

UPLAND OAK AND WHITE OAK SILVICULTURE PRACTICES SERIES FOR-161

Enrichment Planting of Upland Oaks

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Practice Objective and Description

Enrichment plantings have variable success, because standards for seed source, seedling quality, and competition control are generally not utilized in operational settings (10). Additionally, much of the research used to guide management was conducted in the western portion of the Central Hardwood Region where competition intensity is relatively low. The use of high-quality, bare-root seedlings (Figure 1) in productive forests east of the Mississippi River has received only limited attention but has shown improved success over more traditional planting operations.

These guidelines are based on the most advanced research available using high-quality, bare-root seedlings of northern red oak (*Quercus rubra*) and, to a lesser extent, white oak (*Q. alba*), but research is still evolving. This application is focused on moderate to productive sites (upland oak site index 65-80) where development of large advance natural oak reproduction is often problematic (27).

The primary benefit of enrichment planting, if conducted properly, is it provides an immediate input of advance oak reproduction into the system. The objectives of the enrichment planting practice are to:

- provide an immediate increase in the density of advance oak reproduction for the purposes of enriching or supplementing existing natural regeneration sources, or
- to reintroduce oak reproduction in stands where there is very low oak regeneration potential from natural sources including seed, advance reproduction, and stump sprouts.

Figure 1: High-quality (1-0) northern red oak seedlings from a commercial nursery. Measurement scale on table is cm. Photo Courtesy: Stacy Clark, USDA Forest Service.

When to Apply

Artificial regeneration can be used in conjunction with a variety of regeneration practices and even some intermediate stand treatments, particularly in stands where advance oak reproduction is limited. Like many silvicultural practices in hardwood stands, however, costs and resources of the enrichment planting practice can be prohibitive and must be weighed against costs and resources associated with natural regeneration methods. For example, it might be justified to plant in a stand that is scheduled for a regeneration harvest, that has insufficient advance reproduction present, where post-harvest management practices (e.g., herbicide) are not restricted, and harvest revenue can be used to pay for the cost of planting. The manager should consider several conditions and factors to justify the costs and resources associated with planting:

- The landowner objectives include maintaining or restoring a proportion of the oak component.
- The reproductive capacity of the stand is not adequate to maintain the desired future oak component in anticipation of or immediately following a regeneration harvest or practice.
    - Reproductive capacity is determined by estimating the den-

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  - sity of competitive oak regeneration sources, including large seedlings and stump sprouts (26) (27).
  - Density of natural advance reproduction will generally increase as site productivity decreases (2).
- The stand contains over mature or declining oak trees with poorly developed crowns that have low seed production or sprouting potential
  - The threshold for maximum seed production in forests is approximately 22 inches DBH for northern red oak and 26 inches dbh for white oak (11).
  - Oak stump sprout probabilities decline with tree diameter. Northern red oak and white oak sprouting probabilities fall below 50% for trees larger than 8 inches and 16 inches DBH, respectively (18).
- There is an immediate need for advance oak reproduction, such as following a regeneration harvest or a natural disturbance event:
  - There is a regeneration harvest or an intermediate stand treatment that has already occurred or is imminently planned that will result in sufficient light to stimulate regeneration. Typically, this is from a reduction in overstory residual basal area to a maximum of 60-75 ft^2 per acre or 60% full stocking, or a minimum of 30-50% full sun. Follow-up vegetation management may be needed to maintain oak dominance over time.
  - The oak overstory has suffered significant mortality or is experiencing oak decline, spongy moth (formerly known as gypsy moth) defoliation, storm damage, disease, or other natural disasters.
    - The planting needs to occur within 2 years of the harvest or disturbance event and follow-up vegetation management may be needed to maintain oak dominance over time.

Common Examples of Where the Practice is Applied

This practice is most effective on sites of intermediate site quality [site index 65 to 80 for upland oaks]. Consider targeting your planting locations that have site characteristics that increase the competitiveness of planted seedlings and allow for easier access for planting. Specific recommendations are:

- Select planting areas where the reproductive capacity of the stand is below desirable levels. The probability of oak regeneration sources being competitive at the time of crown closure can be calculated from their size and density, with large seedlings (>2-4 feet in height) and stump sprouts being the most competitive (26) (27).
  - If you have abundant natural oak reproduction, consider silviculture methods to recruit those seedlings into a competitive size class prior to the overstory harvest. However, be aware that many of these methods require a relatively long time frame and are highly variable in their efficacy depending on localized site conditions.
- The best sites for planting will be on sites of moderate productivity where natural oak reproduction is insufficiently competitive but competition can be controlled with relatively infrequent entries. Site index between 65-80 upland oak is ideal.
  - Site index greater than 80 will generally require frequent and intense competition control, considered impractical for many managers. Other valuable species can often be grown on these highly productive sites more easily and cheaply than using methods to naturally or artificially regenerate oak species.
    - Though not adequately tested, leaving a higher residual basal and opening the canopy in stages (e.g., a shelterwood establishment cut followed by a shelterwood removal cut and competition control) may improve effectiveness of planting on more productive sites.
  - Site index less than 65 typically results in sufficient natural oak reproduction, particularly white oak, if a seed source is present, because many oaks are more competitive on lower quality sites compared to other species.
    - An exception could occur where oak reproduction is absent, such as pine plantations being converted to hardwood stands.
- Consider selecting areas that have relative ease of access (e.g, short distances to roads, gentle topography) for planting and pre- and post-planting competition control using herbicides or mechanical methods.
- Select stands where deer herd density is relatively low or can be reasonably controlled with fencing or other measures.
- Select stands where prescribed fire will not be used for at least 5 to 15 years. Seedlings will need time to either establish thick bark capable of resisting low-intensity prescribed fires or to have a well-developed root system to sprout prolifically following top-kill from a prescribed burn (estimated to be at least 5 years after planting (8)). Prescribed fire that top-kills planted seedlings will decrease their overall height, but might also help control smaller sized competition.

Examples of Conditions or Situations that Limit Effectiveness

This practice can be applied across a wide range of site conditions and prescriptions. Seedling quality and site conditions are the factors most influential in limiting success of this practice.

Seedling Factors:

1. Do not plant small or poorly developed seedlings with low root and stem growth potential (5) (6) (20) (see Section 9).
2. Do not plant seedlings with symptoms consistent with Phytophthora (*Phytophthora cinnamomi*) root rot disease (Figure 2). Ask the nursery manager about Phytophthora issues as many southern nursery soils will contain this pathogen, particularly in years with excessive rainfall. Red oak is more susceptible than white oak.
3. Mishandling trees during and after lifting will intensify transplant shock. Ask the nursery manager about seedling storage (length of storage time should be shortened (14)) and packaging to ensure seedlings' roots stay moist

and protected from the elements (over packing can lead to root desiccation). Do not leave trees in freezing or hot temperatures and protect them during transport from wind, sun, and breaking seedling stems.

4. Seedlings should not be top-clipped, as this will degrade their ability to develop strong root systems, increase die-back of the largest seedlings, increase browsing probabilities, and decrease the ability to distinguish high-quality seedlings from low-quality seedlings (20) (39) (Clark, unpublished data) (Figure 3).
5. Avoid improper planting techniques. Seedlings should be planted with the root collar flush with the ground. The use of proper planting tools should facilitate high-quality, large seedlings. A standard dibble bar may not work with larger sized oak seedlings.

Figure 2: Root rot disease caused by Phytophthora cinnamomi infected this nursery red oak seedling. Symptoms consistent with this disease are black lesions on the root system and wilting and yellowing leaves. Photo Courtesy: Steve Jeffers, Clemson University.

Site Factors:

1. Select sites with adequate soil conditions. Stony soil, particularly larger rock or other fragments, will limit augers or planting bars. Poorly drained or compacted soils will facilitate root rot diseases.
2. High, unmitigated deer herd densities can result in repetitive browsing to the terminal buds of newly planted seedlings.
3. Seedlings require at least 30-50% full sun to reach their maximum growth potential (10). High residual basal area (greater than 75-85 ft^2 per acre) or stocking (greater than 60%) results in relatively low light levels that reduce growth of planted seedlings.
4. Invasive species, particularly vines such as honeysuckle (*Lonicera spp.*), will reduce survival and growth.
5. Site index greater than 80 for upland oak species will generally have severe competition that is difficult to control and quickly overtops planted seedlings.

Post-implementation Conditions

This practice should result in enrichment of oak reproduction by planting seedlings within a stand that has been treated or otherwise disturbed so that overstory and midstory tree densities have been reduced. Specific conditions include:

- Planting density up to 440 trees per acre of quality-grown and visually graded seedlings.
  - Consider targeting planting areas into small blocks scattered throughout the stand in locations with better access or more conducive site conditions for planting (e.g., less rocky soil or less steep slopes).
- A regeneration harvest, intermediate stand treatment, or natural disturbance event that reduces the basal area to a maximum of 60 to 75 ft^2 per acre or 60 % full stocking, or a minimum of 3%-50% full sun.
- Midstory or non-commercial stems from undesirable species should be treated prior to planting and treated with herbicides to prevent sprouting.
  - Mechanical control without herbicide is generally ineffective at controlling competition (35) (37).
- Animal browsing should be mitigated if needed, using fencing, shelters, or repellants.

Figure 3: Unclipped northern red oak seedlings on the left versus top-clipped seedlings on the right in the late growing season (seedlings were clipped mid growing season). Insets show terminal bud development on unclipped trees and clipping damage on clipped trees. Clipped seedlings had reduced growth and it was more difficult to discern high from low quality seedlings after lifting compared to the unclipped seedlings (Clark, unpublished data). Photo Courtesy: Stacy Clark, USDA Forest Service.

Practice Use Within a Silvicultural Framework

This practice can be implemented within a variety of silvicultural prescriptions, but planting should generally coincide with the stand initiation phase of development. The practice could also coincide with a thinning to at least a B-level (12) to develop larger oak advance reproduction before release by a regeneration harvesting. Specific prescriptions will depend on site conditions (e.g., site productivity, species of competition) and management objectives and constraints (e.g., restrictions on use of herbicides, visual quality objectives).

- For best results, enrichment planting can be conducted immediately following even-aged regeneration treatments including a silvicultural clearcut, a shelterwood establishment cut, or a shelterwood removal cut.
  - The challenge is to regulate light conditions to promote planted oak seedling survival and growth over that of

competitive species.

- Seedlings can also be planted inside or along edges of patch clearcuts, group openings or gaps. Planting within uneven-aged treatments such as group selections, has not been adequately studied, but research on natural oak reproduction suggests openings should have a diameter of least one to two tree heights or be at least 0.1 to 0.4 acres in size (25).
    - Seedling response and competition effects will vary according to position within the gap and slope and aspect of the gaps (28). South-facing slopes and northern edges of gaps will receive more direct sunlight.

Relationships between site productivity, residual crown cover, and severity of competition are important to consider when applying this practice within the silvicultural framework, and the key to success is controlling light levels to balance the survival and growth of planted oak seedlings with that of their primary competitors (10):

- As site productivity increases and residual basal area decreases, competition effects will become more severe, but growth of planted seedlings will also increase.
    - Underplanting in a shelterwood establishment cut followed by canopy reductions over time to incrementally increase light levels might favor planted oak seedlings compared to a single intensive disturbance (e.g., clearcut), particularly on higher quality sites (16). Timing the release of oak seedlings once they are deemed competitive under residual canopies is important to favor planted seedling growth over that of shade-tolerant competition. Planting in midstory removal treatments (26) has not been effective, because light levels are too low to maintain photosynthetic demands, and trees are more susceptible to repetitive deer browsing (7) (8) (24).
    - On lower quality sites, planting under a lower residual basal area can be tolerated because competition will be less severe.
        - However, planting in more open environments can increase risks associated with animal browse and exposure to environmental factors such as frost and heat stress (10).

Data and Observations

Specific observations should be taken prior to and just following implementation of enrichment planting to help determine the suitability of this practice and to mitigate barriers to success. Prior to planting, observations should include the following factors:

- Stand conditions that are conducive for planting. Determine accessibility to roads, slope steepness, and stoniness of soil that can limit practicality of planting or increase cost of planting.
- Determine site productivity. Site index between 65 and 80 is best for oak enrichment planting. For white oak, lower site index (65-75) will be best as this species is slower growing and less competitive than red oak.
- Assess current presence or likelihood of non-native species spread following planting that can limit survival and growth of planted seedlings. Species such as oriental bittersweet (*Celastrus orbiculatus*) and honeysuckle (*Lonicera spp.*) are particularly detrimental.
- If the stand has not yet been disturbed, assess density of advance oak reproduction by size class (less than 2-foot and greater than 2-foot-tall seedlings) and/or density of oak midstory/overstory trees small enough to sprout following harvesting (18); consider planting if oak regeneration sources are insufficient and there is not sufficient time to develop natural oak regeneration sources prior to the planned harvest.
- If the stand has already been disturbed, assess densities of competitive oak regeneration sources (large advance reproduction from seedlings or stump sprouts). If oak regeneration sources are insufficient, consider planting.
- Determine deer herd densities and do not plant if deer densities are relatively high and mitigation measures (e.g., fencing, shelters, repellents) cannot be implemented.

Considerations for observing conditions in the first few years following enrichment planting should include:

- Conduct walk-through inventories to assess species and heights of competing vegetation in relation to planted seedlings.
    - Consider release treatments using targeted herbicide applications if planted seedlings are not in competitive positions.
- Determine need for non-native species control.
- Monitor for deer browse and consider mitigation measures if needed.

Implementation, Timing, and Other Considerations

There are no universally accepted criteria for site selections and prescriptions for enrichment planting, because management objectives and resource constraints will vary. Additionally, prescriptions will vary by species, but research is sparse for most species. There are some generally accepted criteria related to seed source, genetic diversity, and seedling quality, and some practical guidelines to facilitate logistics of planting:

<u>Seed source and seed collection</u>

Communicate with the nursery manager about seed sources. The trees need to be locally adapted (collected within same physio-graphic province) and genetically diverse (from at least 10 mother trees with relatively equal distributions of acorns). Many nurseries buy seed from any available seller, particularly in years with low acorn production, without regard for genetic diversity or local adaptability. Guidelines for seed collection have been developed (Appendix 1 and (9)).

Seedling quality

Controlling for seedling quality is the most efficacious factor in the artificial regeneration process. Seedling quality is defined as trees that have good growth potential and have relatively large stem heights, root-collar diameters, and a well-developed root system, particularly in number of first-order lateral roots (Figure 1) (5) (19) (23). Hardwood seedlings are generally grown as 1-0 (or sometimes 2-0 for white oak species) bareroot nursery stock, and these recommendations do not pertain to other seedling stock such as container seedlings. Seedlings should not be top-clipped (see Section 5). Small seedlings will not obtain the size of larger seedlings in height growth (Figure 4) and are more prone to animal browse and shade from competing vegetation (6). Larger-size seedlings have shown good survival and competitive ability, even on moderate to high-quality sites (3)(6)(8):

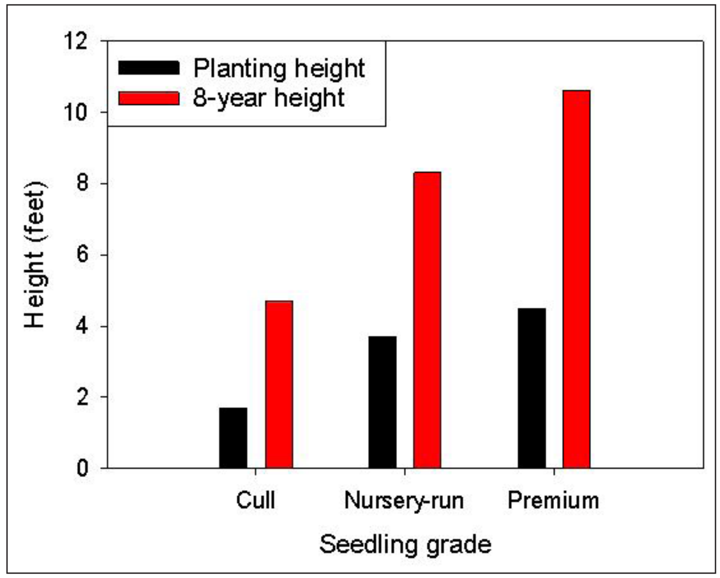

Figure 4: Increased mean growth from seedling grading after 8 years for northern red oak seedlings planted in a commercial clearcut in southwestern North Carolina (Clark, unpublished data).

- Stem height is the most practical metric to use to distinguish quality seedlings and has been strongly correlated to root development and root-collar diameter (5). Most nurseries do not grade seedlings or only discard the very smallest seedlings. Seedlings will need to be graded prior to planting, and overages resulting from grading will need to be accounted for when purchasing trees. This may seem wasteful, but it saves resources over the long term. Planting poor quality seedlings will result in planting failure (24).
    - For northern red oak (1-0), seedlings should average approximately 3 feet in height, and for white oak (1-0), seedlings should average approximately 2 feet in height. Seedlings will vary in quality from year to year, even within the same nursery. In some years, discarding approximately 50% to 60% of seedlings prior to planting is required.
    - Other species: Grading standards have not been well developed or tested for most other species, but a good rule of thumb would be to discard trees less than 2.5 feet in height for red oak species and 1.5 feet in height for white oak species. Kormanik and others (19) provided limited data on expected size of seedlings of various species when grown in a nursery using protocols to produce high-quality seedlings.
    - Lift when dormant (typically February-March).
    - Pruning roots immediately following lifting or just prior to planting is recommended to facilitate planting and to promote new growth from the severed end of lateral roots (21). Prune lateral roots approximately 6 inches from the main tap root.
    - Do not allow planting crews to trim roots without proper supervision.

Site preparation

Site preparation will increase the probability of planting success. Specific methods will depend on specific site conditions, financial constraints, and management objectives:

- Reduce slash loading/concentrations for ease of planting (although slash may inhibit deer access to seedlings) using mechanical or prescribed fire methods.
    - Consider moving slash away from residual overstory trees to reduce fire damage.
    - Management of slash also reduces rodent habitat.
- Prescribed burning prior to planting can also help control competition and slash and provide a short-term nutrient boost to planted seedlings. Ideally, burns should be timed just prior to bud-break in early spring to have the best effect on competition control, but do not burn just after planting establishment.
- Herbicides to control stump sprout competition from undesirables is important. Control measures can be tailored to specific conditions and needs and can include cut-stump treatment, streamline spray of stump sprouts, or pre-harvest hack and squirt.
    - Mechanical control without the use of herbicides generally has no effect on competition in the long-term (36) (38).

Planting methods

The simplest mistake can ruin a planting. Pay attention to these considerations during the planting job:

- It is beneficial to shorten the time between lifting from the nursery and planting in the field. Improper or lengthened storage time following lifting will decrease seedling survival and growth rates (14). If seedlings must be stored from the time of lifting to the planting period, store them in a cooler or a cool dry space, and ensure the seedling bags are not over packed and are tightly wrapped to avoid desiccation.
- The wrong planting tool can ruin the best-planned planting job. A planting shovel, a modified KBC bar (modified to be

approximately 2 inches longer on each side of the blade, Figure 5), or an auger with a 6-inch bit is recommended to plant larger seedlings. A standard dibble bar may not work with larger-sized seedlings. Seedlings are best planted using a bar with a wide, deep blade.
- Supervise the planting crew. Make sure that the large seedlings are appropriately distributed across the site. Planters will plant the large seedlings first to lighten their loads. It is important to have enough people to shadow the planters to ensure the seedling roots are not further trimmed and planted correctly. Seedlings should be planted to ensure the root collar is flush with the ground.
- Trees should stay in bags, preferably in a shaded location, until the planter takes them. The bottom of the bags should be facing the wind, so the roots won't dry out. The fatal mistakes are for the roots to dry out prior to planting and to leave air pockets in the planting hole.

Figure 5: RA KBC bar modified to increase width of the planting bar to facilitate planting larger size seedlings. Photo Courtesy: Stacy Clark, USDA Forest Service.

<u>Spacing</u>
Spacing can be modified to meet landowner objectives, but planting at a lower density (e.g., minimum spacing of 10 x 10 foot=maximum density 440 per acre) than is standard for pine seedlings is recommended due to the higher planting costs associated with planting hardwood seedlings. Also, hardwood plantings are generally conducted to enrich a site, not convert to a single species plantation. A planting density of 300 trees per acre using these guidelines has been shown to result in a recruitment density of 50 trees per acre at years at 7 to 10 years after planting (3).

<u>Animal browse protection</u>
The best approach to mitigate animal browse is to plant taller trees that will more quickly escape browse pressure. Seedlings taller than 1.5-2 feet in height will escape rabbit browse, and seedlings taller than approximately 3.5-4 feet tall have the best chance for escaping deer browse damage. Seedlings larger than 4 feet will only occur in a few species like northern red oak and represent a relatively small fraction of seedlings from the nursery (5) Browsing to the lateral limbs is acceptable, but browsing to the terminal bud will result in repetitive browse that will eventually kill the tree. Trees can be sprayed with a repellent at regular intervals (once every 2 months). Tree shelters (minimum 4 feet tall) and fences (minimum 6 feet tall) can also be erected, but these can be costly and difficult to establish, particularly in forested situations. Shelters and fences will need periodic maintenance.

<u>Post-planting maintenance</u>
Competition control will be needed for most plantings, even those using the highest quality seedlings and on moderately productive sites. Unfortunately, the timing and number of re-entries and their effectiveness has had limited study with oak plantings, particularly on sites with yellow poplar (*Liriodendron tulipifera*) as a primary competitor. There is a tradeoff between cost efficiency of post-planting maintenance and planting success rates that is not well understood. Current recommendations are:
- Competition control using a targeted herbicide application at least once within the first eight years following planting to ensure trees remain in competitive position. Treat stems that are within a 45-degree cone of interference with the crown of the target seedling. Only release seedlings that will benefit from a release (seedlings that are not within 50% to 60% of the height of competing stems will probably not benefit from a release). A basal bark spray can be used by applying a 25% solution of triclopyr ester mixed with an oil carrier to the lower 6 inches of the stem you wish to kill. Basal spraying works best on thin-barked species less than 6 inches DBH. Apply the herbicide solution completely around the stem, until it begins to run off. A hack-and-squirt application of triclopyr ester or imazapyr can also be applied to larger stems to better suit specific site conditions.
- Once the trees have achieved crown closure at year 12 to 25, a crop tree release can be implemented (30). This involves killing undesirable trees (using a chainsaw or herbicide injection) surrounding the desirable tree, but the desirable tree's crown must already be in an upper crown position for this method to be effective.

Site Considerations
Considerations for site selection includes density of advance natural oak reproduction, site productivity factors, harvest considerations, and site conditions that facilitate planting. Specific recommendations:
- Select planting areas where the reproductive capacity of the stand is below desirable levels.
- The best sites for planting will be on sites of moderate productivity where natural oak reproduction will probably not be competitive, but competitive species are less intense or can be controlled more easily. Site index between 65-80 for upland oak species is ideal.
  - As site productivity increases and residual basal area decreases, competition will be more difficult to control, reducing the chance of planting success. However, low quality sites (i.e., site index lower than 65 for northern red oak) typically have sufficient oak reproduction that will be competitive, negating the need for planting.
  - Though not adequately studied, leaving a higher residual basal area (65-75 ft^2 per acre) as site productivity increases may favor the competitive ability of planted oak seedlings by reducing severity of competition (Figure

6). Seedlings will need to be released using one or two entries over time to ensure shade-tolerant species don't dominate (10).
        - On more productive sites, a phased entry approach (e.g., shelterwood prescriptions coupled with competition control treatments) may be best for planted seedlings to help reduce competition severity.
- Sites should be selected that have received an initial harvest to a maximum of 60 to 75 ft^2 per acre, including treatment of midstory stems with combinations of mechanical cutting, girdling or hacking, and herbicide application to produce a minimum of 30% to 50% full sun to meet the seedlings' physiological demands for growth.
    - Underplanting in midstory-removal treatments, also known as the 'oak shelterwood' (26), is not recommended due to poor growth and damage following overstory removal. Light levels were not adequate to sustain seedlings' photosynthetic demands resulting in root atrophy and top dieback (7) (8) (24).
    - A commercial clearcut can be used, particularly on lower quality sites, but will probably require the most post-planting maintenance to control competing vegetation compared to variable retention, shelterwood harvests, or thinnings. Clearcuts can also leave seedlings exposed to animal browse, frost damage, and other environmental stresses (10).
    - For gaps or group openings, consider planting along gap edges, particularly along the northern edges of gaps where direct sunlight is the most intense (28). Trees planted in the gap centers will exhibit the fastest growth but will also endure the most intense competition (32).
- Select sites that have access and topography conducive for planting crews, deer browse protection measures, and follow-up competition control treatments (e.g., moderate slopes, low soil rock content, proximity to roads).
    - Consider targeting your planting locations into smaller sized groups or blocks within the stand that can be more effectively managed in the future compared to widespread planting across the entire stand.
- Select sites that are not compacted or have a hard pan and are well drained.
    - Do not plant in skid rows or landings.

Figure 6: Examples of a competitive northern red oak seedling in a shelterwood harvest in Tennessee 15 years after planting. The top of the measuring pole is at the terminal bud of the planted seedling. Site index was estimated to be 82 for northern red oak. Photo Courtesy: William Durham, USDA Forest Service.

Barriers to Success

As with natural regeneration practices, there are significant barriers that impede success of the enrichment planting practice:

- Seed sources, specifically genetically improved sources, that are adapted for local conditions are generally lacking (40).
    - There is a lack of infrastructure established for seed orchards or seed production areas for most areas resulting in the use of seed from unknown sources sold by commercial seed sellers to commercial tree nurseries. Using seed from northern sources in southern planting areas can lead to failure due to poor adaptation of seedlings to their planting environment.
- Because most planting in the eastern United States is with smaller-sized pine seedlings, there are a lack of planting contractors that have experience in planting large hardwood seedlings.
    - Successful planting will require education and training of planting crews as well as paying them appropriately for planting larger-sized seedlings.
- High deer herd densities will limit success due to repetitive browsing that can kill planted oak seedlings. Mitigation will require fencing, shelters, repellants, or use of larger-size trees that escape deer browse more quickly.
- Administrative, legal, or cost barriers can restrict use of herbicides and/or prescribed fire to conduct site preparation and competition control post-planting.
- Planting is a cost to the landowner, and lack of revenue from timber operations to pay for planting can be a barrier in implementing this practice.

Monitoring

Monitoring will be important in the early years after planting:

- Monitoring in years 1-3 after planting should include:
    - Survival
    - Occurrence of repetitive deer browsing until trees are above browse line (approximately 4.5 feet)

    - Evidence of root rot disease (Figure 2) or other pests, exhibited by wilting, defoliation, or other symptoms of stress. Consult an extension forester or forest health expert.
    - Height growth and competitive abilities. Apply competition control release measures when needed.
- Monitoring in years 3-12 after planting should include:
    - Planted seedlings' competitive abilities. Trees should be approximately 70% to 80% of the height of tallest understory competitor. Apply competition control release measures if needed.
- Monitoring in years 12-25 after planting:
    - Once the trees have achieved crown closure, a crop tree release can be implemented (30). The planted tree's crown must already be in an upper crown position for this method to be effective.

Costs

Costs of the enrichment planting practice will include the costs associated with purchase of seedlings, planting, site preparation, and post-planting maintenance (37).

- Costs associated with planting can be offset with revenues from timber sales or from other programs such as landowner cost-share grants or assistance programs.
- Seedling costs vary by nursery but generally decrease as the number of seedlings purchased increase. Costs for hardwood seedlings range from $0.40 to $0.70 per tree when buying between 100 to 1000 trees, respectively. Most nurseries do not grade seedlings adequately, so cost estimates should include overages related to discarding smaller size seedlings.
- Planting contractors are more accustomed to planting smaller trees such as pine, so costs should be adjusted to compensate for the increased time and effort needed to plant larger seedlings. Consider paying contractors by the number of trees planted rather than the size of the area planted. Costs could range between $0.50 and $1.00 per tree for high quality seedlings.
- Costs associated with any required site preparation treatments (ex. prescribed fire and/or herbicide treatments) must be determined.
- Deer repellant, fencing, and shelters add costs to any planting and will vary depending on the product selected. Cost of shelters range from $3 to $6 per tree while cost of repellant averages $0.10 per tree (not including labor costs of shelter erection or repellant application); however, repellants have to be applied at frequent intervals (every 2 to 3 months) in the first couple of years until seedlings reach browse line (4-4.5 feet), increasing costs associated with labor for application.
- Post-planting maintenance includes release of seedlings using mechanical and herbicide applications. Costs typically range from $100 to $300 per acre.

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White Oak

White oak is more difficult to regenerate naturally and artificially than red oak species due to its inherently slower growth patterns. Culturing white oak artificially is more difficult due to its fall germination phenology, slower growth in the nursery, and larger root system making planting more difficult. Specific concerns are:

- Seed sources (see Appendix 1 for more information):
    - Most states do not have white oak seed orchards or seed production areas for reliable acorn collections or genetically improved seedlings. Consult with the nursery managers on seed sources, as they sometimes rely on sources that are unknown, particularly in years with poor acorn crops.
    - White oak has intermittent annual crops. In poor mast years, weevils destroy the majority of sound acorns.
- White oak is predicted to increase in overall suitable habitat related to climate change because it has a wide range of tolerances to disturbances and grows across a large geographic range on a diversity of site types and conditions; however, it is predicted to lose habitat in the western part of its range (15).
- White oak grows relatively slowly in height compared to red oaks in the nursery but will produce a larger root system. In general, 1-0 seedlings are often too small for planting while 2-0 seedlings are too big (Figure 7). Work with the nursery manager to procure appropriate stock types for the planting. Ideally, assess seedling sizes in the nursery prior to planting to help develop appropriate procedures for planting, such as using larger planting bars (Figure 5).
    - Root system structure of white oaks consists of a relatively large tap root and well-developed lateral roots that make white oak more difficult to plant than most other oaks.
- White oak is the most shade tolerant of oaks, so seedlings can be planted under relatively high residual basal areas (greater than 65 ft^2 per acre) and a relatively wide range of silvicultural prescriptions.
- White oak is well adapted to sites with relatively low productivity, compared to species like northern red oak (less than 75 site index for upland oaks).

Appendix 1. Guidelines for acorn collection

1. Ensure you are prepared for collection. You will need collection bags/containers (cloth bags are best), buckets or tubs for floating/sinking acorns, areas to dry acorns, and coolers to store the acorns until sowing.
2. Collect only enough for what you will plant. Account for a 30% loss due to poor germination and an additional 40% to 60% loss due to seedling grading (i.e., discarding the smallest seedlings). See step number 11 to estimate acorn quantity. It may seem wasteful to collect more than three times the number of acorns than seedlings you will plant, but it saves money over the long run. Planting poor quality seedlings will result in failure (6) (22).
3. Number of sound acorns = (Number of desired seedlings ÷ percent germination rate) ÷ percent of acceptable seedlings during grading.
    - For example, you will need to collect 12,500 sound acorns if you want 3,500 northern red oak seedlings to plant, if you used a germination rate of 70% and a cull rate of 60% (or 40% of your seedlings will be acceptable to plant):
    - 12,500 sound acorns = (3,500 seedlings ÷ 0.70) ÷ 0.4
4. Collect from trees within the same geographic province as the planting location. Generally, collecting from trees within the same seed collection zone or adjacent seed collection zones as the planting area is a good rule of thumb to follow (33). Go to the Eastern Seed Zone Forum website (http://www.easternseedzones.com/) to find seed zone maps.
    - Pay attention to elevation. For example, if you are planting at 4,000 feet, then your collection needs to be from higher elevation trees that are approximate to this elevation.
5. Collect approximately equal amounts from multiple trees (at least 10 trees spaced at least ¼ mile apart from each other), and then bulk them together to ensure a good genetic mix. Genetics affect seedling quality and subsequent field performance (7).
6. You will want to visit collection trees multiple times starting at the peak of the acorn drop. Early dropping acorns tend to be non-viable. Collect acorns within two days of dropping.
    - For white oak, collect before they start germinating on the ground.
7. Ask your nursery manager if they conduct a float/sink test on acorns prior to sowing them. If they do not, then you will want to conduct your own float/sink test by placing acorns in a bucket or tub of water. Immediately discard floating acorns and remove sinking acorns for further processing (13).
8. If you conducted the float/sink test, lay out the sinking acorns on a table or on a mesh screen and dry for a few hours or overnight (Figure 8). The goal is to get rid of all water on the outside of acorns, but not lose any moisture from the

Figure 7: White oak 1-0 (left) and 2-0 (right) nursery seedlings. The 1-0 seedlings represent the tallest 30% of trees from the nursery. The 2-0 seedlings represent the tallest 40% of the trees from the nursery. Photo Courtesy: Stacy Clark, USDA Forest Service.

acorn itself. Protect drying acorns from predators such as squirrels.

9. Discard any debris such as leaves or twigs that will interfere with the machine sower at the nursery.
    - Discard any acorns with the caps on or that have visible cracks or holes.
    - For white oak species, discard acorns with radicals longer than 0.5 inches.
10. Bag clean acorns. Cloth or 2 mil bags are best for white oak, while 4 mil bags are best for red oak (34)].
11. Estimate the number of acorns. Bonner (1) provides seed yield data that can be used to calculate acorn quantity based on weight, but these data are most likely for acorns that have not been processed using the float/sink test; therefore, Bonner's seed yield data may overestimate quantity of sound acorns that have gone through the float/sink test.
    - Northern red oak seed yield data indicates a yield of 62 to 77 acorns per lb. after the float/sink test (3).
    - Be aware that acorn mass can vary among season to season, tree to tree, day of collection within a year, and acorn sizes (3) (23).
    - The most accurate method to estimate acorn quantity is to count out and weigh a representative sample of 100 to 200 acorns, and then weigh the entire collection.
12. Label bags with identifying information.
13. Place acorns in fridge/cooler between 37° F and 40° F with humidity control of less than 50%. Do not freeze them!
14. Deliver acorns to the nursery for sowing.

Figure 8: Acorns are drying and sorted prior to machine sowing. Photo Courtesy: Jason Maxedon, Tennessee Wildlife Resources Agency.

Additional guidelines specific for white oak:

- Seed storage is difficult for white oak, and seed cannot be stored for more than one year.
- It is often difficult to time sowing acorns immediately following fall acorn drop due to conflicts with nursery schedules in preparing beds. Radicals longer than 0.5 inches will break if machine sown, resulting in poor germination and seedling quality.
    - Store white oak acorns just above freezing temperatures in cloth or 2 mil plastic bags (34).

NRCS Conservation Practices

- Core Conservation Practice: Tree/Shrub Establishment (Code 612)
- Supporting Conservation Practice: Site Prep (Code 490)

"Caring for Your White Oak Woods" USDA Natural Resources Conservation Service, 2p.

The selection of prescriptions included in the Upland Oak and White Oak Silviculture Practice Series were established through consultation with silviculture researchers and state forestry management personnel across the region. The peer reviewed individual silvicultural prescriptions were authored by research silviculturists with significant experience in oak management. This series was designed to provide silvicultural guidelines that be used by practitioners and managers along with their knowledge and familiarity with local stand conditions, markets, and contractor expertise to make decision enhancing regeneration, recruitment, and growth and development of upland oaks with a special emphasis on white oak. Other publications in the Series and information on white oak sustainability can be obtained at www.ukforestry.org and www.whiteoakinitiative.org.

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