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Sustaining Northern Red Oak Forests: Managing Oak from Regeneration to Canopy Dominance in Mature Stands

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ABSTRACT

Across the range of northern red oak, managers have problems sustaining current stocking of northern red oak in forests. Oak species are adapted to frequent stand disturbances that reduce the abundance of shade tolerant competitors and control fast-growing pioneer species. A widely recommended approach to regenerating northern red oak is to develop relatively large advance reproduction by manipulating stand structure to provide adequate light to oak seedlings in the forest understory. One approach to develop large oak advance reproduction is to use the shelterwood method with woody competition control. Herbicides, mechanical cutting and fire can be used to manage competing woody vegetation. Underplanting shelterwoods with oak seedlings can be used to supplement natural reproduction. Where landowners desire to maintain some presence of mature forests at all times, alternative approaches such as the group selection method or shelterwood with long-term retention of a low density overstory may be used to promote oak regeneration and recruitment into the overstory. Once stand regeneration has been initiated, maintaining the desired level of oak stocking in dominant and codominant crown positions can be accomplished through crop tree thinning in young stands. Sustaining oak stocking requires a regime of managed disturbances that begin before stand initiation and extend through the first 20 to 30 years of stand development.

Keywords: northern red oak, silviculture, ecology, regeneration, thinning, stand development.

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INTRODUCTION

Northern red oak (*Quercus rubra* L.) is highly valued for its timber and acorn production. It is widely distributed throughout eastern North America occurring in a variety of ecoregions (Sander 1990). Northern red oak occurs on over 16.9 million ha in the eastern United States (Miles 2007), and successional replacement of this species across the landscape would be a major ecological and economic loss. Its current abundance and distribution is linked with the history of fire and land use during the past 200± years (Abrams 1992, Dey 2002, Dey and Guyette 2000, Pyne 1982, Whitney 1994, Williams 1989). Historic disturbances were important in the expansion and dominance of oaks across a diversity of ecological land types throughout eastern North America (Nowacki and Abrams 1992, Hicks 1998). Modern oak forests originated when logging, fuelwood cutting, charcoal production, woods burning, grazing, and agriculture occurred extensively and frequently in the eastern region, completing a progression toward increasingly greater oak dominance that began when Native Americans brought fire to the region (Pyne 1982, Cronon 1983, Williams 1989, Nowacki and others 1990, Abrams 1992, Whitney 1994, Abrams and McCay 1996).

However, disturbance regimes that once favored oak species have changed. Now, oaks are being displaced by shade tolerant tree species as forest succession progresses in response to small-scale, gap-type disturbances, or by shade tolerant or intolerant tree species following catastrophic natural disturbances or timber harvesting in the absence of frequent fire (Abrams and Nowacki 1992, Hix and Lorimer 1991, Johnson and others 2002, Lorimer 1993, Pallardy and others 1988). Loss of oak species is greatest on high quality sites where oak is competing with high densities of shade tolerant species and, in particular, fast growing species such as yellow-poplar (*Liriodendron tulipifera* L.) (Loftis 1983, Beck and Hooper 1986, Schuler and Miller 1995, Weigel and Johnson 2000, Weigel and Parker 1997). Sustaining current oak stocking levels in mature forests is a common management objective and challenge to forest managers. Loftis (2004) described the two "laws" of oak silviculture as being: (1) the presence of competitive sources of oak reproduction and; (2) disturbances that provide timely and adequate release for those sources. The purpose of this paper is to review the literature on northern red oak physiology, ecology and silviculture and synthesize it to give insight into how to regenerate mature forests and manage forest development to sustain northern red oak stocking.

OAK REGENERATION ECOLOGY AND MANAGEMENT

Sources of Oak Regeneration

It is important to consider the sources of oak reproduction when developing a prescription to regenerate northern red oak. Most oak species regenerate from new seedlings (stem and root system same age), seedling sprouts (stem age younger than root age), and sprouts from the stumps of overstory trees cut during harvesting (Johnson 1993). Oak reproduction present before the regeneration harvest is collectively referred to as advance reproduction, and the ability of trees, from seedlings to mature individuals, to contribute to stand regeneration through sexual or vegetative reproduction is known as regeneration potential (Johnson and others 2002). The goal then is to increase the regeneration potential of northern red oak sources of reproduction to maximize success in oak regeneration after harvesting.

Oak seedling and advance reproduction

Northern red oak produces good to excellent seed crops every two to five years (Sander 1990), and oak regeneration failures are not normally related to matters of seed production or germination (Lorimer 1993). During years of bumper seed crops, northern red oak-dominated forests can produce more than 600,000 acorns per hectare (Auchmoody and others 1993). Even in the low light of mature eastern hardwood forests, which often is below five percent of full sunlight (Lockhart and others 2000, Lorimer and others 1994, Miller and others 2004, Motsinger 2006, Parker and Dey in press), northern red oak acorns provide the energy necessary for first year seedling growth. Subsequent growth is usually hampered by low understory light, and within 10 years of germination most oak seedlings are dead (i.e., < 10 percent survival) (fig. 1) (Beck 1970, Crow 1992, Loftis 1988, 1990a). Any survivors are small in size.

Small (e.g., less than 1.0 cm basal diameter) northern red oak seedlings and seedling sprouts have low regeneration potential, (i.e., low probabilities of assuming dominant or codominant crown positions in the regenerating stand (Johnson and others 2002, Loftis 1990b)). The long-term dominance probability for red oak reproduction decreases

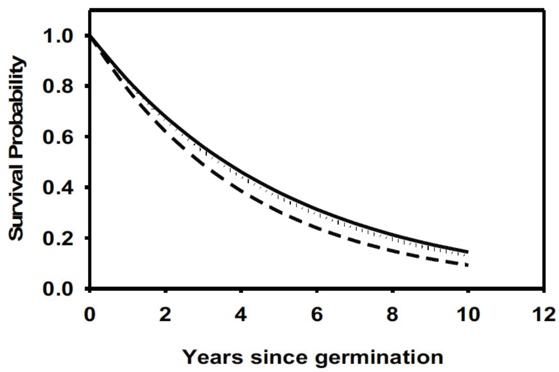

Figure 1— Survival of northern red oak seedlings in the understory of mature mesic forests in the southern Applachians and in northeastern Wisconsin (adapted from Beck 1970 (dashed line), Crow 1992 (dotted line), Loftis 1988 (solid line)).

with increasing site quality because they are out-competed by more rapidly growing species such as yellow-poplar and black cherry (*Prunus serotina* Ehrh.) (Loftis 1990b, Tift and Fajvan 1999, Weigel 1999, Weigel and Johnson 2000). Whether northern red oak reproduction is established naturally or artificially, its regeneration potential increases with increasing initial seedling size (fig. 2) (Johnson 1984, Loftis 1990b, Spetich and others 2002). The key to successful regeneration of northern red oak is to have sufficient numbers of large advance reproduction and potential oak stump sprouts to provide adequate oak stocking at the end of the regeneration period.

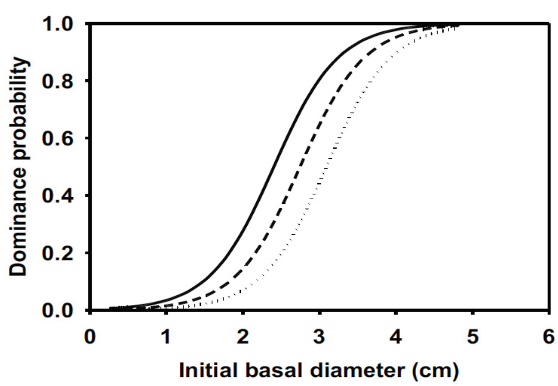

Figure 2— Dominance probability for free-to-grow northern red oak advance reproduction in relation to site quality eight years after clearcutting in the southern Appalachians (adapted from Loftis 1990b). Northern red oak site index 21 m (solid line), 24 m (dashed line), and 27 m (dotted line).

Oak stump sprouts

Another important source of oak reproduction is oak stump sprouts. They are the fastest-growing and most competitive source of oak reproduction (Johnson and others 2002). However, not all oak stems cut in timber harvesting produce sprouts. Thus, current levels of oak stocking in mature forests cannot be sustained by relying on stump sprout regeneration alone, hence the need for and importance of oak advance reproduction. The probability that a northern red oak stump produces a live sprout at the end of the first growing season is highest for smaller diameter trees (e.g., parent tree d.b.h. 10 to 30 cm), decreases with tree age, and increases with increasing site quality (fig. 3)

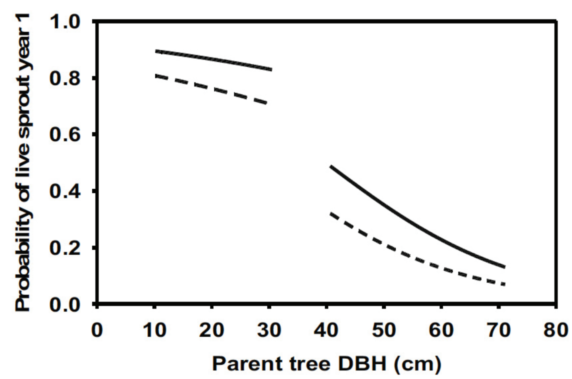

Figure 3— Probability that northern red oak stumps produce a live sprout in relation to initial d.b.h. of the parent tree, tree age and site quality one year after clearcutting in southern Indiana (Weigel and Johnson 1998b). Site index 18 m (dashed line) and 23 m (solid line).

(Weigel and Johnson 1998b). Larger trees have thicker bark that probably reduces sprouting by physically inhibiting development of vegetative buds. Also, older trees have reduced ability to produce sprouts due to physiological senescence. Trees on high quality sites may have improved vigor that initially enhances sprouting capacity.

Longer-term dominance probabilities were reported for northern red oak stump sprouts growing for 15 years in southern Indiana clearcuts by Weigel and others (2006). They defined dominance probability based on the crown class of the most dominant stem in the oak sprout clump. Weigel considered northern red oak sprouts successful, or "dominant" if they were in the dominant or codominant crown class. Northern red oak stump sprout dominance probabilities at stand age 15 decreased with increasing parent tree d.b.h. and age (fig. 4). Further, they estimated

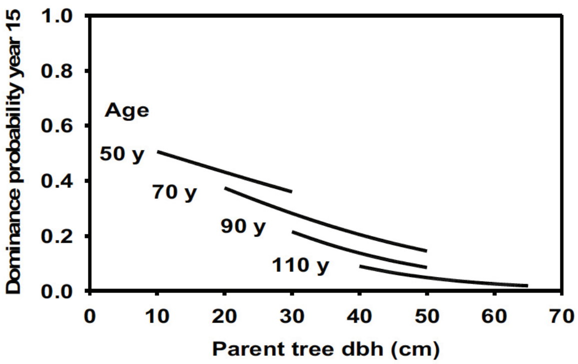

Figure 4— Northern red oak stump sprout dominance probabilities 15 years after clearcutting in southern Indiana (Weigel and others 2006).

conditional dominance probabilities of northern red oak stump sprouts and found that the longer oak stump sprouts persisted in regenerating stands the greater was the likelihood that they would remain dominant at stand age 15 (fig. 5). For northern red oak sprouts that were alive one year after harvesting, the probability they were dominant at age

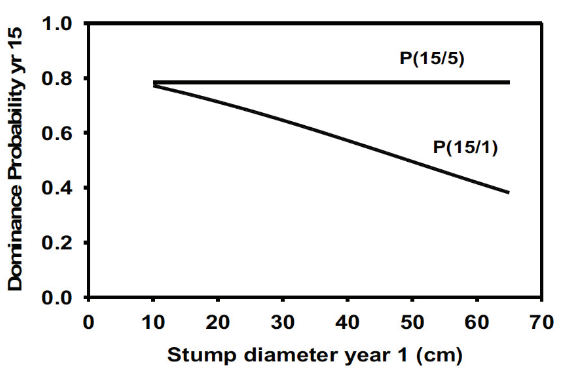

Figure 5— Northern red oak stump sprout conditional probabilities of dominance at stand age 15 in southern Indiana clearcuts – site index 18 m (Weigel and others 2006). Conditional probabilities at stand age 15 are estimated for northern red oak stump sprouts given: (a) they were alive in year 1 (P(15/1)), and (b) given they were alive in year 5 (P(15/5)).

15 decreased with increasing diameter of the parent stump. A sprout on a 10 cm diameter stump had an 80 percent likelihood of persisting as a dominant at age 15, whereas a sprout on a 60 cm diameter stump had only a 40 percent chance of remaining dominant. By stand age 5, if a northern red oak stump sprout was alive, it had a high probability of being dominant at age 15 regardless of the initial size of the parent tree. The less competitive northern red oak stump sprouts are eliminated by stand age 5.

Importance of Light

A primary cause of oak regeneration failure is low light levels (i.e., < five percent of full sunlight) in the understory of fully-stocked, mature forests; light so low that it is not sufficient to meet the respiratory demands and is prohibitive to the development of large oak advance reproduction (Abrams 1992, Gardiner and Yeiser 2006, Hodges and Gardiner 1993, Johnson and others 2002, Lorimer 1993, Lorimer and others 1994, Miller and others 2004). Heavy-shaded forest understories resulted from increasing forest structure due to changes in historical disturbance regimes. Over the past 50 years, the development of shade tolerant understory canopies has followed fire suppression, elimination of woods grazing by livestock, and changes in timber harvest practices (Lorimer 1993).

Northern red oak is intermediate in shade tolerance (Sander 1990). In many forest situations there is insufficient light to support increases in northern red oak seedling root and shoot biomass. Often, understory light is below the light compensation point for northern red oak, which is two to five percent of full sunlight (Gottschalk 1987, Hanson and others 1987). Light saturation of photosynthesis in northern red oak occurs between 20 to 40 percent of full sunlight (Ashton and Berlyn 1994, McGraw and others 1990, Teskey and Shresta 1985). Positive shoot growth in northern red oak seedlings requires more than 20 percent of full sunlight, and seedling diameter and height growth increases with increasing light levels up to 50 to 70 percent of full sunlight (Gottschalk 1994, Musselman and Gatherum 1969, Phares 1971). The physiology of northern red oak natural advance reproduction and planted bareroot seedlings is similar in forest understories. Both types of reproduction respond equally well to increases in light intensity and resource availability following shelterwood harvesting, midstory canopy removal, and other practices that reduce forest stocking and density (Parker and Dey in press).

MANAGING LIGHT IN FORESTS

Midstory Removal

Increasing light for oak advance reproduction in forest understories is accomplished by timber harvesting (e.g., clearcut, shelterwood, group selection), removing midstory or ground-level woody vegetation, or combinations of these two approaches. The density of midstory and understory woody vegetation can be reduced by mechanical cutting, herbicide application or prescribed burning. Stems of any size can be cut with saw or ax. Herbicides can be applied by spraying foliage, basal stem, or cut stump, or by stem injection depending on tree size and chemical used. When properly done, herbicides have the greatest potential to permanently eliminate most woody competitors with one treatment (Miller 1993, Quicke and others 1996, Groninger and others 1998, Kochenderfer and others 2001). Care must be taken in applying herbicides because oaks are susceptible to any chemicals used to control their hardwood competitors. Prescribed burning, which is commonly done in the spring as relatively low intensity surface fires, can reliably girdle or kill trees less than 12 cm d.b.h.; larger trees are able to survive these fires intact, with only minor stem wounding (Barnes and Van Lear 1998, Dey and Hartman 2005, Reich and others 1990, Waldrop and Lloyd 1991). Cutting larger trees followed by burning in subsequent years is one way to reduce stand density and increase light because the shoots of small diameter stump sprouts are very susceptible to low intensity fires. Spring surface fires can kill most acorns that are not buried under the wet duff or in mineral soil, and cause high (e.g., 70 percent) mortality of oak seedlings less than three years old (Auchmoody and Smith 1993, Brose and Van Lear 2004, Johnson 1974). Therefore, burning should be delayed for several years following a good acorn crop.

Whether mechanically cut or killed by fire, stems of smaller-sized (10 to 20 cm d.b.h.) hardwoods often resprout and may need to be controlled again in the future. After harvesting, sprout growth can be great in the high light environment of clearcuts, but increasing amounts of residual overstory trees suppress growth. Hence, there is a negative relationship between overstory shade, hardwood sprout growth, and growth of other competing woody vegetation. The extent of this influence depends on the specie's shade tolerance. On good- to high-quality sites in the southern Appalachians, Loftis (1990b) recommended maintaining an intact main forest canopy while reducing stand basal area by thinning from below to control fast-growing, shade intolerant yellow-poplar while favoring northern red oak advance reproduction. He cautioned that reductions in stand basal area should be decreased (e.g., from 40 percent to 30 percent) as site quality increases (from 21 m to 27 m site index for northern red oak). The challenge is to reduce overstory stocking to increase light to oak while not stimulating the growth of competitors.

Increasing understory light levels by midstory removal has been shown to significantly improve the survival and growth of northern red oak advance reproduction. Lorimer and others (1994) were able to increase understory light from one percent of full sunlight in undisturbed stands to seven to nine percent by reducing the density of the understory woody canopy in Wisconsin mesic oak-northern hardwood forests. They cut the stems of woody species that were taller than 1.5 m and sprayed the stumps with Tordon 101R. This level of light increased the survival and growth of planted northern red oak and white oak seedlings. In the central Appalachians of West Virginia, Miller and others (2004) reported that survival and growth of natural northern red oak advance reproduction was significantly increased after a 22 percent reduction in stand basal area, which was done by thinning from below. They found that understory light was increased from 2 to 12 percent of full sunlight when they applied herbicide by cut stump or stem injection to all tree stems greater than 0.6 m tall in the understory and all trees in the intermediate and suppressed crown classes. Similarly, Motsinger (2006), working in Mississippi River bottomland forests in Missouri, increased understory light levels to 16 percent of full sunlight and improved the survival and growth of pin oak (*Q. palustris* Muenchh.) reproduction. In Mississippi, Lockhart and others (2000) increased understory light to 30 percent of full sunlight in bottomland pine-hardwood forests by removing trees in the intermediate and suppressed crown classes, thus improving the growth of cherrybark oak (*Q. pagoda* Raf.) advance reproduction. The higher light levels achieved in this study may be largely a result of the abundance of pine in the overstory, and light's increased ability to penetrate pine foliage and crowns compared to a pure hardwood canopy of similar stand stocking. In a diversity of forest types across eastern North America, it has been demonstrated that removal of midstory woody stems benefits oak reproduction by increasing light, but light intensity after these treatments, in general, are still significantly below the light levels associated with maximum net photosynthesis and growth.

Overstory Harvesting

In general, more significant reductions in overstory canopy density are necessary to increase understory light to 30 to 70 percent of full sunlight, which is required for maximum net photosynthesis and growth in northern red oak advance reproduction. Regeneration methods that substantially reduce overstory stocking are recommended for oak regeneration (Hannah 1988, Gardiner and Yeiser 2006, Johnson and others 1986, Loftis 1990a, 1993, Sander and Graney 1993, Smith 1993, Spetich and others 2002, Weigel and Johnson 1998a). Oak reproduction grows rapidly in group selection openings that are at least as wide as the height of the adjacent forest (Marquis 1965, Minckler 1961). The clearcutting method has been most successful in regenerating oaks in xeric ecosystems where large advance reproduction has been able to accumulate before harvesting (Johnson and others 2002). However, releasing small oak reproduction to full sunlight by clearcut or large group selection harvests on high quality sites without concurrent competition control has not been successful because oak seedlings are quickly suppressed by either well-established shade tolerant advance reproduction or fast-growing, shade intolerant species (Beck and Hooper 1986, Brose and Van Lear 1998, Canham 1988, 1989, Jensen and Parker 1998, Loftis 1983, 1990b, McQuilkin 1975, Orwig and Abrams 1994, Ross and others 1986, Smith 1981, Weigel and Parker 1997).

In a diversity of forest types, shelterwood harvesting that reduces stand stocking by more than 40 percent, or basal area by more than 50 percent, or crown cover by more than 30 percent can provide 35 to 50 percent of full sunlight to oak reproduction provided the midstory canopy is also removed (Gardiner and Yeiser 2006, Godman and Tubbs 1973, Leak and Tubbs 1983, Lorimer and others 1994, Parker and Dey in press, Sander 1979, Schlesinger and others 1993). As mentioned earlier, maintenance of higher residual shelterwood density and continuous canopy cover in the main overstory helps to control shade intolerant competitors (Loftis 1990b, Schlesinger and others 1993). Schlesinger and others (1993) found that control of taller understory woody competitors in the Missouri Ozark Highlands is not necessary to promote oak advance reproduction growth on low quality sites (i.e., site index 18 m black oak) where oak reproduction did best growing under a 40 percent stocked shelterwood. In contrast, oak reproduction on more productive sites (i.e., site index 21 m black oak) did best when stocking was left at 60 percent and woody understory competition was controlled. These Missouri Ozark ecosystems are outside of the range of yellow-poplar and really do not have a comparable aggressive shade intolerant competitor. Final removal of the shelterwood is triggered when the needed stocking of large oak advance reproduction is present, and depends on management goals for oak stocking at stand maturity. Dominance probability models such as those presented by Loftis (1990b) or Spetich and others (2002) are helpful in assessing the regeneration potential of oak advance reproduction, and timing the shelterwood removal.

Oak Recruitment into the Overstory

For the first few years after a disturbance, tens of thousands of small seedlings and sprouts per hectare compete for the free growing space, but the winners of this competition become apparent in just a few years. As stand age increases after clearcutting, density of all trees, as well as number of dominant and codominant trees, decreases (fig. 6). In central Appalachia, there may be as many as 7,400 trees

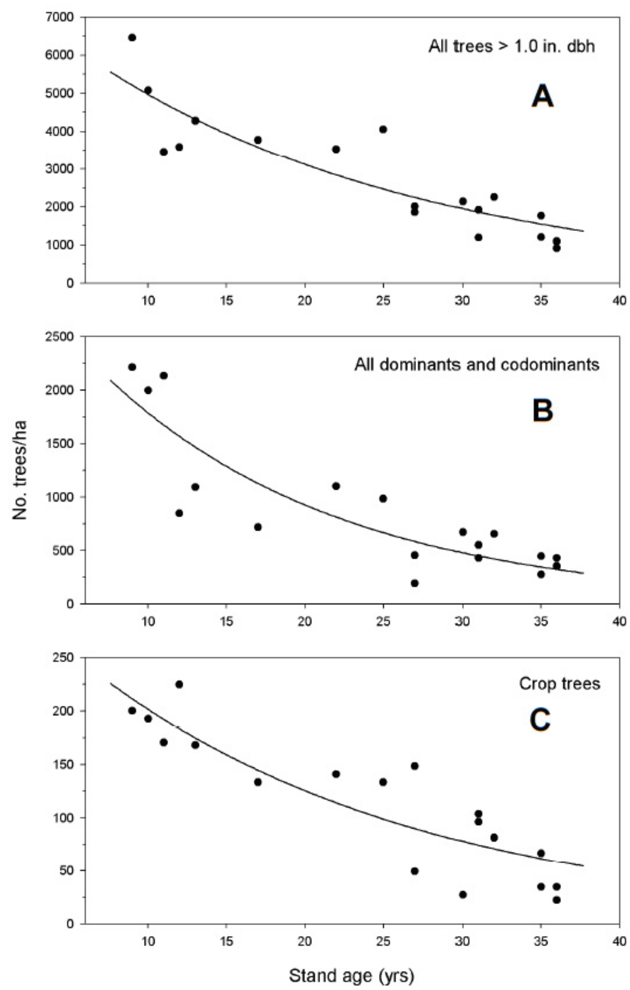

Figure 6— Number of trees per hectare of (a) all trees >2.5 cm d.b.h., (b) all dominant and codominant trees, and (c) only crop trees in 18, even-aged, mixed hardwood stands on northern red oak site index 20 to 21 m in the central Appalachians. Circles are observed densities and lines are regression estimates of average density by stand age (from Miller et al. 2007).

per hectare in a 10- to 15-year-old mixed hardwood forest clearcut (site index 20 to 21 m northern red oak), where the overstory trees are 9 to 12 m tall at canopy closure (fig. 6a) (Miller and others 2007). Although a young stand contains thousands of trees per hectare, only the canopy dominant and codominant stems can persist for many years and provide long term benefits. For example, a typical 15-year-old stand averages 3,700 trees per hectare (≥ 2.5 cm d.b.h.) (fig. 6a), of which only one-third of the trees are in competitive positions in the canopy (fig. 6b).

Without management intervention, suppressed and intermediate northern red oaks have low probability of becoming more dominant as stands progress toward maturity. Ward and Stephens (1994) studied stand dynamics in second growth northern red oak-mixed hardwood forests in Connecticut as the stands developed from age 25 to 85. Northern red oak trees were distributed among all crown classes at stand age 25 with the majority of the oaks in the intermediate and larger classes. However, the only northern red oaks to persist to stand age 85 were those that were dominant or codominant. They reported that about 75 percent of the dominant northern red oak at age 25 remained dominant after 30 years, but only about 25 percent of the codominant oak remained in the codominant class by age 55. Most of the codominant trees dropped into the lower crown classes or died. Between stand age 25 and 55 most of the intermediate and suppressed oaks died. Northern red oak trees that express dominance early are the only trees that are able to persist as dominants into maturity. Thus, stands must be thinned at an early age to favor oak so that managers have flexibility in meeting their stand stocking objectives. This is more imperative on high quality sites, or where oak is competing with fast-growing species such as yellow-poplar.

The probability of oaks recruiting into the overstory as canopy codominants and dominants is modified by site quality. As forests progress through the stand initiation stage to the stem exclusion stage (Oliver and Larson 1996), oaks have a higher chance of becoming dominant on low to average quality sites than on higher quality sites (Johnson and others 2002). Hilt (1985) observed in 29 Ohio Valley clearcuts of oak-dominated forests that the proportion of oak in the reproduction was similar for the first 14 years regardless of site quality, and that 20 to 30 percent of all trees were oaks. After stand age 15, the proportion of oak increased dramatically to 60 percent of all trees on sites of relatively low quality (15 to 18 m site index). They were one-third of stand density on medium quality sites (18 to 21 m site index), but dropped to about 10 percent of stand density on high quality sites (21 to 24 m site index). Stocking of dominant, competitive oak can be increased even on high quality sites by thinning (cleaning) to release potential oak crop trees.

Crop Tree Thinning

Crop trees are defined by management objectives. The tree's market value, wildlife value, esthetic value, or "diversity" value determines whether or not it meets management objectives. Species and quality are key characteristics in identifying potential crop trees. Northern red oak that exhibit good bole quality (i.e., straight, branch-free boles, no cankers, no low forks, good attachment to stumps) and good vigor (i.e., healthy crown and bark development, etc.) are desirable crop trees. Only a small percentage of dominant and codominant trees qualify as crop trees (fig. 6c). A 15-year-old stand that contains about 1,200 dominant or codominant trees per hectare may have only 160 potential crop trees (Miller and others 2007).

It is also important to recognize that the number of potential crop trees declines as the stand ages (fig. 6c). Trees continue to compete for growing space and some overstory trees lose their canopy status and even die as the stand matures. Each year some potential crop trees succumb during the natural thinning process. In the absence of crop tree release treatments, stands older than 25 years often contain less than 100 crop trees per hectare (fig. 6c). In any given stand, the management objectives can be even more restrictive than the general characteristics described here. As a result, the crop tree densities in Figure 6c probably overestimate the number of potential crop trees in most stands.

The number of crop trees released within a typical hardwood stand varies depending on site quality, species composition, stand age, management objectives, and cost of pre-commercial operations. As a result, it is important to understand how hardwood stands develop and change over time so that release treatments can be applied effectively to achieve management objectives. When the stand is mature, the main canopy will contain 148 to 173 dominant and codominant trees per hectare, so there is no need to release more than this density when the stand is young. In most cases, however, the release treatment will involve far fewer trees (fig. 6c) due to their actual availability.

Guidelines for spacing of crop trees are less precise. Hardwood stands that form from natural regeneration exhibit random patterns in their distribution of potential crop trees. It is not unusual to find a clump of three or four potential crop trees growing in close proximity or scattered 15 to 30 m apart. A general guideline is to focus on finding the best available crop trees, regardless of spacing, and provide them with an adequate release. Avoid releasing trees that do not qualify as crop trees just for the sake of achieving an even distribution, as this approach may not be an efficient use of resources. In rare cases where crop trees are abundant and dispersed throughout the stand, seeking an even distribution of crop trees is acceptable, so long as each crop tree receives an adequate release.

In young hardwood stands, the best time to apply release treatments is when the canopy begins to close and continues for about 10 to 15 years after canopy closure. The stand age at canopy closure varies with site quality. On high-quality sites, where abundant resources accelerate stand development, canopy closure can occur about age 8 to 10 years. On poorer sites, where fewer species are competitive and stand development is somewhat slower, canopy closure can occur about age 13 to 15 years. Keep in mind that young stands contain more potential crop trees compared to older stands (fig. 6c) and thus opportunities to improve long-term species composition of the overstory are greatest in young stands that are less than 25 to 30 years old because the number of crop trees per hectare tends to diminish with stand age.

In older hardwood stands approaching large pole or small sawtimber size, there are still opportunities to culture dozens of crop trees per hectare to improve vigor, growth, and spacing of desirable trees as the stand matures. Beyond age 25 or 30 years, the number of potential crop trees can range from 62 to 99 trees per hectare, but this number will decline in coming years if such trees are not favored with crown release.

In sawtimber stands, crown release can be applied as a commercial operation, thus yielding timber sale revenue to offset other management costs while favoring selected crop trees. The problem with delaying the release until operations are commercial is that the number of remaining crop trees is relatively low in older stands and the opportunity to enhance oak stocking has long been lost. The overstory in commercial stands may include 148 to 173 trees per hectare, but usually less than half of them are desirable crop trees if the

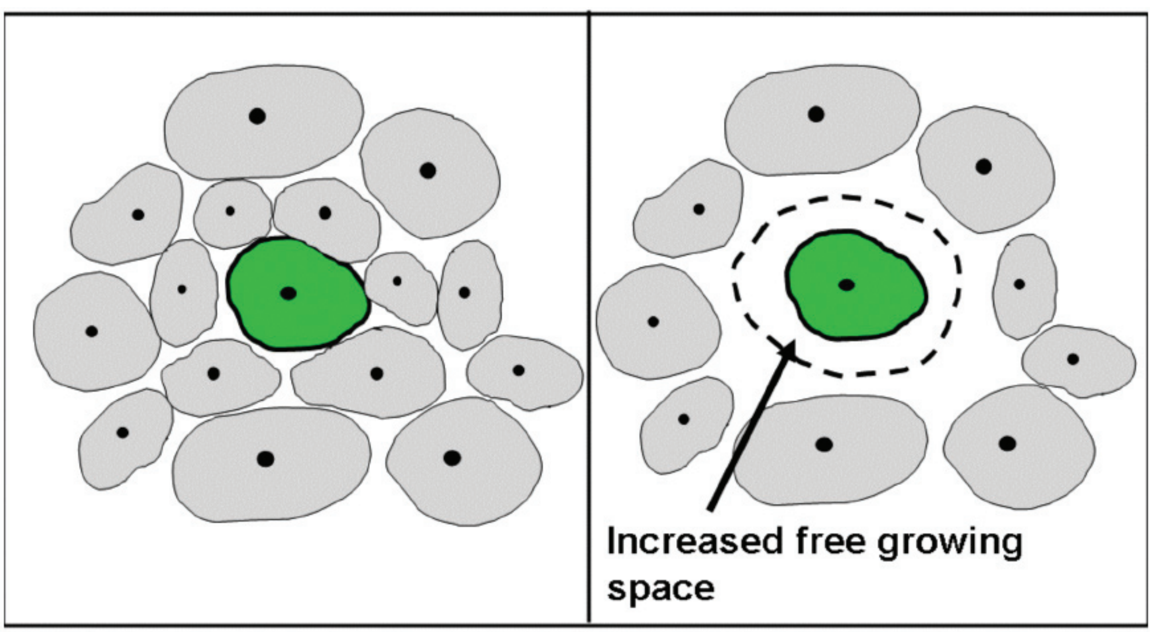

Figure 7— A crop tree crown (dark) shown from above the forest canopy. The left diagram represents a crop tree crown before release with 6 adjacent competitors. The right diagram illustrates the free growing space available when a crown-touching release is applied to remove competing trees from all sides of crop tree. (Diagram produced by J.W. Stringer and published originally in Miller and Stringer 2007).

stand has not been managed before. Ideally, release treatments should be applied when the stand is younger to retain as many crop trees, and as many oak crop trees in the overstory as the stand matures.

Cleanings can be used to deaden or remove trees that are limiting the horizontal crown expansion of an oak crop tree, thus increasing its free growing space and improving its survival probability. Generally, a crown-touching release is used to eliminate adjacent competing trees whose crowns touch that of the crop tree (fig. 7). The increase in growing space provides for an increase in direct sunlight and below-ground resources available to the crop tree. The crop tree can then develop more leaf area and a larger crown, thus increasing photosynthesis, stem diameter growth, and root growth. Improved vigor and crown size also has the potential to improve mast production of individual trees.

Thinning treatments can be used to provide various degrees of release based on the proportion of the crown that is left free-to-grow. In most cases, it is beneficial to retain trees in the overtopped and intermediate crown classes adjacent to crop trees. Such trees might be important for wildlife and aesthetics. They can also protect timber crop trees by partially shading their boles and protecting them from sunlight that can trigger epicormic branching.

Thinning Oak Stump Sprouts

Early thinning around oak sprout clumps can increase oak stocking at the end of the stem exclusion stage of stand development, especially on high quality sites. Weigel and others (2006) found an inverse relationship between oak stump sprout dominance probability and site quality within the range of 18 to 22 m site index for northern red oak in southern Indiana. Favoring oak reproduction through precommercial thinning gives managers greater densities of more highly competitive oak reproduction from which to work with to attain desired stocking levels at stand maturity. It is a better to have too much oak, rather than not enough, when sustaining oak is a primary management objective.

To maximize the development and competitiveness of oak stump sprout reproduction, it is helpful to thin around individual stump sprout clumps, thus releasing all the sprouts arising from a single stump. Thinning should be done early, i.e., by stand age 5. The number of oak stump sprout clumps to release follows the same recommendations given above for crop trees, and is ultimately determined by their availability, spatial distribution in the forest, and the desired level of oak stocking at stand maturity. Not all oak stumps produce sprouts following harvesting; their sprouting capacity depends, in part, on the species, and tree size and age (Dey and others 1996, Johnson and others 2002). In general, northern red oak sprouting potential declines with increasing tree diameter and age (Weigel and Peng 2002, Weigel and others 2006). Initial sprouting frequency of northern red oak stumps increases with increasing site quality, but long-term survival and dominance of oak stump sprouts declines with increasing site quality due to the greater intensity of competing vegetation than is found on lower quality sites (Weigel and Peng 2002, Weigel and others 2006). Release of desirable oak stump sprout reproduction may not be enough to meet oak stocking goals, especially when regenerating older stands that have lower stump sprouting potential. Therefore, additional crop tree release of young oak that regenerated as advance reproduction may be necessary.

Early thinning (e.g., at age 5) of oak sprout clumps to a single stem can significantly increase tree diameter for species in the sections Quercus and Lobatae (Lowell and others 1987, 1989, Dwyer and others 1993). Johnson and Rogers (1980, 1984) estimated that 25th-year diameter of northern red oak stump sprouts can be dramatically increased by thinning the sprout clump to a single dominant stem. Thinning oak stump sprouts at any age between five and 15 years significantly increased 25th-year diameter (fig. 8).

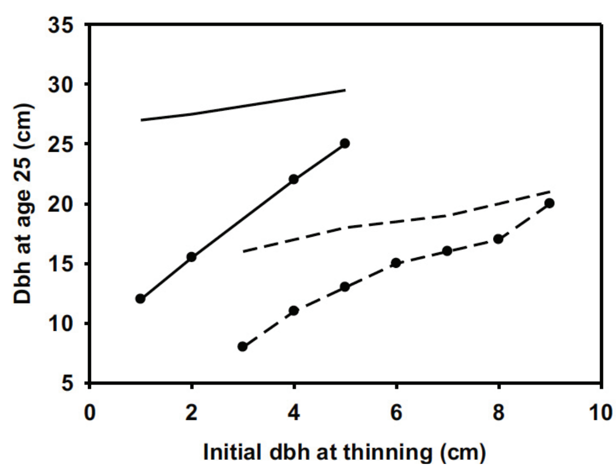

Figure 8— Comparison of estimated 25th-year diameters of northern red oak stump sprouts that were thinned to a single stem (lines without symbols) or not (lines with symbols) at ages 5 years (solid lines), or 15 years (dashed lines) (Johnson and Rogers 1980, 1984).

Initially smaller diameter oak sprouts showed the greatest increase in diameter by stand age 25. The earlier the thinning, the greater was the expected increase in 25th-year diameters. Groninger and others (1998) thinned 12-year-old chestnut oak (*Q. montana* Willd.) and scarlet oak (*Q. coccinea* Muenchh.) stump sprout clumps in Virginia clearcuts by reducing sprouts to a single dominant stem per stump and removing surrounding competitors that had crowns touching the oak crop tree. They found that thinning by chainsaw or herbicide (stem spray or stem injection with 2,4-D or triclopyr): (1) effectively controlled competing stems both within and external to the oak stump sprout clump; (2) significantly increased crop tree diameter after five years; (3) did not affect total height; and (4) herbicides did not cause unusual mortality of crop trees.

CONCLUSION

Sustaining oak stocking requires managing forest regeneration and recruitment processes to enhance oak regeneration potential and its long-term competitiveness through to stand maturity. There are three defining stages in stand development relevant to sustaining northern red oak. In the initial mature forest stage, beginning several years or more before the parent trees are removed, sources of oak reproduction must be present in sufficient numbers, size, and distribution to compete with other vegetation on the site. Oak regeneration potential at this point is largely determined by the probable contributions expected from advance reproduction and stump sprouts. In the stand initiation stage, oaks must be released by a timely and adequate reduction in the canopy such that residual trees do not interfere with the oaks as they compete for dominant or codominant status in the young stand. Once the canopy of the young stand closes, a third critical stage begins during which the young oaks in the upper canopy of the new stand must maintain their status for decades until the stand is mature. Again, upper-canopy oaks can be sustained for long periods by providing a timely and adequate crown release in the young stand.

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