Northern Red Oak Regeneration: Biology and Silviculture

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I would like to dedicate this paper to the late Dr. Henry I. Baldwin, the first Research Forester at the Caroline A. Fox Research and Demonstration Forest, my friend and mentor. I will always remember our annual rides to Petersham and the discussions held along the way.

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Introduction

Oaks, (genus *Quercus*) are an important group of trees in the United States. Recently many scientists have become alarmed about the failure of oak types to regenerate. This paper will review the problems with oak regeneration, the biology of seed production and make recommendations to improve the chances of obtaining adequate red oak regeneration.

There are approximately 70 species reported by Olson (1974). Oaks are an important wildlife food due to the acorns they produce as seeds. In fact, in New England about 30 species use acorns as a source of mast (Yamasaki - Personal Communication). Where both red and white oak occur together, a somewhat steady supply of mast is provided due to differing cycles of seed production between the two species.

Northern red oak is presently the most valuable timber species in New England. Currently, high quality, blemish free red oak veneer logs fetch approximately $1,000 per thousand board feet delivered to the mill. Good quality sawlogs range between $700 to $800 per thousand board feet delivered to the mill (University of New Hampshire Cooperative Extension 1997).

Northern red oak is also valued as firewood due to its high heat value. A cord of red oak can supply about 21.7 million BTU's (British Thermal Units) compared to 19.1 million BTU's for red maple and 13.3 million BTU's for eastern white pine (Allen). However, red oak requires two growing seasons to adequately cure to the proper moisture content to achieve maximum burning efficiency.

Oaks are classified into the family *Fagaceae* and the genus *Quercus*. This genus has three subgenera, (1) *Lepidobalanus*, the white oaks, (2) *Cyclobalanus* which are foreign to the United States and (3) *Erythrobalanus*, the red or black oaks (Harlow and Harrar 1937).

Red Oak Ecology

Sander (1990) reports the best site conditions to grow northern red oak are deep, well drained loams to silty clay loams. He also reports that the depth and texture of the A horizon are important. Deep A horizons and finer textures are more beneficial for red oak growth. Aspects ranging from north to east are preferred. Red oak grows best on lower to middle slope positions.

Red oak is found on a range of sites from xeric (very dry) to mesic (moderately moist). It is found on a range of aspects and slope conditions from lower slopes and flat terrain to mountain and ridgetops with very shallow soil occupying any aspect. Wet soils don't commonly support stands of northern red oak. Reed (1988) classifies northern red oak as a "facultative upland" species occurring 67% - 99% on upland sites. It may occasionally occur in wetlands (1% - 33%).

Red oak is generally considered be an early successional to mid-successional species. It nearly always grows in an even aged condition and appears to be unable to survive in its own shade (Peet and Louks 1977). Northern red oak often follows disturbance by fire and as such may be classified as a pioneer species. Unlike most pioneers, red oak is heavy seeded and long lived with a moderate growth rate. Cline and Spurr (1942) found northern red oak to be a component of the dry ridge tops of the Pisgah Mountains old growth stands in southwestern New Hampshire and suggested that on those sites it may be part of the physiographic climax.

Red oak may be associated with past agriculture as the second stage of an alternating cycle with "old field" white pine. White pine commonly invades abandoned agricultural land. Over time, red oak appears to accumulate in the vacant understory of the white pine stand, probably due to the influence of squirrels and bluejays. As the pines mature and are harvested, the northern red oak advanced regeneration responds to the increased light conditions and captures the site for another rotation. If white pine doesn't re-invade the red oak stand, possibly because the agricultural effects have been muted, northern red oak may also become difficult to re-establish.

Fire is probably the single most import factor in establishing northern red oak on non-agricultural lands. Originally, fire was believed to pose a problem in establishing red oak. In 1907 Greeley and Ashe suggested that regenerating white oak wouldn't be difficult as long as fire was eliminated from the regenerating stand. To the contrary, fire appears to be essential in developing suitable northern red oak advanced regeneration. Crow (1988) cites work by Dorney (1981) in southeastern Wisconsin dealing with soils supporting oak and sugar maple. The occurrence of past fires appeared to be the factor most likely deciding whether the site would support oaks versus sugar maple. Where fire was absent, sugar maple was dominant.

Crow (1988) stresses the importance of fire in maintaining oak savannas in the North Central region of the United States. Referring to historical references, without the influence of fire, savannas quickly closed with woody growth (20 to 40 years) resulting in the development of understories of shade tolerant species.

According to Lorimer (1989) the oaks have adapted to fire by two means (1) through increasing bark thickness and (2) by the ability to resprout after becoming *top-killed*. Northern red oak doesn't produce bark as thick as many other oaks. The bark of black oak (*Q. velutina*) is thicker than white oak (*Q. alba*) and white oak is thicker than northern red oak. As such it is less prevalent in oak savannas. Red oak does, however, resprout very well. For example, following a fire, Swan (1970) found that 87% of the oaks resprouted compared to only 43% of the northern hardwoods. Johnson (1974) reports that in Wisconsin following a low intensity burn, 92% of the one year old red oak seedlings were top-killed but 38% resprouted. Red oak is an excellent resprouter because it forms many dormant buds on the root collar, about an inch below the forest floor, where they are often protected from high temperatures associated with fire (Johnson 1993). Continued dieback of the shoot often results in large root to shoot ratios which can provide rapid shoot growth when the proper environment is provided.

Ward and Stephens (1989), working in a Connecticut stand 45 years after an intense surface fire, reported three times more oak occurred in a burned portion of a stand than an unburned portion. Brown (1960) found similar results in Rhode Island.

One explanation for the reduced occurrence of red oak in New England forests may be the low incidence of fire compared to that of a century ago. Records from the New Hampshire Forestry Commission for the years 1910 to 1934 (State of New Hampshire - 1937) show an annual average of 366 fires burning 8,755 acres, exclusive of fires caused by railroads. In the years from 1986 to 1995, the annual average was 484 fires but only 414 acres were burned per year (Robert Nelson-personal communication). In 1996 only 89 acres burned in the state. The difference between the periods of 1910 - 34 and 1986 - 95 shows a reduction of 8,341 acres per year or 95% annual reduction in acreage.

Foster (1988), using a variety of sources, reconstructed the fire history from 1635 to 1938 for the Pisgah Mountain old growth forest in southwestern New Hampshire. For that time period, 15 incidences of fire were recorded, with one occurrence listed as severe and two occurrences termed broad scale. Of the remaining occurrences most were of unknown scale or severity. Foster links these fires with catastrophic windthrow, particularly with softwood stands, so their effect on red oak regeneration is unclear. Still the presence of fire throughout the period shows that fire has been a part of the ecosystem.

Flowering and Acorn Development

■ Flowering

Northern red oak begins flowering at approximately age 25 but doesn't reach maximum flower production until age 50 - 200 years. Flowers are incomplete and imperfect. Incomplete flowers lack one or more of the four basic floral parts such as petals, sepals, carpels and stamens (Raven *et al.* 1992). An imperfect flower contains only stamens or carpels but not both. Each oak flower contains either male or female structures. Northern red oak is monoecious (Sander 1990, Raven *et al.* 1992) which means that both the staminate (male) and pistillate (female) flowers occur upon the same tree. Cecich (1992) reported research by Irgens-Moller (1955) that the genus *Quercus* is capable of self fertilizing, but that Jovanovic *et al.* (1971) could not reproduce the same results.

The staminate flowers (Plate 1) are located upon amments (catkins) usually appearing in April or May. They originate on the previous year's twig from male buds or mixed buds (Cecich and Haenchen 1995). The stamens produce pollen in the anthers. Pollen contains two cells, a generative cell which divides into two sperm cells and a tube cell which will produce the pollen tube, providing the sperm a pathway to the ovule (Raven *et al.* 1992).

The pistillate flowers (Plate 2) are usually borne individually or in small clusters of two, three or more, from the leaf axils of the present year's twigs. The flower is small and not showy, and is easily overlooked. The stigmas are thought to be receptive to pollen for a period of about one week when they are bright red and flexible (Cecich and Haenchen 1995).

Flower production seems to be related to carbohydrate and nitrogen levels although the relationship isn't fully understood (Kramer and Kozlowski 1960). Increased levels of carbohydrates in the tree's crown generally results in increased flower bud initiation. Inversely, increased levels of nitrogen in the leaves generally reduces flower bud initiation due to higher utilization of carbohydrates in growth. This may help explain why there is seldom two successively good acorn years in a row.

In the *Erythrobalanus* subgenus (red and black oaks), acorn development takes two seasons. The pollen, usually wind disseminated, meets the stigma during the acorn's first season. Wolgast and Stout (1977) working with bear oak (scrub oak), *Q. ilicifolia*, showed that relative humidity was an important factor in pollen set on receptive stigmas. Generally, pollen set was more successful in low humidity conditions. When the relative humidity exceeded 61%, no acorns matured.

The pollen tube germinates within 24 hours and elongates to the base of the style during the first season. Cecich and Haenchen (1995) report that pollen tubes may be too numerous to count. The pollen tubes ceased growing about mid-May and the flower and pollen tube begin a resting stage until the next season. They weren't sure why the pollen tubes stopped elongating but speculated that either the rudimentary ovary sends the wrong signal or an inhibiting signal until it reaches a suitable stage of development early in the second season.

During the second season, the pollen tube connects to the ovary and fertilization takes place. It takes approximately 13 months for the pollen tube to reach the ovule and for pollination to occur (Olson and Boyce 1971). In the subgenus *Lepidobalanus* (white oaks), the entire process, including maturation of the acorn, is accomplished in a single season.

Many researchers suggest that flowering of oaks can be heavy but that acorn crops are often light to non-existent (Cecich 1992, Wright 1953). Flowering abundance seems to be a poor indicator of the forthcoming acorn crop. Often, an abscission layer forms between the flower and the stem resulting in the loss (death) of the acorn. This loss may have many causes such as pollination failure, insect attack or disease. The majority of the causes aren't yet fully understood. Cecich *et al.* (1991) noted flower abortion of up to 95% in northern red oak during two years of monitoring. He noted activity by treehoppers (*Homoptera: Membracidae*) at the time of abortion. Treehoppers are sucking insects with stylets that feed on the flowers of red oak. Apparently, the oak flowers turned brown and fell off within a week of feeding.

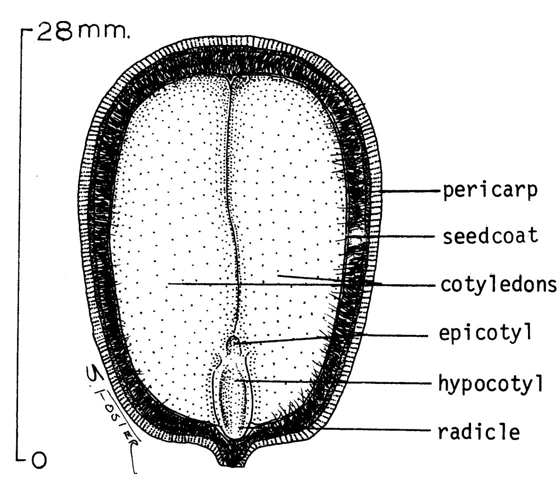
■ Acorn Development

Red oak produces epigynous flowers with inferior ovaries; in other words the flower parts are located above the ovary. During the first growing season the acorn shows little development (Plate 3). During the second season, after fertilization takes place, the acorn rapidly develops until late August and September when the acorn matures. According to Steiner (1995) as a general rule of thumb, acorns that fall from the tree with the cap attached are pre-mature and probably not viable.

Figure 1 shows the anatomy of a typical red oak acorn (from Olson 1974). The leathery outer part of the acorn shell is called the pericarp. Inside, the membranous seedcoat is found next. The acorn contains two cotyledons. The embryo is located at the pointed tip of the acorn. The radicle is closest to the outside followed by the hypocotyl (the region between the radicle and the cotyledons in the developing seedling) then the epicotyl (Daniel *et al.* 1979).

Figure 1

QUERCUS



■ Predation on Acorns

Insects

Many insects prey upon acorns. In this paper, the most common insect predators will be discussed. Gibson (1981) studied the relative rates of infestation by several genera of insects. The genus *Curculio* was the most common with the genera**,** *Conotrachelus, Melissopus, Valentinia* and *Callirhytis* well represented.

Curculios, which are weevils, included the species *C. proboscideus, C. sulcatulus, C. orthorhynchus, C. nasicus* and *C. longidens*. During 1963 when Gibson (1981) studied populations in Belknap County, New Hampshire, 26% of all acorns were infested with *Curculio* of various species. In that same year Chittenden County, Vermont ranged from 38% - 54%, Penobscot County, Maine reported only 6.5% infestation and Berkshire County, Massachusetts reported 60% infestation of the acorn crop to *Curculio*.

Curculio weevils invade young, developing acorns and deposit eggs. The eggs hatch, releasing larvae that eat varying amounts of the cotyledons, epicotyl, hypocotyl and radicle. In the fall, larvae emerge from the acorn leaving a characteristic exit hole in the shell. The larvae will spend the winter underground, pupate in early summer and emerge as an adult weevil in July to August (Anderson 1960).

Conotrachelus weevils were also studied by Gibson (1981) and weren't found in any of the above reported localities. The two species of concern in the northeast are *C. posticatus* and C. *naso*. Anderson (1960) reports their life cycle to be similar to *Curculio* except that adult weevils emerge during autumn and overwinter.

Callirhytis is a genus of wasp that affects the young developing acorn. The galls, depending on species, can be either a pip gall or the acorn's shell can be completely filled with tiny galls. In New England Gibson (1981) found acorns affected by *Callirhytis* in 1963 to range from 0 to 31%.

Stelidota octomaculata is a sap beetle that can be a serious pest on red oak (Galford *et al.* 1991). These beetles feed upon and breed inside the radicles of germinating acorns. They also breed in the seeds of maples, hickory, walnut and pecan.

Melissopus laterfereanus is commonly referred to as the acorn moth. It is found throughout most of the United States and southern Canada (USDA 1985). The larvae feed inside the young developing acorn and often destroy the cotyledons and the embryo. The adult moth has a wing spread of 11-20 mm and is reddish-brown in color. Larvae hibernate in cocoons beneath the surface of the ground (Furniss *et al.* 1992).

Valentinia glandulella is another acorn moth. Galford *et al.* (1991) reports it to be a secondary pest of acorns often entering through cracks or exit holes already established in the acorn shell. In the spring it is one of the first acorn predators, attacking the radicles and cotyledons.
In Ohio a survey was conducted to assess the damage to the acorn crop from insects (Galford *et al.* 1988). During Autumn 1986, in areas determined to have had a light crop, 100% of the acorns sampled were killed by insects. In areas that contained a bumper crop, 40% of the acorns sampled were killed. It was noted that acorns that landed on bare soil had better success against predators. The authors suggested this success was due to the acorns' radicles entering the mineral soil quickly and being less susceptible to attack. In the same paper, the authors reported that spring prescribed burning was beneficial in regenerating oak seedlings by consuming forest

litter, a cover for *C. posticatus* and *S. octomaculata* (see Silvicultural Techniques - wildfire). They suggested that fall burning may also be effective but had no data at that time.

In a study conducted at Sugar Hill State Forest in Bristol, NH, during a light acorn crop year, Bofinger (personal communication) found 95% of the acorn crop in 1995 was killed by insects. No data were available pertaining to which insect genera were most commonly found.

Squirrels and Blue Jays

Squirrels and jays move and consume acorns. According to Healy (1996) squirrels and jays "can move staggering numbers of acorns." He reports that squirrels bury acorns within 200 yards of the source tree. Steiner (1995) suggested that in Pennsylvania, squirrels may not be a large consumer of viable acorns because even in good years, squirrel populations are often low. Squirrel populations at the time of establishment of many presently mature stands may have been much higher although no quantitative data is available to support such claims. Anecdotal evidence has suggested that past populations may have been considerably higher (N. Lamson - personal communication).

Blue jays may bury acorns as far as three miles from the source (Healy 1996). Jays prefer small nuts such as beech nuts and small acorns (Dr. Carter Johnson, personal communication). They often carry up to five pin oak or only two to three red oak acorns per trip. Jays then bury the nuts in the forest for retrieval and consumption at a later date. Darley-Hill and Johnson (1981) reported data from 11 collecting trees totaling 130,000 acorns of *Quercus palustris* that were dispersed by blue jays in Virginia. Of these, only 49,000 were consumed. In this study the remaining undispersed acorns were examined for soundness. Nearly all contained curculionid exit holes. In a another study of jays by Johnson and Adkisson (1985) dealing with beech nuts, 100% of the nuts tested that were collected by jays were sound and germinated compared to only 11% collected by the researchers directly from the trees.

Darley-Hill and Johnson (1981) described the characteristics of the sites where jays were likely to plant acorns. Ninety-one percent of the sites were "disturbed conditions" such as lawns or bare soil. They concluded that shallow litter, vegetation less than 20 centimeters in height and areas exposed to sunlight (insolated) were attractive to jay caching. At these sites jays actually buried the nuts, a measure that probably helped minimize predation by insects.

Seedling Establishment

■ Germination

Northern red oak germinates in the spring following a cold treatment by winter weather. Olson (1974) suggests a period of 30 - 90 days at temperatures between 32 to 41 degrees F are required to break embryo dormancy. He also suggests the media be moist but well drained. Northern red oak, as well as other species, germinated within this temperature range, the radicle emerged but the epicotyl did not appear even after 220 days.

Germination begins with the cracking of the acorn shell and emergence of the radicle (embryonic root). The radicle is very sensitive to desiccation until it penetrates the mineral soil. Once in the mineral soil, the seedling will produce a deep tap root. The cotyledons are hypogeal in that they remain within the acorn shell and the shell remains on or in the soil. Emergence of the epicotyl (the embryonic shoot which produces the stem and leaves) is generally delayed until favorable conditions exist. Most northern red oak acorns contain a single fertilized embryo (Plate 4).

Disturbing the forest floor may be an important factor in aiding acorn germination success. In New Hampshire, many oak stands don't contain oak advance regeneration although understory light levels appear appropriate. On New Hampshire State lands, two stands were thinned during an acorn bumper crop to nearly the same densities, one conventionally using chainsaws and a cable skidder and the other by a feller buncher and grapple skidders. Time of year also was different. The stand cut with chainsaws was operated during the summer previous to the acorn drop. The stand thinned by the feller buncher was operated following the acorn drop. In the first stand oak regeneration is scanty, in the second stand (Plate 5), up to 128,000 seedlings per acre have been recorded (State of NH unpublished data). Feller bunchers must approach each stem to be cut, and grapple skidders seldom use the onboard winch. This travel between skid roads produces much mixing of the forest floor. In the stand harvested with cable skidders, much winching took place resulting in little soil scarification. The implication is that mixing of the forest floor permits acorns to settle low into the ground litter possibly aiding germination success and discouraging predators. Unfortunately, these two logging operations were conducted in different years and no comparative data is available beyond simple observation.

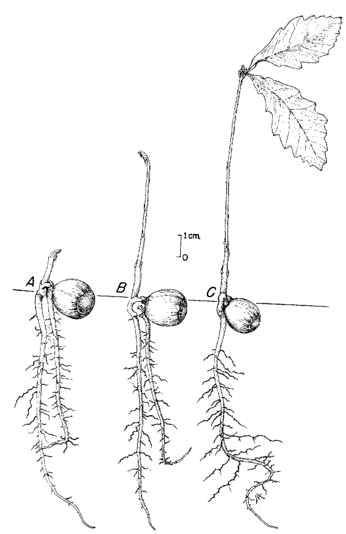
Red oak seedlings can germinate in relatively low light levels (7 to 10% of light levels occurring in clearcuts). This equates to a residual crown cover density of about 86%. (Johnson 1994, Pubanz and Lorimer 1992). Roberts (1991) found no significant difference in seedling growth under canopy densities ranging from 40 to 100% with the understory removed. The understory can often provide intense shade conditions. Removal of the understory shade may be more useful in procurring advance red oak regeneration than altering the overstory.

■ Development

Red oak seedling survival following germination may be erratic. If not browsed by wildlife or attacked by insects, the seedling may continue to grow in the understory. Often seedling losses are high. Seedlings often dieback and resprout from adventitious buds at the root collar, thus enlarging their root system (high root to shoot ratio) in preparation for eventual release (Johnson 1994).

Much of an oak's early growth is in the root system. In the first couple years, natural seedlings may produce a tap root of one to two feet in length (Figure 2 from Olson 1974).

Figure 2



■ Stump sprouts

Stump sprouts can be a significant contributor to the stocking of the next stand. Sprouting is regulated by parent tree size and age (Johnson 1994). As age and stump diameter increase, sprouting capability decreases. Generally, red oak sprouts into clumps of several stems. Many of these sprouts are suitable for crop trees (Lamson 1976).

Predators of Advance Regeneration

Gypsy Moths

Gypsy moths can have an important deleterious effect on northern red oak advance regeneration. Hicks *et al.* (1993) surveyed defoliation levels in clearcuts of various sizes in West Virginia and compared them to the surrounding forest. Defoliation levels were closely related between the clearcuts and the surrounding forest, being 42% and 49% respectively in 1991 and 13% and 20% respectively in 1992. Clearcut size generally did not have an effect except that in clearcuts greater than 25 acres, defoliation seemed to be lower. Based on lower defoliation rates toward the center of these large clearcuts, they assumed that the surrounding forest served as reservoirs for gypsy moth caterpillars.

Hix *et al.* (1991) studied the effects of gypsy moth defoliation in two physiographic provinces, the Appalachian Plateau in southwest Pennsylvania and the Ridge and Valley province in northwest Maryland. In the Appalachian Plateau, oak regeneration in general, decreased after gypsy moth defoliation. One size class, the one to three feet tall, slightly increased, but the overall count of oak regeneration was down (from 6696 stems per acre to 4738 stems per acre).

In the Ridge and Valley province, oak regeneration in general increased after defoliation from 10,288 to 12,964 stems per acre. In nearly all cases within the two provinces, the number of regeneration stems greater than three feet tall decreased. They noted that black birch (*Betula lenta L.*) was lacking in the Ridge and Valley province plots and was prevalent on the Appalachian Plateau plots. Black birch as well as other aggressive understory competitors may have a decisive negative impact over oaks in the regeneration layer.

Deer Browsing

Browsing from white-tailed deer (*Odocoileus virginianus*) can be devastating to northern red oak regeneration. Depending upon species composition of the stand, deer may prefer browsing on red oak over many other species. Kittredge and Ashton (1995) studied browsing preferences of tree species by white tailed deer in northeastern Connecticut. Small hemlock and black birch seedlings (less than 19 inches) were prefered over other species of a similar size. Although red oak was not a preferred species, deer also showed no significant avoidance of it during browsing. Deer expressed a greater preference for all species over 19.7 inches in height. Repeated browsing on oaks can give competing vegetation a greater advantage in occupying the site because deer often browse only the new growth.

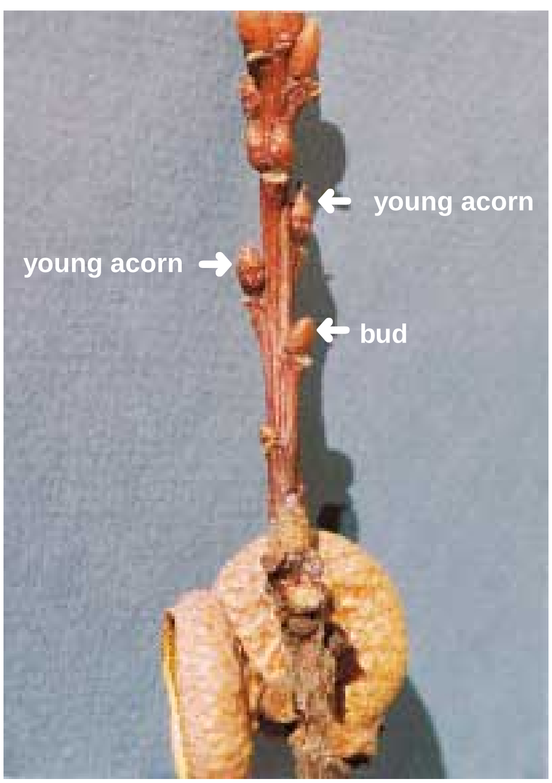
Plate 1

Staminate (male) flowers of northern red oak borne upon amments or catkins (photo by Tom Lee).

Plate 2

Pistillate (female) flowers of northern red oak located in leaf axils of current year's twigs. Styles and stigmas can be seen as upward projecting limbs (photo by Tom Lee).

Plate 3



A first year twig of northern red oak. Acorn caps remain from mature acorns at the bottom of the photo. Above the caps, the first structure on the right side of the twig is a bud, with young acorns above the bud on the left and right side of the twig (photo by Tom Lee).

Plate 4

A germinated red oak acorn. The cotyledons remain in the acorn shell (hypogeal). The radical has become a long tap root. The epicotyl has emerged following favorable conditions to become a shoot (photo by Tom Lee).

Plate 5

Red oak regeneration obtained after mechanized harvesting at Kingston State Park in New Hampshire. The harvesting occurred after the acorns dropped, resulting in seedling densities as high as 128,000 stems per acre (photo by I. Seaboyer) .

Plate 6

Two red oak seedlings from the New Hampshire State Forest Nursery. The seedling on the right exhibits typical "carrot" morphology. The seedling on the left (in hand) resulted from undercutting cultural practices.

Regeneration Evaluation

■ Size, Data Tally and Quantity of Plots

Methods exist to quantify the amount and condition of the existing regeneration. For northern red oak and other eastern hardwoods the plot size most often suggested appears to be the 6 foot radius (1/385 acre) circular plot (Marquis *et al.* 1990, Marquis 1987, Marquis and Bjorkbom 1982, Marquis *et al.* 1975, Grisez and Peace 1973). This size is suggested because it relates to the ground area occupied by a tree of threshold merchantable size (five inches dbh). In other words, it is implied that a stocked plot will develop into a five inch dbh stem.

Oaks don't possess any distinctive commercial value until they reach a dbh of approximately 12 inches. So, perhaps oak regeneration plots should use that area or about 1/250 acre plots (about 7.4 foot radius) to indicate whether the stand will be adequately stocked when the stems reach sawlog size. Work by Oliver (1978) in central New England suggested relatively few established red oaks at the time of stand initiation are needed to fully stock a stand at maturity. Reconstructing stands dominated by red oak, he found as few as 150 stems per acre at stand initiation resulted in red oak dominated stands. Studying the growth habits and mode of stem emergence into the B stratum (similar to overstory co-dominants) he suggested that more oaks may not be beneficial because the oak to oak competition (interaction) may slow diameter growth and require intensive thinning regimes. Although Oliver didn't distinguish the 150 oak seedlings as established, it's important that the few oaks present in the stand be vigorous and capable of eventually reaching the overstory. Established oak seedlings may be those seedlings greater than 4.5 feet tall at the time of stand establishment.

It may be desirable to maintain oak as a subordinate component of a stand. Pure oak stands attract many acorn predators that make successful regeneration of oaks difficult. In New England it is common to find light to heavy stocking of red oak advance regeneration under white pine canopies. Introduced by squirrels and jays into the pine stand, the germinating acorns encounter little predation from acorn consumers. This helps confirm intuition that acorn predators focus on oak stands where acorns would likely occur

Marquis (1987) suggests a standard plot for eastern hardwoods so that stocking data can be comparable among foresters. Plots less than six feet in radius such as the milacre plot, are often too small to evaluate a stand adequately or require a large sample size to do the job satisfactorily.

When tallying regeneration plots, it is more important to assess if a plot is adequately stocked than to compute the number of stems per acre or per plot. The idea is to assess that the stand is well stocked and that the regeneration is well distributed through the stand. A stand may contain many thousand red oak seedlings but if they are stocked unevenly so that few or none occupy many areas of the stand, these vacancies may stay with the stand throughout its life. Instead, it is preferable to evaluate the percent of the plots stocked with reliable, acceptable regeneration stems. Marquis (1987) and Grisez and Peace (1973) suggest no fewer than 70% of the plots be stocked with regeneration of desired species and sizes.

Marquis (1987) recommends a minimum of 20 plots per stand to adequately evaluate the regeneration in stands up to 20 acres. For larger stands, add one plot for each additional five acres. Barrett (personal communication) gives a set of formulas for calculating the number of plots required based on the probability of the proportion of plots stocked to the proportion not stocked. These formulae are:

$s = \sqrt{p(1\text{-}p)}$

$n= [(t * s)/E]^2$

where n = # of plots required, t = confidence limits multiplier (from a t-value table), s = square root of [p(1-p)] where p = estimated percent of plots stocked, E = allowable limits of error.

So, to calculate how many plots are required to assess stocked plots with a 95% confidence limit and a precision of +/-20%, and if we estimate from experience that half of the plots will be stocked, plugging into the equation we get the following;

s = square root of [.5(1.0 -0.5)] = .5

t = 2 for 95% confidence limit

$n = [2(.5)/.2]^2$

$= [1.0/0.2]^2$

$= [5]^2$

= 25 plots

An adjustment for a finite number of plots is; na=n/(1+n/N) where N is the possible number of plots (acres/plot size)

Using .5 for p will produce the maximum number of plots because it represents the highest variation (50/50). Any other number will reflect a lower variation between stocked or unstocked plots (70/30, 20/80, etc.). Either the ratio will be relatively more uniformly stocked or unstocked.

To assess if a plot is adequately stocked with oak regeneration, Marquis *et al.* (1990) suggest using the following guidelines;

Counting Oaks

Less than 2 inches tall - Don't Count

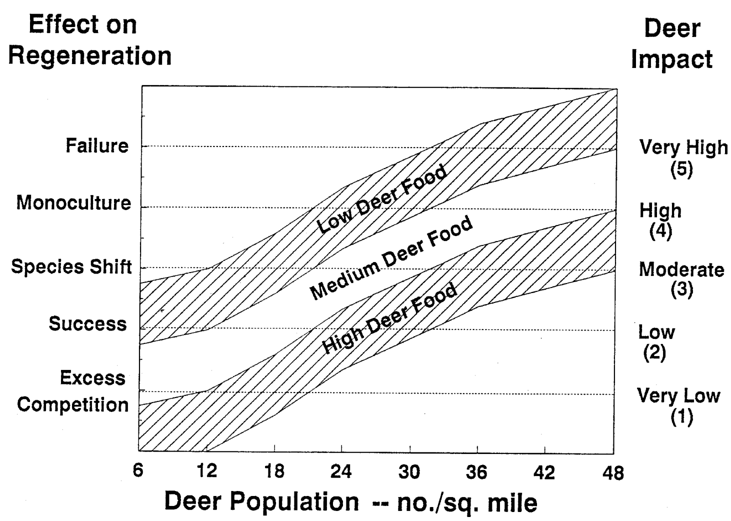
2 inches to 1 foot tall - Count each stem as 1 stem

1 foot to 4.5 feet tall - Count each stem as 2 stems

Greater than 4.5 feet tall - Consider the plot to be stocked

Marquis *et al.* (1990) developed a deer impact index for use in the Alleghenies (Figure 3). The index incorporates deer population levels and abundance of food supplies to predict the impact of deer browsing on red oak regeneration. When the deer impact index (DII, see Figure 4) is one then a plot needs to tally 10 or more (as counted above) in seedlings less than 4.5 feet in height to be stocked. If the deer impact index is three, a plot needs to tally 30 seedlings (as counted above) to be considered adequately stocked. Regardless of the deer impact index, any oak regeneration greater than 4.5 feet tall automatically makes the plot stocked. Figure 5 shows the estimated deer populations for New Hampshire (New Hampshire Fish and Game Dept. - Personal Communication).

Figure 3



Graphic from Marquis *et al.* (1990) for determining the Deer Impact Index(DII) to be used with figures 4 and 5

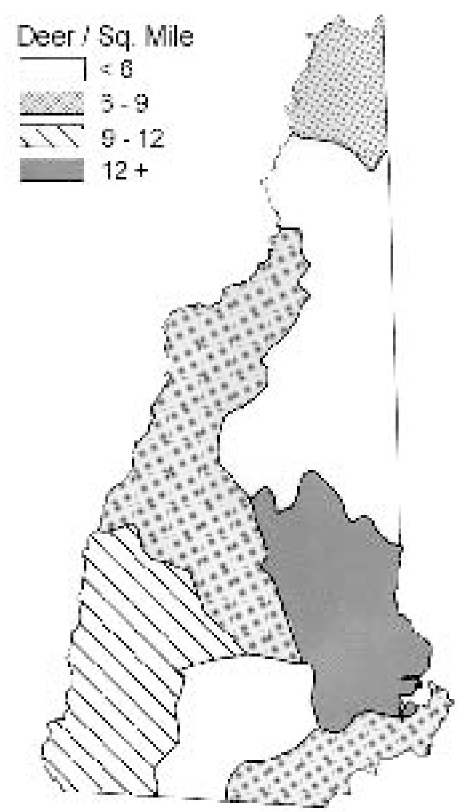
Figure 4

From Marquis *et al.* (1990)
Weighted seedling count per plot
to be considered stocked

DII	Wt'd Count
1	10
2	20
3	30
4	40
5	60

Figure 5

Deer Density Per Square Mile



From NH Fish and Game Department
Drawn by Inge Seaboyer

Silvicultural Techniques For Regenerating Northern Red Oak Stands

In most cases regenerating northern red oak will be a long process because acorns require a great amount of time to build large root systems capable of producing shoots that will be competitive with other hardwood regeneration. Success in regenerating red oak is limited and any recommendations made at this time are still preliminary. The process can be divided into three distinct steps: (1) establishment of red oak advanced regeneration, (2) development of advanced regeneration to 4.5 feet in height and (3) release of advanced regeneration.

■ Natural Regeneration Techniques

Weed Control

In all cases controlling competition from brush and other hardwoods is important. Fire can be an effective tool for weed control because it kills back competing hardwoods and promotes an increase in root:shoot ratio. Fire can be expensive and in New England the window of opportunity may be small. However, fire is the most natural means of weed control and may be the most acceptable to the public.

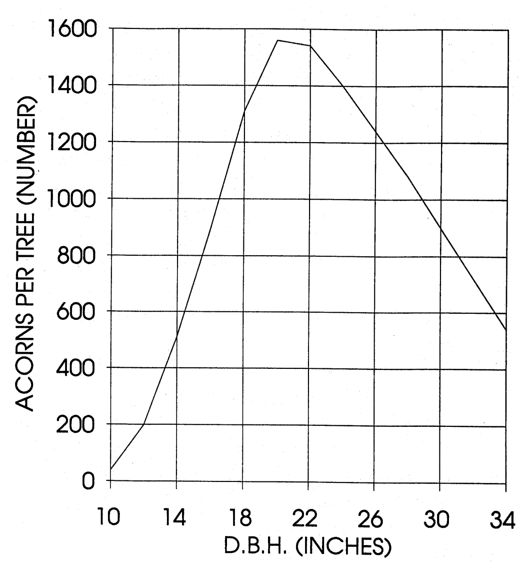
Herbicides are also an effective tool in controlling competing vegetation. It is beyond the scope of this paper to suggest in detail safe uses of herbicides. However, Loftis (1990) used Tordon 101 [Picloram (4-amino-3,5,6-trichloropicolinic acid) + 2,4-dichlorophenoxyacetic acid] successfully as a stem injection and as cut surface treatment in oak stands in Georgia and North Carolina.

Establishing Advanced Regeneration

Timing forest operations with a good seed crop can be an important step in providing adequate advanced regeneration. Assessing the seed crop is easier as the crop matures. Because red oak acorns require two seasons to mature, first year observations of the nut crop size can be difficult. First year acorns are small and difficult to see in the tree crown from the ground. Also, many things can cause acorn abortion before they are mature and viable. Flexible management strategies can be helpful.

Oak crowns from well managed stands should periodically produce an abundant crop of acorns for regeneration. Generally, open crowns are capable of producing many more acorns than closed crowns (Johnson 1994). Larger stem diameters (and consequently larger crowns) also produce greater crops of acorns than smaller diameter stems until about 20 to 22 inches dbh. Figure 6 (from Johnson 1994) shows that after 22 inches, acorn production seems to slowly decline (Downs 1944). This may be due more to senescence than size because 70% of the stems Downs studied were over mature and decadent (Johnson 1994). The relationship with tree sizes greater than 22 inches dbh and the downward trend in acorn production is presently questionable without further study.

Figure 6



Estimated average yield of northern red oak acorns over 7 years by diameter class in the southern Appalachians (from Johnson 1994, adapted from Downs 1944).

Scarification is important because it buries the acorns into or below the soil surface, making them less susceptible to predators and providing good conditions for germinating radicles. As such it makes sense to do shelterwood cutting during bareground seasons. Careful timber extraction that provides scarification throughout the forest instead of only on designated skidder trails may help establish widespread regeneration. Fire can also be beneficial by burning the duff layer and destroying insect predators.

Crushing the understory to provide an open condition may help discourage low competition. It may also increase the burial of acorns by bluejays.

Maintain a well stocked canopy to provide shade to discourage the initiation of competing vegetation and to provide an abundance of on-site seed sources.

Developing Advanced Regeneration

The development goal should be to provide at least 150 to 385 established red oak stems per acre. These stems should be at least 4.5 feet tall and less than 4 inches in diameter at breast height to be considered established. Stems greater than 4 inches dbh aren't generally considered advance regeneration and as diameter increases above 4 inches, sprouting ability may decline.

Modest thinnings from below with a short re-entry period provides gradually increased light conditions. Also periodically crushing the advanced regeneration will help to increase the root to shoot ratio providing vigorous seedling sprouts. Fire can also provide a desired root to shoot ratio by top-killing advanced regeneration and competing vegetation.

At Bear Brook State Park in southern New Hampshire, a white oak stand growing on sandy outwash was the site of a spring wildfire. Advance regeneration of white and red oak is much heavier there than in the surrounding unburned areas. Though pre-burn regeneration data is lacking, this scenario seems to fit the fire pattern.

Loftis (1993) was successful in bringing present oak regeneration to a more desirable size by reducing the stand basal area by 25 to 30% for site index 90 sites, 30 to 35% for site index 80 sites and 35 to 40% for site index 70 sites. The removals were from below and Loftis stressed that no gaps in the overstory existed after treatment. The treatment by Loftis used herbicides - Tordon 101 [Picloram (4-amino-3,5,6-trichloropicolinic acid) + 2,4-dichlorophenoxyacetic acid] applied with a tree injector or through a cut surface treatment because most of the material was un-merchantable.

Frozen ground logging may help protect the root collar of advanced regeneration from excessive damage from logging machinery.

Release of Advanced Regeneration

When adequate numbers of established advanced regeneration are present, removing the over-story shade to provide good growth is important. Oaks must have sufficient light to compete effectively with other hardwood regeneration. Often the final cut of a shelterwood is used to provide this condition. When large clearings are not desirable, patch cutting or group selection cutting may be an alternative. Patches or groups must be large enough to provide adequate light. Clearings should be wider in the narrowest dimension than the height of the surrounding trees. Operationally, 1/4 acre openings are probably the practical minimum with larger openings being more desirable.

Artificial Regeneration

Nursery Science

New methods have been devised for raising red oak seedlings in the nursery. Much of this section will report the work of Schultz and Thompson (1990).

The handling procedures of bare root nurseries can be stressful on red oak seedlings because in the lifting process many of the lateral roots are less than one mm in diameter and are often broken off. For these seedlings to compete and perform well after outplanting, larger first order lateral roots are required to provide a place for higher order laterals to form.
To provide these laterals nurseries practice undercutting. This operation involves dragging a steel blade at a designated level under a nursery bed to cut off many of the longer seedling roots. Under the ideal moisture and fertility conditions of the nursery, new roots can develop. Undercutting changes root morphology from the typical "carrot" root to a root with many primary lateral roots (Plate 6). Also, the cut tips of the main root(s) develops three to six wound roots, thus increasing the absorptive capacity of the root system. At the New Hampshire State Forest nursery, seedlings are undercut at approximately two to four inches and harvested at about eight inches in depth. Thus four to six inches of improved root length are supplied with each seedling. Outplantings of these new and improved seedlings have been successful.

Tree Shelters

Tree shelters are a product originating in Great Britain. They simply consist of a single translucent plastic tube surrounding a planted seedling, held in place by a wooden stake and plastic ties. Their performance together with planted improved red oak seedlings has been well documented in the United States, especially from the Allegheny Mountains to the South (Walters 1993, Smith 1992). Tests conducted on New Hampshire State lands, have shown annual height growth in excess of 40 inches in some cases. Unfortunately, their success in New Hampshire has been erratic and unreliable.

Kittredge *et al.* (1992) experimented with applying tree shelters to natural reproduction to encourage faster growth over other competitors and to discourage deer browsing. Seedlings were cut above the ground line and covered with a tree shelter. Results were very favorable for large diameter seedlings (8-15 mm) with some sprouts growing above the 150 cm (60 inches) shelter in the first year.

Acorn Planting

Some experimental planting has been done on New Hampshire state lands with pre-germinated acorns. One experiment in an oak-beech stand had poor results (< 50% survival after the first growing season). At the time it was thought that the failure was due to planting the acorns too deep (5-10 centimeters), a depth chosen to prevent scavenging by rodents.

Another planting experiment in a recently clearcut red pine stand also failed. Germinated acorns were planted one to two inches below the ground surface. The acorns were heavily preyed upon by acorn predators (probably squirrels) resulting in less than 20% survival.

Summary

Northern red oak has been identified as a species that is difficult to regenerate under traditional silvicultural techniques. Its importance to the northeastern forest is unsurpassed as a source of mast for wildlife populations. Many of the acorns produced are fed upon resulting in loss of a seed crop for the next generation of forest.

Red oak is naturally found on a wide range of sites. It grows best on deep, well-drained loams with deep A horizons. However, red oak often regenerates more readily on poorer sites where it can compete better with faster growing hardwoods. It is generally considered an early to mid-successional species because it often follows heavy disturbance such as fire.

One possible explanation for the recent difficulties in regenerating red oak may be the excellent job of fire suppression. Wildland fire was probably very important in establishing and releasing red oak seedlings and establishing new oak forests. This was accomplished by top-killing all the vegetation below the overstory and permitting the oaks to re-sprout with vigor due to a high root to shoot ratio. The absence of fire in today's forest permits aggressive tolerant species to capture understories and eventually replace oaks within a stand.

Some limited success in regenerating oaks has been accomplished by controlling competitive understory species using herbicides, prescribed wildland fire and mechanized timber harvesting. The ability of oaks to re-sprout and develop a high root to shoot ratio, can make individual young oak stems competitive with other species.

Planting oak seedlings has yielded mixed success. Generally, for plantings to be successful, improved seedling stock with fiberous roots must be used. Site preparation is needed to keep competition from other species in check. The use of translucent plastic tubes as tree shelters has also been useful in some experiments, although costly and often difficult to maintain.

There is still much to be learned about regenerating red oak. Even if we as land managers can regenerate this species, the expense, labor and environmental effects may not permit it economically and socially. None-the-less, this is a challenge we must not ignore!

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