impossible, and the oak component usually diminishes when oak-dominated stands are regenerated. Oak stocking of 30–50% represents a strong oak component, with other species occupying the majority of the stand. Oak stocking of 15–30% represents a minor oak component and less than 15% represents little or no oak. Use this information to answer the first question on Chart 1. Follow Chart 1 and, if needed, Chart 2 until a prescription is found. Reference numbers in some question boxes are keyed to data elements in Form C.

Form C. Regeneration and Vegetation Cover Summary

Expected Seedling-Origin Oak Stocking		Vegetation Class Percentages							(4) Height > 0	(5) Height ≥ 10ft
Expected Sprout-Origin Oak Stocking		F	ML	LS	OT	(2) Inhibiting Vegetation (F + ML + LS + OT)	(3) BB	NO		
(1) Total Oak Stocking (Seedling + Sprout)										