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Ecology and Management of Northern Red Oak in New England

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131 Main Street, 214 Nesmith Hall, Durham, NH 03824

Ecology and Management of Northern Red Oak in New England

Authors
William B. Leak, research forester, U.S. Forest Service, Northern Research Station, Durham, NH. bleak@fs.fed.us

Mariko Yamasaki, research wildlife biologist, U.S. Forest Service, Northern Research Station, Durham, NH. myamasaki@fs.fed.us

Jeff Ward, chief scientist, The Connecticut Agricultural Experiment Station, New Haven, CT. jeffrey.ward@ct.gov

Ken Desmarais, assistant ranger, U.S. Forest Service, White Mountain National Forest, NH, formerly N.H. Division of Forests and Lands, Dept. of Resources and Economic Development. kdesmarais@fs.fed.us

Karen P. Bennett, extension forestry professor and specialist, UNH Cooperative Extension, Durham, NH. karen.bennett@unh.edu

ABSTRACT: Northern red oak (*Quercus rubra* L.) is one of the highest-valued species in New England for both timber production and wildlife amenities. However, the species is declining due to regeneration difficulties, dwindling farmland abandonment, and losses from deer browsing. Much of the available research information is from regions outside of New England, and may not apply. This publication is an attempt to assemble and evaluate information on red oak ecology, management, and habitat especially applicable to New England.

Key Words: northern red oak, New England oak stands, oak regeneration, oak wildlife habitat.

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ECOLOGY AND MANAGEMENT OF NORTHERN RED OAK IN NEW ENGLAND

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INTRODUCTION

Northern red oak (*Quercus rubra* L.) is one of the most valuable and heavily used species in New England for timber and wildlife purposes. Because of regeneration difficulties, red oak is declining in abundance throughout New England. Because most of the research is from the midwestern, mid-Atlantic and southeastern states, where red oak appears to occupy a different niche than in New England, much of the available information may not apply. This paper provides silvicultural and habitat recommendations for northern red oak stands with particular reference to New England, based on literature both from within and outside the region, coupled with a synthesis of many observations by the authors and practicing foresters. Since oak-pine is a common New England forest type, there are references to the pine component in the regeneration and thinning discussions.

Although red oak is a persistent survivor with some individuals surviving for centuries, low oak regeneration numbers underlie the region-wide concern over oak regeneration and the distinct possibility of a future decline in abundance.

GEOGRAPHICAL DISTRIBUTION

In this section, we'll look at the abundance of red oak between and within states (online Forest Inventory and Analysis [FIA] tables 2015), its common associates, and some of the historical trends.

Northern red oak is more common in the southern portions of New England where it comprises 12 to 16 percent of the cubic volume in Massachusetts, Connecticut, and Rhode Island (Table 1). In northern New England, red oak accounts for 3 to 4 percent of the volume (Maine and Vermont) and about 12 percent in New Hampshire. Red maple, on the other hand, accounts for 12 to 20 percent of the volume in all New England states. In the sapling sizes, however, red oak accounts for less than 1 percent up to about 3 percent of the stems, whereas red maple comprises between 8 and 24 percent of the saplings. The percent sampling errors for these categories are large (greater than 25 percent) especially for the red oak sapling numbers in CT, MA, RI and VT. In parts of southern New England, observations and preliminary studies show black birch, not red maple, is likely to predominate following regeneration harvests.

Table 1.—Percent of net cubic volume of northern red oak and red maple on timberland by state in 2015; and percent of sapling numbers (1.0-4.9 inches dbh) for commercial and noncommercial species. (Data from FIA core tables for 2015 CT, MA, ME, NH, RI, and VT at: https://www.nrs.fs.fed.us/fia/data-tools/state-reports/ and Forest Inventory Data Online web-application version: FIDO 1.5.1.05e St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. [Available only on internet: http://apps.fs.fed.us/fia/fido/customrpt/app.html]. Accessed 26 April 2017.

State	Red Oak Volume	Red Oak Saplings	Red Maple Volume	Red Maple Saplings
	------------------------ Percent ------------------------			
Connecticut	14.4	3.0	19.7	23.2
Maine	3.9	0.6	11.8	11.6
Massachusetts	12.4	2.5	15.8	18.8
New Hampshire	12.0	2.2	14.6	11.9
Rhode Island	16.4	1.1	16.6	23.8
Vermont	3.6	0.4	12.6	7.7

Although red oak is a persistent survivor with some individuals surviving for centuries, low oak regeneration numbers underlie the region-wide concern over oak regeneration and the distinct possibility of a future decline in abundance.

Red oak commonly occurs with white pine as the oak-pine type in mid-New England. This feature provides the opportunity to work with these species in mixture, or to alternate between the two.

During the postglacial period (roughly the last 14,000 to 12,000 years), the abundance of oak varied greatly. In southern Connecticut (Davis 1969), pine, spruce, and birch, with some oak, dominated the tree pollen record between 14,000 and 9,000 BP (years before present). Spruce dropped out by 9,000 BP and pine declined drastically between 9,000 and 8,000 BP, while oak became one of the dominant species groups during this period and remains so today.

A different historical pattern prevailed in mid-New Hampshire (Likens and Davis 1975). Spruce and miscellaneous other species dominated between 12,000 to 11,000 BP. Then pine, with a moderate proportion of oak, dominated from 11,000 to 8,000 BP, with an increase in hemlock and birch during the latter part of this period. Pine and oak declined to current levels after 8,000 BP, giving way to beech, hemlock, birch, and miscellaneous other species. Apparently, these historical patterns with oak and pine reflect the propensity of these species to thrive in moderately warm climates or warm habitats such as shallow or sandy soils or, further north, on south-facing slopes.

SITE FACTORS

Northern red oak occurs within a unique range of site conditions related to soils, climate, elevation, canopy positions within-stands, and past disturbance, especially agricultural and fire. At Harvard Forest in Petersham, Massachusetts (Stout 1952, Whitney 1991), red oak is especially characteristic of well-drained tills on midslopes, which are often shallow to bedrock. These tills generally have a sandy, washed substrate. On lower slopes with more poorly drained soils and a compact pan layer, sugar maple and ash become more common although oak is still present. Excessively drained outwash sands and gravels also support oak, usually a mixture of species, and the red oak is moderate to poor quality; where it is not replaced by black oak (at least in southern New England). These deep sandy soils are nutrient-poor and better suited to white pine than oak (Hallett and Hornbeck 2000). The effects of aspect in this region are less important. On hilltops with very shallow, excessively drained soils, other oaks (white and black in the north and chestnut and scarlet in the south), pitch pine, and other truly xeric species predominate. This general pattern probably holds throughout southern New England as far north as the southernmost counties of New Hampshire, Vermont, and Maine. Early work in Connecticut (Hicock et al. 1931) indicated red oak occurred in moderate abundance across a wide range of soil types and drainage classes.

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As one moves north, however, red oak on nonagricultural sites becomes more restricted to shallow bedrock and outwash sites, especially those facing south to southwest. Apparently, red oak is hardy on droughty soils (Karnig and Lyford

1968) due, perhaps, to its unique root system—seedlings with a strong taproot that develops into deep-rooted, wide-spreading laterals (Lyford 1980)—or to the resistance of its roots to dehydration (Parker 1968). The sandy tills are dominated by beech and red maple, or they will be dominated by these species judging from the understory, perhaps with a component of oak on south-facing slopes. Unlike southern New England, richer sites are dominated by northern hardwoods with a complete absence of red oak.

There are numerous stands dominated by oak on till soils in southern to mid-New Hampshire, Vermont, and Maine. Understory conditions indicate that these sites will revert to northern hardwood-hemlock, especially beech. The high oak component is probably due to past disturbance, especially agricultural disturbance. The role of white pine as an old-field species is well-known based on numerous observations and documentation (Lutz and Cline 1956). Oak regenerates better than expected under pine stands (McKinnon et al. 1935, Caron 1986, Leak 1987). The likeliest theory is that the acorns distributed by birds and mammals are buried and protected from insect predation and better able to thrive in the partial shade and seasonally dry duff. One logical conclusion from these observations is that oak-dominated stands on till soils originated under old-field white pine. The pine was cut, and the oak grew. The current understory, however, reflects the community best adapted to till soils in mid to northern New England—often northern hardwoods.

The common herbaceous and shrubby species found in oak stands have been documented to a limited extent. Deciduous stands on old-field sites in northern Massachusetts were found to have understories dominated by species such as acuminate aster, hay-scented fern, wintergreen, running clubmoss, *Rubus* spp., and low-bush blueberry (Whitney and Foster 1988). Understory tallies from an oak regeneration survey in southern New Hampshire (Leak 1987) found a similar list of species, but showed that xeric sites (i.e., outwash, shallow bedrock) were dominated by low-bush blueberry, ground-cedar, treefern, and similar plants, while the slightly better soils had more Canada mayflower, wintergreen, bracken fern, starflower, and other less-xeric species. One of the more common shrubs, on sandy tills especially, was beaked hazel, which can be a serious competitor to tree regeneration. Where oak stands transition to northern hardwoods with a high beech component in mid-New Hampshire, the understories may become very sparse, containing only a few stems of sarsaparilla, woodfern, Canada mayflower, etc.

Regeneration of red oak is one of the most perplexing silvicultural problems in the eastern deciduous forest, and in New England in particular.

Little information is available on elevational ranges of oak. In southern New England, there is no strict elevational limit resulting from climatic factors. In mid-New Hampshire, red oak occurs on south-facing shallow bedrock sites up to 2,000 to 2,500 feet elevation, and perhaps higher.

REGENERATION

Regeneration of red oak is one of the most perplexing silvicultural problems in the eastern deciduous forest, and in New England in particular. Poor sites, especially in southern New England, quite commonly support both oak and pine regeneration (Sewall III and Brown 1995). But few stands on good sites are regenerating the proportion of oak that exists in the overstory, and many of the best stands exhibit little or no oak regeneration. No completely reliable, economically feasible solutions have yet been developed and tested in New England. Planting with tree shelters can be successful in southern New England (Ward et al. 2000) and the mid-Atlantic (Schuler et al. 2005), but the installation and maintenance costs limit their feasibility for most New England landowners.

Seed Production and Losses

Observations over a 26-year period in Wisconsin (Godman and Mattson 1976) showed that northern red oak produced good seed crops (61 to 100 percent of a full crop) or medium crops (36 to 60 percent of full) about 38 and 19 percent of the time. In other words, a medium to good crop was produced at least every other third to fifth year. However, variation from place to place is the rule. In Pennsylvania (Grisez 1975), there were only poor crops or worse over a 6-year observation period. During the same period in Wisconsin, four medium to bumper crops were produced. Observations in southern New Hampshire (personal information, T. Walski, N.H. Fish and Game Dept.) indicated average to excellent crops during 4 years out of 11, with two additional fair crops. This equates to a reasonable crop nearly half the time. Other northeastern observations suggest large crops are produced every 2 to 10 years. Several of the poorest years were during or immediately following defoliation by the gypsy moth (Gottschalk 1989). With this perplexing level of variability, it seems necessary to verify potential mast crops by observing year-old acorn production (Figure 1).

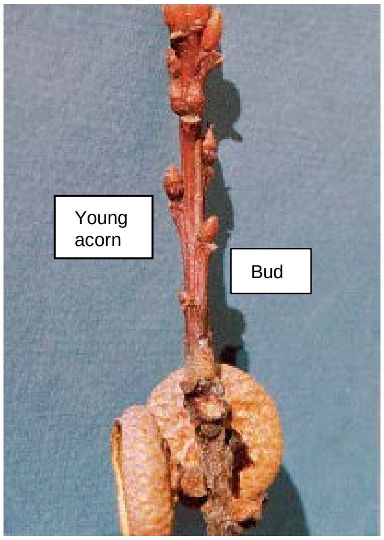

Figure 1.—A first year twig of northern red oak. Acorn caps remain from mature acorns at the bottom of the photo. Above the caps, the first structure on the right side of the twig is a bud, with young acorns above the bud on the left and right side of the twig. (photo by Tom Lee from Desmarais 1998).

Production data from Pennsylvania showed a range from about 300,000 acorns per acre in a bumper year, down to 20,000 or less in a poor-or-worse year (Auchmoody et al. 1993). This source provided the following rule-of-thumb on acorn production per square foot of ground surface:

Table 2.—Production from Pennsylvania of acorns per acre (Auchmoody et al. 1993).

Acorn Crop Rating	Acorns per acre	Acorns per square feet
Bumper	>250,000	5+
Good	125-250,000	3-5
Fair	65-125,000	1.5-3
Poor	20-65,000	0.5-1.5
Trace or none	<20,000	0-1.5

A 3-year study in Massachusetts showed a range in sound acorn production from about 75 to 545 thousand per acre, with thinned stands producing slightly higher numbers than unthinned (Healy 1997a). Mixed oak stands in southern Michigan (Gysel 1957) and the southern Appalachians (Downs and McQuilkin 1944) showed about the same range in acorn production (all oak species) as the Pennsylvania study. The southern Appalachian study indicated that best production was from trees about 18 to 26 inches diameter breast height (dbh), with minimal production from trees smaller than 14 inches or larger than 30 to 32 inches dbh. Variation among trees is very high.

In general, total production of acorns does not appear to be a limiting factor for regenerating oaks. Real impacts begin to occur, however, when we look at seed losses from various causes. Estimates have been made in Pennsylvania that only

¼ to ½ of the acorns are sound when they drop from the tree (Marquis et al. 1976). This estimate is close to that from the southern Appalachians (Downs and McQuilkin 1944) of $^1/_5$ to $^3/_5$ sound acorns during seedfall. Sound acorns in Massachusetts accounted for about 42 to 68 percent of the crop (Healy 1997a). Most of the losses are from insects, including several species of weevils (genus *Curculio*) and a moth (genus *Mellissopus*). In addition, studies in Virginia and Wisconsin (Johnson and Adkisson 1986) indicate that blue jays may remove up to 58 percent of an acorn crop, eating some and storing others in the ground at some distance from the seed source. No doubt, squirrels and chipmunks also remove some acorns prior to seedfall.

Greater acorn losses occur after seedfall. In New Hampshire (Yamasaki et al. 1991), only about 2 percent of acorns on the ground surface were not destroyed by red squirrels, gray squirrels, chipmunks, and insects of three families—wireworms (Elateridae), weevils (Circulidae), and sap beetles (Nitulidae). The type of predation varied with location. In one area, ¾ of the losses were from mammals; in another area, insects caused ⅔ of the losses. In many locations, deer and turkey heavily consumed surface acorns as well. Buried acorns suffered much lower levels of predation—about half of the acorns buried 1-inch deep escaped predation, and produced live seedlings—although observations indicate that some sprouted acorns may be removed and eaten by squirrels. Similar results occurred in Pennsylvania (Auchmoody et al. 1994)—surface acorns suffered predation rates of over 90 percent, while only 50 percent of the acorns buried 1-inch were lost to small mammals and insects. Paradoxically, predatory activity on acorns can be beneficial to the regeneration of white pine by causing ground disturbance (Alexander 1980), which helps explain the commonly observed presence of white pine understories under an overstory of oak. The general conclusion from these and other studies is that few acorns survive to become seedlings unless they are buried by some disturbance, such as logging activity, or unless there is a bumper seed crop which overwhelms use by seed predators.

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Regeneration Establishment and Beyond

The standard approach for regenerating oak is through release of established advance regeneration, coupled with stump sprouts, through shelterwood harvests followed by overstory removal. (Hannah 1987, Kelty et al. 2003, Brose et al. 2008). The establishment of this advance regeneration usually takes place slowly following light thinnings from below or light shelterwood harvests. Scarification from the harvest operation during a good to moderate seed year that buries the acorns can improve the percent that germinate (Rathfon et al. 2008). The advance regeneration consists of seedlings and seedling-sprouts as well as stump sprouts. For a detailed discussion of the biological and silvicultural aspects of the red oak regeneration process, see Desmarais (1998).

Stump-sprouting ability declines rapidly with tree-size and age; vigor might also be a factor. Data from the North Central region indicates that about 30 to 50 percent of the stumps from mid-sawtimber-sized trees produce viable sprouts (Johnson 1993, Sander 1977), while few sprouts are produced by trees over 26 inches dbh. An unpublished study of 224 oak stumps in Connecticut found most oak stumps with diameters of 10 inches produced sprouts, while few sprouts developed from stumps with 30-inch diameters—especially older stumps (Figure

2). Stumps from smaller poles and saplings, however, reliably produce vigorous sprouts.

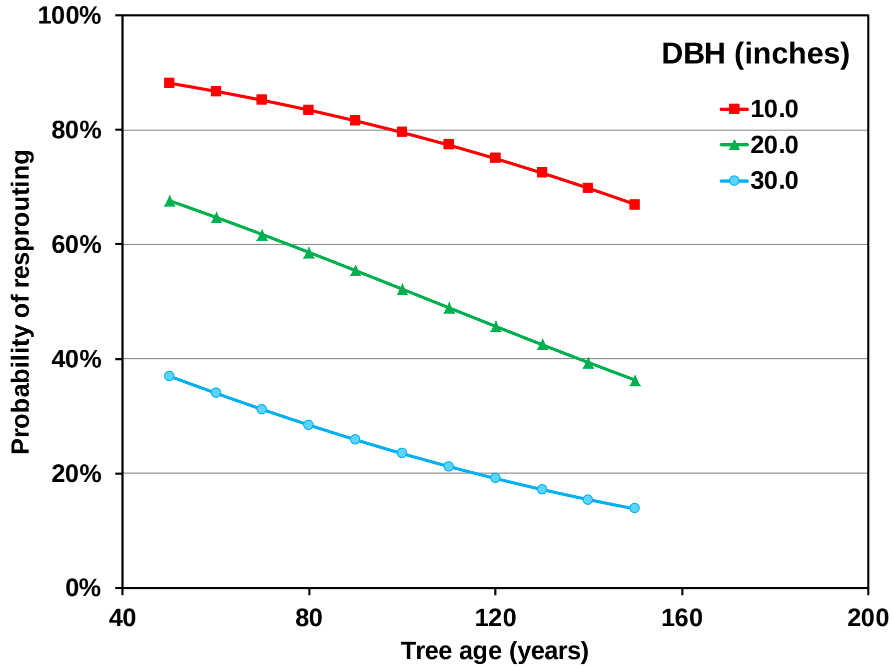

Figure 2.—Estimated proportion of stumps producing sprouts from a survey of 224 oak stumps in Connecticut.

Developing advance regeneration, by partial release through shelterwood harvests prior to full release when the overstory is removed, is the standard approach for regenerating oak.

Observations in New England indicate that while harvests in sawtimber stands may produce some stump sprouts, many of those sprouts die within a few years from competition or repeated browsing. Stump sprouts produce acceptable stems, especially when originating near the ground line. Usually one major stem develops from cut saplings or poles, with two to four codominant stems developing from small sawtimber stumps. Double or multiple-stemmed clumps tend to have lopsided crowns and leaning boles, factors which lead to eccentric stems and tension wood (Sorensen and Wilson 1964), but they also seem to self-prune higher and faster. Early cleaning and weeding can reduce the number of stumps with multi-stemmed clumps.

In general, it is doubtful whether stump sprouts can be regarded as a major factor in the regeneration of New England oak stands because larger, older stumps produce few sprouts, and those that do develop are often severely damaged by browsing. Most commercial operations do not create numerous small stumps that sprout prolifically, except perhaps for biomass operations in small-diameter, low-quality stands or light shelterwood operations with harvesting from below.

Seedling sprouts are seedlings that have died back and resprouted, sometimes repeatedly, from the root or base of the stem. This behavior is characteristic of oaks, and produces a large root-to-shoot ratio that facilitates rapid growth and high survival rates following release. Developing advance regeneration, by partial release through shelterwood harvests prior to full release when the overstory is removed, is the standard approach for regenerating oak. Much of the advance oak regeneration that gradually accumulates in understories consists of seedling sprouts. Often, these are not readily distinguishable from seedlings; and the two categories often are lumped together in regeneration tallies. Whether from seedlings or seedling sprouts, the root-collar of seedlings should be at least ¼ inch in diameter before being considered established and ¾ inch in diameter to be considered competitive. (Brose et al. 2008).

Seedlings, technically speaking, have developed from the germination of acorns without any resprouting. Most emerge the first year after dispersal, but a small percentage may emerge the second year (Steiner et al. 1990). Commonly, seedlings are considered established only after reaching fairly large size, about 4.5 feet tall (Sander 1977), though there are some indications in New England that even young, small oak seedlings will survive following release (Smith and Ashton 1993). However, many small oak seedlings are only equivalent to a single competitive seedling sprout. Seedling-sprouts and stump sprouts (from small stumps) probably could be regarded as established at heights less than 4.5 feet with a root collar diameter ¾ inch.

The few regeneration studies of red oak in New England generally reveal minimal stocking. A survey in northeastern Connecticut (Kittredge and Ashton 1990) across a range of sites and stand densities reported less than 50 stems per acre greater than 20 inches in height. Stands typed as pine-hemlock-hardwood had the largest number, more than twice as many stems as stands typed as hardwood or hemlock-hardwood. The pine-hemlock-hardwood type also had more red oak stems under 20 inches tall. This survey also showed that red oak was relatively less abundant in the understory than in the overstory. This phenomenon may be unimportant if minimal mortality and rapid growth allow a small number of seedling-sapling oaks to maintain a strong presence in the future stand. Another Connecticut study found abundant oak seedlings (less than 4 feet tall) following gypsy moth-induced mortality, though seedling density decreased by 68 percent in the subsequent 20 years (Ward et al. 1999). The same study noted oak sapling (greater than 4 feet tall and less than 1-inch dbh) density decreased from 77 to 20 stems per acre over the same 20-year period.

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Oliver (1978), working in Connecticut, suggests that low oak densities in sapling stands can result in oak-dominated stands at maturity. However, research in the Catskills (Lorimer 1981) shows that suppressed oak do not survive well. Since there is so little clearcutting or shelterwood release cutting in oak stands in New England, the trend described above—few oak in smaller diameter classes—might well lead to a continuing decline in red oak under current forest management practices.

A survey of 14 oak-pine-hardwood stands in southern New Hampshire (Leak 1987) showed that oak tended to be more dominant under pine stands than under hardwood, regardless of the lack of oak in the overstory (Table 3); an observation made elsewhere (Caron 1986) likely due to the bird and mammal transport of acorns. Since seed predation has such a major influence on germination and survival, we suspect that seed predation may be less severe under pine, but this has yet to be proven. Oak dominance was highest under a pine stand on an outwash soil, but otherwise the relations between soils, competition, ground cover, and oak regeneration dominance were unclear (Table 4).

Table 3.—Stand attributes and percent milacres dominated by red or white oak (where oak was the tallest stem between 0.5 feet tall and 2.9 inches dbh) or other species. Cut and uncut stands in southern New Hampshire (Leak 1987).

	Pine		Oak-hardwood	
Attribute	Uncut	Cut	Uncut	Cut
No. of stands	1	4	4	5
Oak BA (square feet)	0	2	50	38
Pine BA (square feet)	170	90	3	14
Total BA (square feet)	195	93	126	79
% milacres dominated by:				
Oak	19	32	1	14
White pine	12	2	6	8
Beech	0	0	51	6
Red maple	25	24	6	22

Table 4.—Relation of cover type and soil deposit to percent milacres dominated by oak (red and white), total stems per acre of tree species (0.5 feet tall to 2.9 inches dbh), and percent ground cover. Cutover stands in southern New Hampshire (Leak 1987).

Cover type	Soil deposit	Percent oak-dominated milacres	Numbers per acre tree stems	Percent ground cover
Pine (4 stands)	Outwash	65	2,325	34
	Sandy sediment	19	4,063	44
	Silty sediment	32	9,253	50
	Wet pan	14	4,250	79
Oak-hardwood (5 stands)	Shallow bedrock	8	5,000	58
	Coarse sandy till	2	2,600	8
	Fine sandy till	35	7,100	50
	Fine sandy till	12	11,626	52
	Fine till over pan	12	14,187	61

Fire is often regarded as the factor most responsible for the origin of oak-dominated stands, but documentation in New England is minimal. A study in northeastern Connecticut (Moser et al. 1996) showed that an understory fire severe enough to kill some of the overstory produced an oak-dominated understory; this effect resulted from the sprouting ability of fire-killed seedling and sprouts coupled with their rapid height growth following release. A light understory fire produced little effect. While these studies were conducted in mature forests, most wildfires in the early 1900s were in "young growth" (Hawes 1923) and two separate studies found prescribed fires in seedling-sapling stands improved the competitive status of oak. (Ward and Brose 2004, Ward 2015a).

Regeneration Lessons from the Past

In view of the widespread burning and agricultural activities of Native Americans in southern New England (Day 1953), it is conceivable that such disturbances were responsible for some of the oak stands in that region today, and the paucity of modern-day oak regeneration. Prior to widespread forest fire suppression that began after World War I, wildfires annually destroyed an average of 3 percent of Connecticut's forests (Hawes 1923). North of Massachusetts, however, except perhaps in the coastal regions, burning did not appear to be widespread (Day 1953).

An untested and interesting hypothesis is that before modern-day harvesting techniques and equipment, stands were harvested at a smaller size (and a younger age), which would increase the proportion of stumps that produced sprouts.

Another line of reasoning suggests many of the oak-dominated stands in both northern and southern New England resulted from farm clearing and abandonment. The ability of oak to resprout after repeated grazing, to survive in sod, and to regenerate under old-field pine, which was subsequently harvested, could help explain the occurrence of nearly pure oak stands in this region.

An early study (McKinnon et al. 1935) in northern Massachusetts and southern New Hampshire of the regeneration following old-field pine clearcuts tends to support this suggestion. Data from over 170 stands originating from pine clearcuts up to 45 years old showed that red oak was the predominant free-to-grow crop tree (Table 5). Good sites supported a greater variety of species (e.g., white ash), and a greater total number of crop trees.

The proportion of red oak appeared to become more predominant as stand age (time since clearcutting) increased, probably due to oak's vigorous crown development as compared to species such as ash (Patton 1922). Adding further credence to the idea that these old-field stands that developed after pine clearcuts could develop into almost pure oak stands, the numbers of free-to-grow oak crop trees in the older stands in Table 5 (following pine clearcuts) are 2 to 3 times the proportions and numbers of oak canopy stems found in 20 to 40 year-old mixed stands in Connecticut (Ward et al. 1999).

An untested and interesting hypothesis is that before modern-day harvesting techniques and equipment, stands were harvested at a smaller size (and a younger age), which would increase the proportion of stumps that produced sprouts.

Table 5.—Numbers of free-to-grow crop trees per acre by species, site class, and stand age (years since clearcutting) following clearcutting of old-field pine in Massachusetts and New Hampshire (McKinnon et al. 1935). A. Good sites, B. Medium sites, C. Poor sites.

A. Good Sites: Good sites are the fertile to moderately fertile till soils at lower to mid-slope positions.

Age	Red oak	White ash	Paper birch	Black birch	Hard maple	Black cherry	Yellow birch	White pine	Other	All
1-2	215	245	37	6	42	12	2	15	4	578
5	268	130	51	38	32	46	15	24	9	613
10	64	46	204	13	22	0	0	5	4	358
15	121	66	95	17	24	1	7	6	2	339
20	104	61	31	1	41	1	28	3	0	270
25	88	11	45	8	3	1	3	0	2	161
30	133	12	15	5	2	0	1	0	2	170
35	95	6	21	9	4	0	1	0	0	136
40	89	5	31	8	5	1	3	0	2	144
45	107	0	19	4	2	5	0	0	4	141

B. Medium Sites: Medium sites are the moderately fertile upper slopes and ridge tops.

Age	Red oak	White ash	Paper birch	Black birch	Hard maple	Black cherry	Yellow birch	White pine	Other	All
1-2	112	120	6	13	0	42	0	5	1	299
5	107	62	42	7	17	29	0	14	19	297
10	175	8	50	7	2	2	0	9	6	259
15	70	3	25	0	3	0	0	6	0	107
20	127	0	10	2	0	2	0	0	8	149
25	124	2	7	1	0	0	2	0	14	150
30	123	2	13	3	1	0	0	0	0	142

C. Poor Sites: Poor sites are the dry and sterile sandy soils.

Age	Red oak	White ash	Paper birch	Black birch	Hard maple	Black cherry	Yellow birch	White pine	Other	All
1-2	654	0	0	0	1	14	0	6	12	98
5	98	0	0	0	0	16	0	12	10	136
10	36	0	0	0	0	0	0	0	2	38
15	84	0	1	0	0	1	0	12	13	111
20	88	4	4	0	0	0	0	12	24	132
25	90	0	7	3	0	0	0	3	3	106
30	226	0	0	0	0	0	0	0	2	228
35	45	0	0	0	0	0	0	8	78	131

Clearcutting in pine stands older than 50 years, where advance hardwood growth was developing, produced better regeneration than cutting of younger stands. Red oak was a minor overstory component of the cutover pine stands, less than 10 percent of the hardwood species, whereas red maple comprised about half of the hardwood component. White pine comprised only a minor component of the crop trees found in the regenerating stands, and the component declined over time (McKinnon et al. 1935, Table 5).

Intensive regeneration techniques developed in Pennsylvania and the southern Appalachians should work in New England. Detailed prescriptions (Brose et al. 2008) involve chemical applications to minimize the competitive understory, (often beech in New England), shelterwood harvesting to provide adequate light, and subsequent prescribed fire to favor the fire-resistant oak. The shelterwood harvest, coupled with adequate scarification to prepare a seedbed and bury the acorns, should be timed with at least a medium acorn crop. However, in Connecticut, Ward (2015a) did not find shelterwood followed by burning to consistently improve oak regeneration over the short term. Burning the young stands 3 to 5 years after overstory removal seemed more effective.

Upper-elevation sites, somewhat shallow to bedrock, in the New England mountains often develop a component of red oak especially on southern and western exposures. On the Bartlett Experimental Forest NH, two such stands were available for study. One stand developed following a clearcut 35 years earlier and contained over 100 high-quality, well-distributed, dominant pole-sized stems. The uncut portion of that stand had only 11 square feet of basal area per acre of mature oak coupled with about 500 stems of advance oak seedlings ½ to 1 foot tall. A nearby uncut stand had 22 square feet per acre of mature oak with about 2,000 vigorous oak seedlings up to 1 foot tall. Possibly, release of 500 to 2,000 seedlings per acre through clearcutting (overstory removal) on these sites with shallow soils will produce regeneration with an adequate oak component (Leak and Yamasaki 2013a).

Another option worth testing is the application of small patch cuts near an oak seed source. Although oak seedlings will not develop beneath a beech understory, it is likely that they will survive and develop an adequate root system beneath an early successional overstory (pin cherry, aspen, grey birch, for example). As the overstory dies or is harvested, there should be some component of oak available for release in the advance regeneration. However, if the overstory fails to decline as the oak develops and the sapling oaks in the intermediate and suppressed crown classes have poor dbh to height ratios, they can “rainbow” under snow or ice loads or even strong winds.

SUCCESSION

The impact of red oak regeneration levels on the maintenance of oak stands is understood by looking at successional trends to determine how much regeneration is enough. The best long-term data in New England on the development of oak stands is an 80-year record from south-central Connecticut (Ward et al. 1999, Ward 2013a). This record followed the development of unmanaged mixed hardwoods that were 20 to 40 years old in 1926/27 and growing on sites varying from wet (swamp and muck) to dry (somewhat excessively drained or drier). One area burned-over in 1932, providing some successional information on the effects of burning; the fire was severe enough to cause some overstory mortality.

The impact of red oak regeneration levels on the maintenance of oak stands is understood by looking at successional trends to determine how much regeneration is enough.

Percent basal area of red oak in the initial stands averaged 12 percent, and was nearly identical to red maple (13 percent) and black birch (13 percent). Seventy years later the proportion of red oak had nearly doubled (23 percent), while that of red maple (12 percent) and black birch (15 percent) remained about the same (Ward et al. 1999). Over the same time period, the number of canopy stems (dominant and codominant) declined by fully two-thirds, reflecting increased size of surviving trees. While the absolute density of red oak in the upper canopy declined, the proportion of the upper trees that were northern red oak increased from 13 to 22 percent during the study (Table 6). Concurrently, the proportion of upper canopy red maple stems declined from 13 to 11 percent; surprisingly, the proportion of black birch increased slightly from 13 to 15 percent (Table 6).

Table 6.—Stand density (stems per acre) of canopy trees (dominant and codominant) over all moisture classes excluding muck (Ward et al. 1999)

	1927	1997	1927	1997
Northern red oak	29.9	15.4	13%	22%
Red maple	30.2	7.4	13%	11%
Black birch	29.7	10.6	13%	15%
All species	236.5	68.9	100%	100%

Ingrowth (trees that became 0.6 inches dbh) of all oak, including northern red oak, was high only on the area that had a wildfire and only in the 20 years after the fire. Otherwise, oak ingrowth averaged less than five stems per acre per decade—less than 4 percent of all ingrowth. In contrast, maple, birch and beech ingrowth has been 2 to 15 times greater than oak on unburned areas (Table 7). Apparently, red oak will not maintain itself under the dense crowns and small openings found in uncut stands, or in even larger openings from mortality caused by gypsy moth defoliation.

Table 7.—Stand ingrowth (stems per acre per decade) over time by species group and disturbance type (Ward 2013a).

		1927 -1937	1937 -1957	1957 -1967	1967 -1977	1977 -1987	1987 -1997	1997 -2007
Oak	Fire	0	244	11	2	15	2	1
	Multi	13	2	1	8	11	2	1
	Single	18	17	4	4	5	4	2
Maple	Fire	2	154	26	15	15	12	10
	Multi	15	23	35	85	34	12	7
	Single	20	44	29	48	39	18	7
Birch	Fire	4	114	9	9	17	12	8
	Multi	15	19	35	122	85	33	16
	Single	12	13	13	20	12	10	5

Fire= 1932 summer wildfire
Multi= multi-year episodes of moderate to severe gypsy moth defoliation
Single= one-year moderate to severe gypsy moth defoliation

Suppose we applied the successional trends described above to the limited sample of regeneration data provided in Table 3. Red oak dominated an average of 19 and 32 percent of the milacres under uncut and cut pine stands respectively. It seems reasonable to suggest that overstory removals in these stands would eventually result in stands composed of twice that amount of oak—40 to 60 percent of the basal area or more if intermediate cuttings to favor oak were carried out. In similar fashion, overstory removals in the uncut and cut hardwood stands, which have 1 and 14 percent oak-dominated milacres, might result over time in mature stands with about 2 and 30 percent oak, respectively. We might conclude, in this example, that current oak regeneration under pine will maintain well-stocked oak stands; current levels under oak-hardwood will not.

Long-term successional trends in red oak stands in New England have never been determined. Successional studies in mid to northern New England suggest that hemlock would be a major climax component on outwash sands or shallow bedrock (Leak 1982), while beech with a component of red maple would be the dominant climax species on sandy, well-drained tills and beech with a component of sugar maple would be the climax species on finer-textured tills. The regeneration studies previously cited show that sugar maple was a noticeable understory component in northeastern Connecticut stands (Kittredge and Ashton 1990), while birch, red maple and beech were predominant in south-central Connecticut (Ward et al. 1999). Recent FIA surveys (FIDO 2016) show red maple as a major ingrowth species in southern New England with eastern white pine, American beech and birch components. Apparently, red maple, beech, and birch with white pine could predominate in maturing stands in southern New England depending, upon site conditions. Eastern hemlock had been a major component, but has rapidly declined in the past few decades because of hemlock woolly adelgid and elongate hemlock scale. Hemlock decline in northern New England is not yet a factor in successional development of stands.

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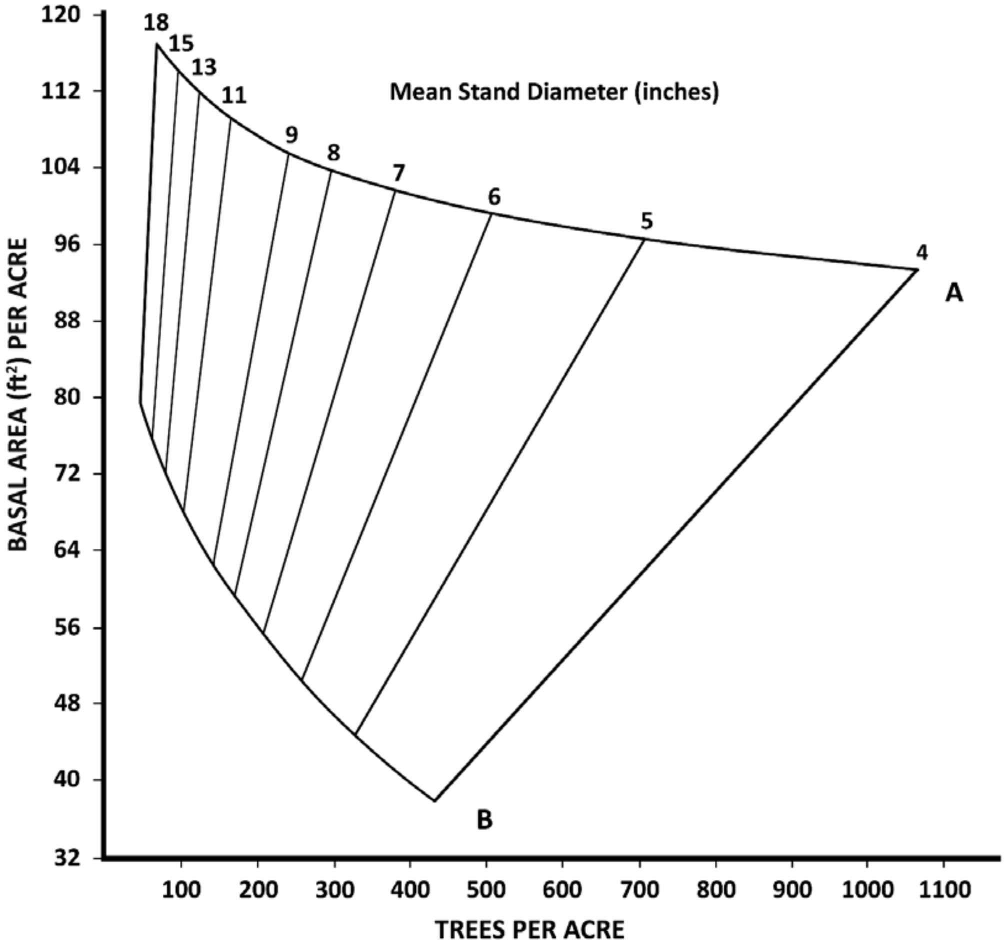
STOCKING, GROWTH, AND QUALITY

Stocking

A stocking chart for New England red oak stands (Figure 3; 50 percent or more oak composition) applies to stems in the main crown canopy (i.e., excludes suppressed trees) (Sampson et al. 1983). The A-line was developed from regression analysis of fully stocked stands; basal area values range from the mid-90s in small-diameter stands up to a little below 120 square feet in stands averaging 18 inches mean dbh. The B-line (suggested average optimal stocking after thinning) was developed from crown dimensions of dominant trees; values range from about 40 square feet in small-diameter stands up to 80 square feet in larger-diameter stands. We suggest that clear boles and full crowns be present before thinning to the lowest recommended stocking in young stands. Stands nearing the A-line could benefit from additional spacing to enhance diameter growth and crown development of trees that will form the mature stand. Trees in stands with stocking below the B-line will be subject to live branch retention and possible epicormic branching if the crowns are small or there is defoliation from the gypsy moth. Stands with stocking below the B-line will likely develop an abundant understory of shade-tolerant species that could hinder future oak regeneration. The B-line in the Sampson guide is similar to that developed in

Wisconsin for trees in the main canopy (McGill et al. 1999), however, the A-line for New England is lower, reaching a maximum of about 120 square feet per acre as compared to more than 140 square feet in the Wisconsin guide.

Figure 3.—A stocking guide for northern red oak in New Hampshire showing basal area and numbers of trees by mean dbh. Applies to main crown canopy of stands with 50% or more red oak (redrawn from Sampson et al. 1983).



Relative density is an alternative guideline for thinning. It represents a useful parameter over a wide range of stand ages and sizes and is usually set at 60 percent of full stocking. For example, based on the oak stocking chart (Figure 3), 60 percent of the A-line would represent about 70 square feet per acre for the large-diameter stands and down to 55 to 60 square feet for the small-diameter stands. For some forest types, the range is much greater. For additional discussion of residual stocking objectives, see the section on growth and yield which discusses the importance of tree vigor and quality in determining optimum residual stocking.

In the same study (Sampson et al. 1983), a yield table for red oak was developed (Table 8) showing mean stand diameters (main canopy stems only), volumes, trees per acre, and basal area as well as years to reach a given stand diameter by site index class. The volumes, which are approximate, correspond most closely to site index class 65. Note that the estimated time to attain 18 inches mean stand diameter is 101 years. However, when interpreting the estimates in Table 8, remember that oak diameters vary widely around the mean diameter (Table 9). Managed stands, however, will exhibit a more uniform diameter distribution and will, of course, attain large diameters in a much shorter period of time. Based on the diameter-growth studies listed below, it appears quite possible to produce 20-inch red oak in 60 to 70 years (Figure 4).

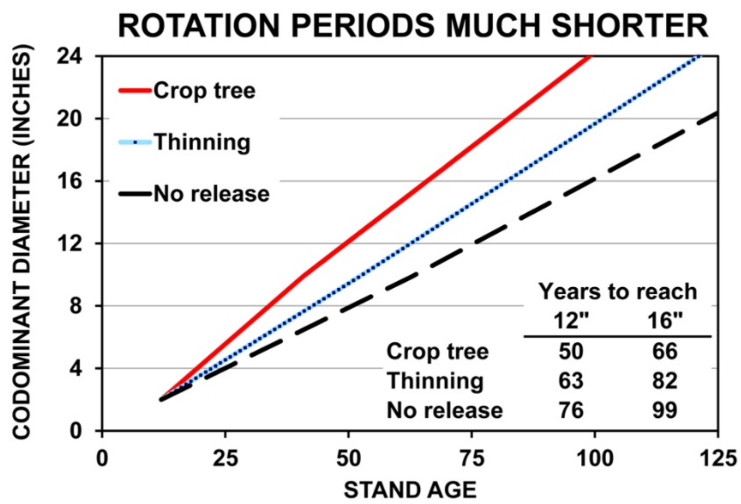


Figure 4.—Connecticut results showing management can shorten rotations

Red oak has naturally good stem form and quality potential. Using New Hampshire as an example, about 94 percent of the trees greater than 5.0 inches fall into the acceptable class and less than 3.5 percent in the preferred class (Frieswyk and Widmann 2000), i.e., the trees that are suitable for top-grade sawlogs or veneer. However, under management, these numbers could change radically—and even reversed.

Table 8.—A yield table for unmanaged red oak in New England showing mean stand diameter (MSD); volumes, trees (main canopy), and basal area per acre; and years to reach a given MSD by site index class (Sampson et al.1983).

	Volume				Years to Reach MSD. by Site index		
MSD.	Cubic Feet	Board Feet	Number of trees	Basal area	55	65	75
(inches)				(square feet)			
4.0	1,259		1,070	93.4	34	31	23
5.0	1,920		708	96.7	54	47	38
6.0	2,319		506	99.4	62	54	45
7.0	2,580	1,664	380	101.6	66	59	49
8.0	2,772	3,465	297	103.7	70	62	53
9.0	2,918	5,649	239	105.6	74	66	57
10.0	3,039	7,788	197	107.4	78	70	61
11.0	3,199	9,708	165	108.9	82	73	65
12.0	3,287	10,942	141	110.7	86	77	69
13.0	3,396	11,814	121	111.5	90	81	73
14.0	3,466	12,255	106	113.3	94	85	77
15.0	3,503	12,432	93	114.1	98	89	81
16.0	3,617	12,840	83	115.9	102	93	85
17.0	3,645	12,939	74	116.6	106	97	89
18.0	3,749	13,308	67	118.4	109	101	93

Table 9.—Examples of diameter distributions (numbers of trees per acre by dbh class) in two unmanaged mixed oak-hardwood stands in southern New Hampshire (Leak 1987).

STAND 1

Dbh	Red Oak	Beech	Black Birch	Red Maple	Paper Birch	White Pine	Other	All
4	17.5	11.5	28.6	28.6		5.7	5.7	97.6
6	15.3	15.3	5.1	15.3	5.1	5.1		61.2
8	8.6	5.7	8.6	2.9			5.7	31.5
10	5.5	14.6	5.5	3.7				29.3
12	3.8	6.4	3.8	1.3		2.5		17.8
14	6.6	3.8	1.9					12.3
16	6.5	1.4	.7		.7	.7	.7	10.7
18	2.3	1.1				.6		4.0
20	.9			.5				1.4
22								0.0
24	.6							0.6
All	67.6	59.8	54.2	52.3	5.8	14.6	12.1	266.4

STAND 2

Dbh	Red Oak	Beech	Red Maple	White Pine	Hemlock	All
4	0.0	100.3	57.3			157.6
6	31.8	31.8	25.4			89.0
8	46.5	14.3	10.7	3.6		75.1
10	59.5	6.9	2.3			68.7
12	15.9	1.6	1.6	1.6		20.7
14	8.2					8.2
16				1.8		1.8
18						0.0
20				0.6		0.6
22		0.5				0.5
24					0.4	0.4
26				0.3		0.3
All	161.9	155.4	97.3	7.9	0.4	422.9

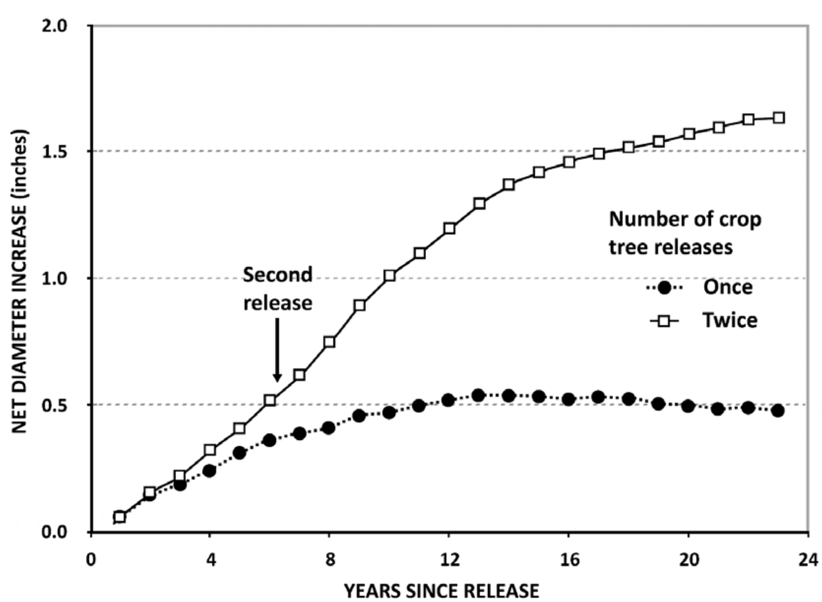
Growth and Yield

Sapling stands of red oak responded well to early release treatments in a Connecticut study (Ward 2013b). Diameter growth increased markedly with the level of release and crown class. Over the first 4 years following treatment, dominant stems under the 75 to 100 percent release treatment grew better than 1/3 inch per year (Table 10). Height growth of dominants and codominants was only slightly reduced. Intermediate and suppressed crop trees also responded to the release treatments. Under 100 percent release, intermediate stems more than doubled in diameter growth up to a rate of about 1/5 inch per year. An 18-year, and then a 24-year follow-up (Ward 2013b) confirmed that crop-tree release, especially two releases 5 years apart, significantly increased the proportion of oak that remained in the upper canopy, increased the growth-rate, and focused growth on the highest-quality stems (Figure 5).

Table 10.—Annual dbh growth (inches-4-year period) of sapling red oak by crown class and percent release (Ward 2013b).

Percent Release	Dominant	Codominant	Intermediate	Suppressed
	(inches)			
0-24	.25	.17	.08	.03
25-49	.31	.18	.11	.04
50-74	--	.21	.12	.10
&5-100	.37	.29	.20	--

Figure 5.—Net mean diameter increase of oak saplings relative to unreleased trees (redrawn from Ward 2013b).



Perkey et al. (1993) also advocated crown release on up to four sides; that is, unless damage to the crowns or boles occurs. One caution on crop-tree release—red oak stands develop best as mixed stands (50 to 75 percent oak) since the large, spreading crowns cause severe within-species competition.

Red oak stands develop best as mixed stands since the large, spreading crowns cause severe within-species competition.

It is a fairly common belief that older stands of oak will not respond well to thinnings (e.g., Hibbs and Bentley 1983). However, crop-tree thinnings in five 70 to 90-year-old upland oak stands in Connecticut increased red oak diameter growth by over 50 percent, up to a rate of nearly $^3/_{10}$ inches per year (Ward 2002). Release on two, three, or all sides increased diameter growth by 25, 43, and 57 percent respectively (Figure 6). Growth-rates increased in all size classes (Figure 7) and development of epicormic branches on the butt log was largely limited to the slowest-growing trees. Similarly, another Connecticut study reported diameter growth of 80 to 110 year old sawtimber red oak in four previously unmanaged stands increased by 54 percent following complete release and 29 percent with partial release (Ward 2011). The increased growth of individual trees was sufficient to maintain stand growth-rates similar to that of unmanaged stands. However, the New Hampshire results (see New Hampshire case study in next section) showed little diameter-growth response to residual basal areas approaching B-line levels, and produced maximum volume and basal area growth at high stocking levels.

Figure 6.—Annual diameter growth (upright bars show one standard error) by percent crown release of red oak sawtimber in southern New England. Bar-graphs linked by horizontal lines were not significantly different (Tukey's HSD test at P<0.05). (redrawn from Ward 2002).

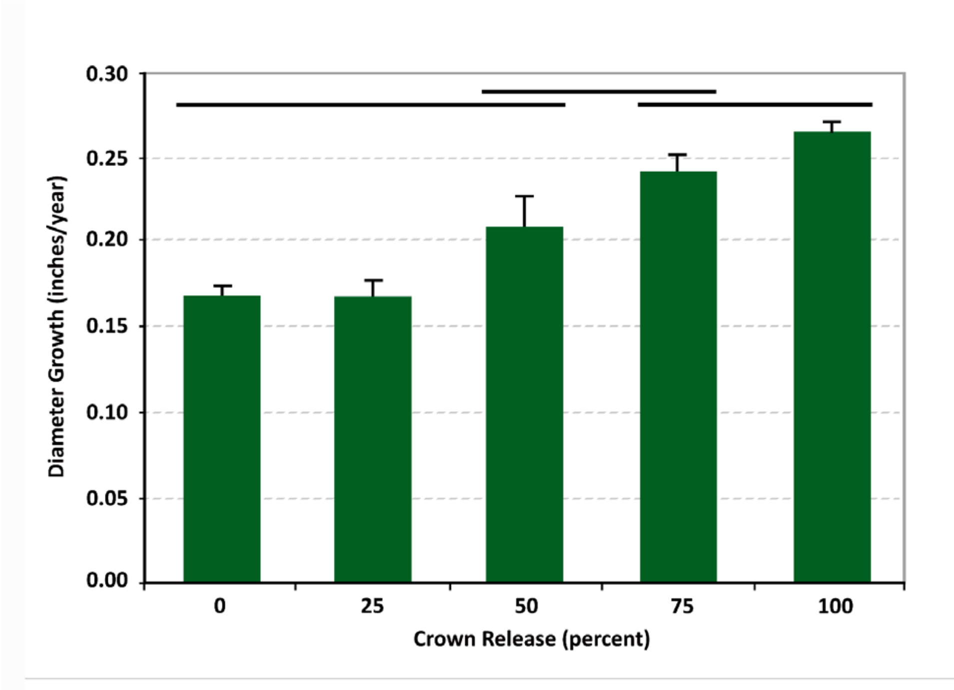
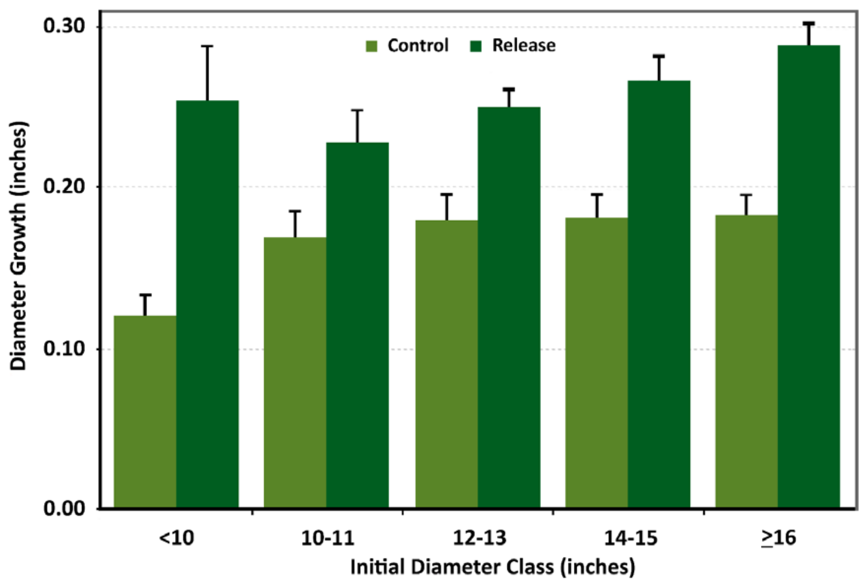


Figure 7.—Mean annual diameter growth of released and control red oak sawtimber trees by initial dbh class (upright bars show one standard error). Significant (P<0.03) for all dbh classes (redrawn from Ward 2002).



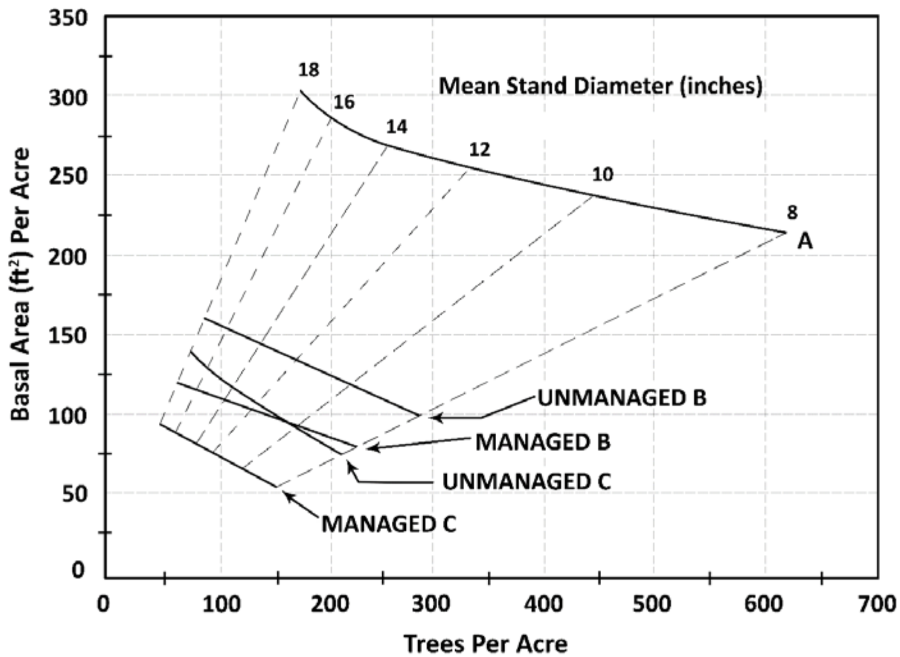
Long-term studies (14 to 17 years) in Connecticut documented growth responses from five silvicultural options:

1. Shelterwood—40 square feet residual basal area
2. Diameter-limit—60 square feet residual
3. Multi-age crop-tree—40 square feet residual
4. High-grading—20 square feet residual; and
5. Uncut—100 square feet plus basal area.

The diameter-limit, shelterwood, and crop-tree methods produced comparable annual growth-rates of about 200 board feet per acre, a little less than the uncut response of about 240 board feet. However, the crop-tree approach produced significantly greater growth-rates in oak, as compared to other species, possibly due to the more efficient removal of competing non-oak species (Ward et al. 2005). Fuelwood thinnings in Connecticut mixed oak stands, about 50 to 120 years old, also resulted in board-foot growth-rates for all species of a little less than 200 board feet annually per acre (Ward 1991).

White pine is such a common associate of red oak that the two often are efficiently managed together (Waskiewicz et al. 2013). Stocking goals of previously unmanaged white pine may be much higher than that of red oak; however, managed white pine stands will gradually develop a much lower optimum basal area level due to crown expansion. A stocking chart for white pine, showing managed and unmanaged optimums is included (Figure 8). Another option is low-density management of white pine where the optimum mid-rotation stocking is about 60 square feet basal area per acre (Leak and Yamasaki 2013b, Seymour 2007).

Figure 8.—Revised white pine stocking guide for managed stands (redrawn from Leak and Lamson 1999).



A New Hampshire Case Study

Because limited growth information is available for northern New England, we are using a limited, but good case study to examine what we might expect for growth and production from a more northerly region than from southern New England.

Growth

Eight growth plots have been maintained on two New Hampshire State Forests for periods of 13 and 9 years; these are $^{1}/_{10}$-acre circular plots located, respectively, at Vincent State Forest in Deering and Walker State Forest in Concord. The plots were established immediately after commercial crop-tree release left a range of residual stocking. Plot data are shown in Tables 11 and 12 and Figure 9.

As shown in Table 11, species composition consisted initially of about 25 (one plot) to 67 percent red oak with varying amounts of beech, red maple, and black birch. Average stand diameters ranged from 8 to 13 inches; annual change in mean dbh ranged from 0.10 to 0.14 inches and showed little relationship to residual basal area. Note that dbh change was somewhat less than the growth-rates in southern New England (Figure 6 and 7); however, change in mean dbh is affected by mortality patterns and ingrowth—somewhat different than dbh growth on sample trees.

Table 11.—New Hampshire Plots. Average dbh growth and species composition (percent of basal area: initial post-thinning and final).

Residual Basal Area	Mean Dbh	Annual dbh Change	Red Oak (initial) (final)	Beech (initial) (final)	Red Maple (initial) (final)	Black Birch (initial) (final)
(square feet)	(inches)		(Percent)			
47 W	8.1	.14	66.7 77.8	11.1 11.1	0 0	11.1 11.1
57 V	10.9	.14	31.3 35.7	6.3 21.4	43.8 14.3	18.8 28.6
59 V	9.9	.13	50.0 42.1	0.0 10.5	31.3 26.3	12.5 10.5
84 W	10.5	.14	60 50	0.0 0.0	40.0 50	0 0
90 W	10.5	.12	57.1 53.3	0.0 0.0	21.4 20	0 0
91 V	10.2	.12	60 56.3	13.3 12.5	13.3 12.5	13.3 12.5
98 V	13.4	.10	25.0 23.1	16.7 15.4	58.3 61.5	0 0
109 V	12.0	.15	50 50	42.9 42.9	0 0	0 0
**			***	***	***	***

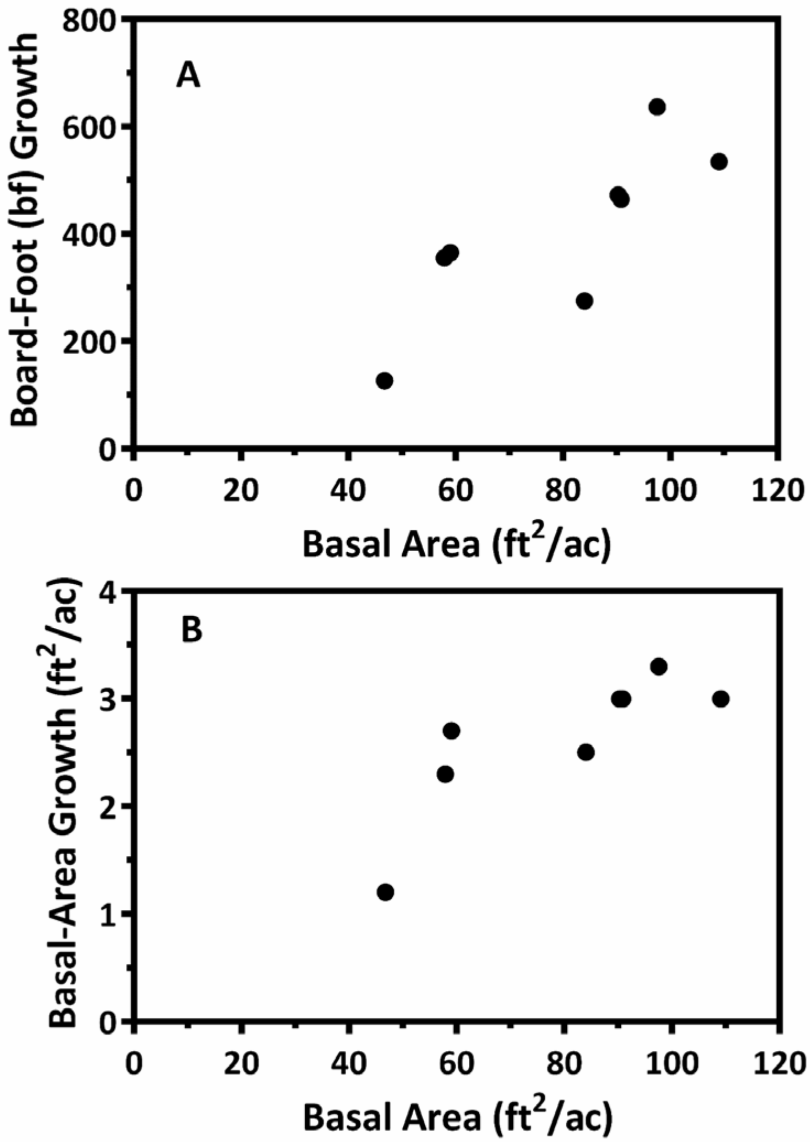
** W and V denote Walker and Vincent plots.

*** Initial percents are right after thinning; final percents are at end of growth period.

Table 12.—New Hampshire Growth Plots. 9 and 13-year growth periods.

Basal area per acre	Initial board foot volume	Annual board foot growth	Annual cubic foot growth
47	2,332	126	29.9
58	2,426	355	88.9
59	2,734	365	101.2
84	6,110	275	72.2
90	5,291	472	86.0
91	8,004	464	111.1
98	6,045	636	122.1
109	10,912	534	128.6

Figure 9.—Board-foot (A) and basal-area (B) responses to basal area levels on Walker and Vincent, New Hampshire study plots.



The primary effects of residual basal area were related to basal area and volume growth. Annual board-foot growth ranged up to about 600 board feet per acre on one plot and was closely related to higher residual basal area per acre (Table 12, Figure 9). Average annual board foot growth over all plots was 404 board feet per acre, a rate shown to be attainable on good sites at mid-basal areas of 70 to 80 square feet in the Central States (Dale 1972). This high rate of sawtimber growth in New Hampshire was only moderately affected by sawtimber ingrowth (i.e., trees that grew from poletimber to sawtimber-size during the growth period). The highest annual ingrowth-rates were about 105 to 125 board feet per acre, and averaged only 29 board feet over all plots.

However, the volume growth is strongly related to stem development. Upper logs that were not sawtimber at the time the plots were established, grew large enough to become sawlogs. Table 13 shows the volume growth itemized by log position on Plot 4 at Vincent State Forest which had the greatest volume increase. Volume growth in the butt logs (211 board feet per acre per year) closely paralleled the growth of Connecticut stands (roughly 200 board feet per acre per year). An additional 273 board feet per acre per year was realized from the first log above the butt log and an additional 152 board feet per acre per year from the second log above the butt log. These upper logs generally are lower quality than the butt log but the volume can be substantial. For example we estimate the stumpage value growth of the butt logs on plot 4 to be approximately $89 per year compared to the approximate value of the upper logs to be $122 annually even though these prices were adjusted for log quality. The Vincent plots were densely stocked and developed very straight stems. The best quality stems also seemed to be located on very good sites. The implementation of crop tree release seems to have been timed well with stem development.

The New Hampshire case study suggests considering vigor and condition of the growing stock as well as site quality instead of a strict reliance on stocking chart levels.

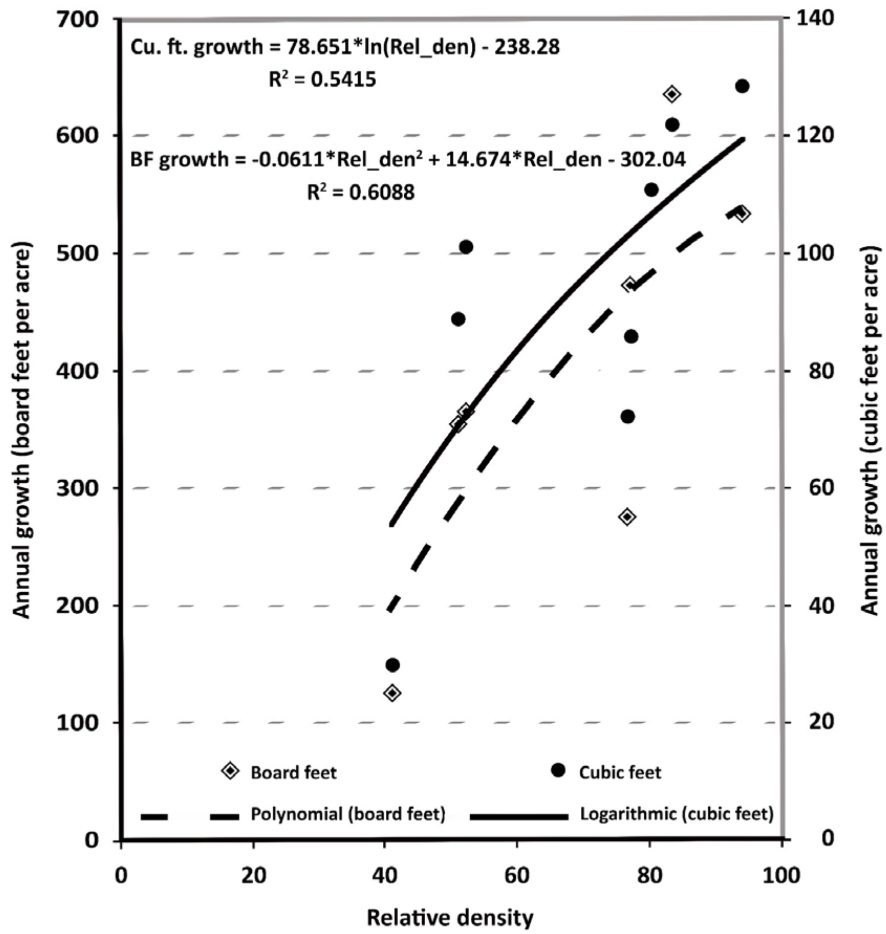
Table 13.—Volume growth by log position (Vincent State Forest (plot 4)

Tree segment	2001	2014	Volume Change	Annual Change
Butt log	5,173	7,918	2,745	211
Second log	871	4,426	3,554	273
Third log	0	1,971	1,971	152
Total	6,045	14,314	8,270	636

Annual basal area growth peaked at about 2.5 to 3 square feet per acre in the 90s. Placing the stand well above the B-line on the red oak stocking chart (Figure 3). The New Hampshire case study suggests considering vigor and condition of the growing stock as well as site quality instead of a strict reliance on stocking chart levels.

In line with the growth responses to high levels of basal area, both cubic-foot and board-foot growth were closely related to relative density (Figure 10). Maximum growth occurred at relative densities approaching 100 percent. Remember that the B-line on the oak stocking chart occurs at about 60 percent.

Figure 10.—Board-foot and cubic-foot growth related to relative density, Walker and Vincent, New Hampshire study plots.



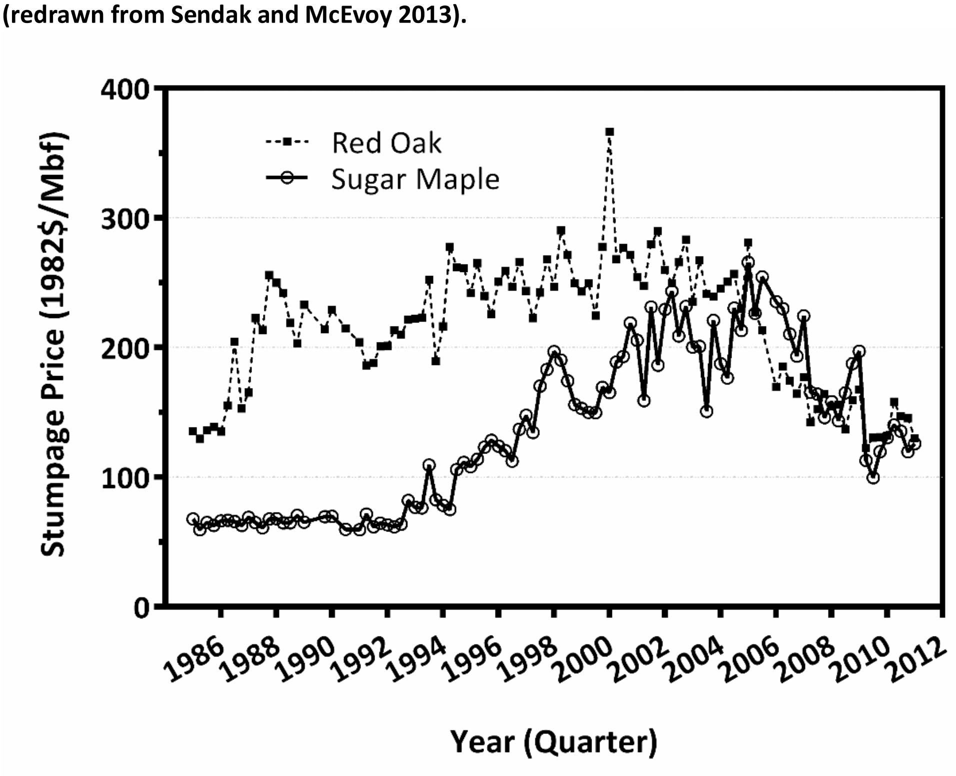
The board foot volumes per acre (Table 12) are somewhat higher than shown in the Table 8 yield table. It is not uncommon for plot volumes to run higher than the broad averages represented by yield tables especially on high quality sites.

Cubic-foot growth on the New Hampshire plots ranged from 30 cubic feet annually to 130 cubic feet. High growth-rates were maintained at the upper residual basal areas, although the relationship between cubic-foot growth and residual basal area was less pronounced than observed with board-foot growth. As with the board-foot growth, the cubic-foot rates indicate that growth responses appeared to be more related to stand and site characteristics including tree vigor and condition, spacing, structure, and soils rather than residual basal area. Cubic-foot and board-foot growth were not clearly related to species composition of the stands (Table 11). The two most rapidly-growing plots had high proportions of beech and red maple, but this relationship was unclear for the other rapidly growing plots.

Financial Results

Red oak enjoyed a steady increase in stumpage value across New Hampshire from the mid-1980s to about 2004 when a change in consumer preferences and demand brought sugar maple prices to the same level as red oak (Figure 11) (Sendak and McEvoy 2013). Vermont prices exhibited a similar but more erratic trend. In southern New England, stumpage for all species fell in 2004 (Masswoods 2016). Prices for sugar maple west of the Connecticut River have since rebounded and are similar to red oak. Peak stumpage values in northern New Hampshire reached about $400 per Mbf (thousand board feet) in 2015. Stumpage prices vary greatly among regions, location and years, but these figures provide a clear indication of the value of red oak sawtimber, and the potential financial rewards from investing time and effort in regenerating and growing quality oak.

Figure 11.—Red oak and sugar maple stumpage trends in New Hampshire (1985-2011) (redrawn from Sendak and McEvoy 2013).



The eight New Hampshire growth plots showed exceptional changes in dollar values and rates of value-increase over the 9-year (Walker) and 13-year (Vincent) growth periods (Table 14). Beginning with stumpage values per acre of about $1,000 to $1,500 per acre, values increased by $121 to $188 per year, an annual rate of 8.6 to 7.7 percent. The rate of financial growth may have been higher on the Walker plots because of a shorter time period and less crown closure since thinning. The Walker plots also had very low starting values so even a moderate amount of value growth would seem high when calculating rate of return. Even though the Walker State Forest plots had a higher rate of return

(8.6 versus 7.7 percent), the Vincent plots grew a much higher value per acre ($2,441 versus $1,087).

Since no records of any investment costs for the establishment of oak were found for these stands, value per acre as well as rate of return need to be considered. With no starting costs (i.e., planting or site prep), the higher dollar returns are analogs to free money at the start of the stand life that was invested in timber. (It is better to receive a gift of $1,000 that earns 5 percent than only a gift of $200 that earns 6.5 percent). The Vincent State Forest timber has done much better financially even with a lower rate of return. The question now is what to do for future revenues. The forester will need to consider potential rate of return from tending and how harvest revenues can be invested compared to continuing these stands at their present rate of growth. Maintaining denser stands can result in more volume and value; on the other hand denser stands often result in longer "technical" rotations to meet a desired dbh which could diminish rates of return. The effect of time on a timber investment can be significant.

Table 14.—New Hampshire growth plots. Mean annual change in red oak timber value per acre since plot establishment.

	Vincent	Walker
Starting value ($)	1,506	990
Final value ($)	3,947	2,077
Increase ($)	2,441	1,087
Mean annual value increase ($)	188	121
Annual percent value change (%)	7.7	8.6

Summary: Stocking and Growth

Results from the studies in Connecticut and New Hampshire were variable. But some generalities remain. Early crop-tree treatments appear effective, with early responses in dbh growth of up to 100 percent following release on four sides. This response declines over time but still remains significant.

Although the oak stocking charts provide general guidelines on the bottom line for residual stocking levels, vigor and quality-potential remain paramount.

Thinnings in older stands at 70 to 90 years of age also produce a significant dbh growth response in Connecticut of up to 50 percent following release on all sides. However, complete release from commercial thinning in the New Hampshire stands showed little added response in dbh growth. Following commercial thinning, board-foot growth in New Hampshire increased with higher stocking levels up to about 100 square feet per acre residual basal area, equivalent to 90 to 100 percent relative density, while cubic-foot growth followed a similar, but less pronounced, trend. Although the oak stocking charts provide general guidelines on the bottom line for residual stocking levels, vigor and quality-potential remain paramount.

Connecticut studies show post-thinning volume growth estimates of about 200 board feet per acre annually. New Hampshire results showed average thinning responses of about 400 board feet per acre annually, and these occurred at residual basal areas of 80 to 100 square feet per acre. Only a moderate proportion of this was in board-foot ingrowth (the movement of poletimber trees into sawlog size classes). The best explanation for the high growth-rates is the health and vigor of these high-density New Hampshire stands probably due to site quality and the log-potential above the butt log.

Health, vigor, site and economic maturity (peak of grade change) should be the guiding principles when commercially thinning oak stands. In addition, oak stands should be managed as mixed stands with 50 to 75 percent oak. The large, spreading crowns result in severe within-species competition with premature mortality of some oaks growing in close proximity to each other.

SILVICULTURAL PRESCRIPTIONS—Step-by-Step

Prescription Survey

To use the prescriptions below, first classify the stand as mature (ready for regeneration), small to medium sawtimber, or sapling. A mature stand has 50 percent or more of the volume classified as mature or ready for removal including trees that have reached their peak of grade improvement (see Red Oak Grade Specifications under Special Topics). Use any standard prism-survey technique, or a walk-through. Enter the guide below at the appropriate stand-size category.

In mature stands, evaluate the regeneration. This requires careful visual examination usually with supplementary milacres (1/1000 acre) plots. If per acre, there are roughly over 200-advance regeneration oak stems 4 feet tall and ¾-inch basal diameter, go to step 2 below. Pine may also be included in the regeneration count. The advance regeneration should be essentially free-to-grow with no overtopping by tolerant (e.g., beech, maple) understory stems though overtopping by light-foliaged species (e.g., grey birch) is allowable. The advance regeneration can be in groups or patches or area-wide—a feature that will dictate the silvicultural approach. If the advance regeneration qualifies, go to step 2; otherwise, step 1.

Prescriptions

Considering the range of silvicultural systems available, the best option for growing oak, from regeneration to final harvest, appears to be shelterwood with intermediate crop-tree thinnings, both precommercial (optional) and commercial. However, special attention must be given to seed crops, buried acorns, amenable sites and development of stable advance regeneration to make this system work (Schuler and Miller 1995). This approach can be applied at a range of scales from small-acreage groups or patches (uneven-aged management approach) up to entire stands (even-aged).

Wildlife habitat guidelines include maintaining the following where available:

1. At least one or two larger diameter cavity trees per acre
2. Dead trees (snags) for foraging or sheltering habitat
3. A large down hollow log or two per acre for ground cover
4. Retention of softwood patches or individual trees (softwood retention)
5. A range of wildlife habitat conditions across a property, or several adjacent properties
6. Areas with multiple raptor nests, often near old roads, trails, and openings and evaluate their current use by forest raptors.

7. Healy et al. (1999) suggest identifying the best acorn-producing stems over a 3-year period prior to harvest to retain to maximize the potential acorn production potential of these stands as well.

Thus the step-by-step approach would be to:

Step 1: Establish regeneration—applicable to mature or near-mature stands.

In the fall, following a moderate to good seed year, apply a preparatory shelterwood harvest (cutting from below) to leave approximately 80 square feet basal area of overstory in mixed oak. Bury the seed and eliminate the understory with logging or other disturbance. Time the first shelterwood cut to a good oak seed year. Otherwise, preparing the site would be like tilling a garden, not planting seeds and hoping the crop will grow. Similarly, remove (harvest) as many light-seeded "weed" species (e.g., red maple and black birch) as possible to reduce the number of new seedlings of these species competing directly with the oak seedlings. Prescribed fire has been used to prepare the seedbed in the mid-Atlantic and further south (Brose et al. 2008) but its effectiveness in New England is unknown. However, do not burn for at least one year after a mast year or you will kill the new seedlings and/or acorns.

Evaluate regeneration 5 to 10 years later. If advanced, free-to-grow oak (4 feet tall; ¾-inch basal diameter) is present in acceptable numbers (over 200 per acre), go to step 2. If regeneration is not adequate, a second shelterwood harvest with ground disturbance may be needed to crush and invigorate the developing oak regeneration. This may need to be repeated a few times, every seven to 10 years or so, to improve the vigor and competitiveness of the red oak advance regeneration.

Sometimes an oak understory will have developed under a managed pine stand; this can be released as in step 2. Conversely, there may be an established pine or pine-oak understory that could be released as in step 2. New sprouts from harvested trees can also provide a source of regeneration. In Connecticut, however, only about half the sawtimber oak produce sprouts and these only do well in areas of low deer-density.

Step 2: Release regeneration.

When advance oak regeneration (or oak-pine) is 4 feet tall and ¾-inch basal diameter (which might be 10 years following the last shelterwood), release the regeneration completely by complete overstory removal. Often, the advance regeneration is patchy and can be efficiently released by group and patch release. The edge of the gap should be at least one tree-height from the edge of the advance oak regeneration. Otherwise shade from the surrounding forest and competition from roots of large trees will stunt the growth of oak seedlings. Complete release through overstory removal is required to allow the oak to develop rapidly beyond browse height. Avoid excessive ground disturbance during final overstory removal, although top-damaged oak seedlings and sprouts will resprout. If the advance oak stems show any signs of flat-topped crowns or lack apical dominance, resprouting will re-invigorate them and improve potential stem quality.

Deer damage may be severe, especially in southern New England, requiring special control by increased hunting intensity or temporary fencing. Brush barriers have not proven effective in trials in southern New England. Where ecological or wildlife considerations are more important than financial considerations, temporary wire cage around stump sprouts or vigorous regeneration shows promise. (Figure 12)

Figure 12.—Two-year old oak stump-sprouts not protected in the foreground and protected by temporary wire cage in the background.

Fire is a helpful tool for freeing the fire-resistant, well-established advance growth of oak from competing vegetation. In Connecticut, prescribed burning in young clearcuts has been more beneficial for promoting oak than fires in shelterwoods (Ward 2015a). Some shelterwood cuts scheduled for final overstory removal may have oak regeneration likely to be overtopped by species with faster juvenile height growth (e.g., birch, aspen) or remain overtopped by established non-oak competitors after the final harvest. On these areas with marginal oak, a rough fire break around the perimeter of the harvest could be established during the harvest operation. The roughed-out fire breaks would minimize site preparation prior to burning, if an inventory several years after the harvest determined oak is overtopped. Using prescribed fire in a seedling stand would minimize the development of fire scars and associated internal decay because stems would be top-killed and sprouts would develop from root collars. While this approach will delay stand growth for several years, the cost of a slightly longer rotation is likely outweighed by the long-term benefits of higher oak dominance for both economic and ecological objectives.

Step 3: Optional pre-commercial crop-tree thinning—applicable in sapling stands approximately 10 to 25 years old.

Release up to 50 to 100 red oak per acre on three to four sides. Release a component of other desired species to maintain the mixed-stand condition. If the oak stems have not completed establishing the merchantable length for upper sawlogs, releasing stems too much too early will cause them to lose apical dominance.

Step 4: Commercial crop-tree thinning—applicable in small to medium sawtimber approximately 50 to 70 years old.

Remove poor quality stems of all species, and mature short-lived species. Release the best crop trees on at least two or three sides. Residual basal areas down to 60 square feet should produce adequate growth per acre although, as shown in the New Hampshire data, growth response may be more related to vigor and tree condition than a strict reliance on residual stocking. When economically feasible and where possible to maintain uniform stand density, remove low-value species which produce seeds and hence seedlings that will compete with future oak regeneration.

Low residual basal areas will trigger understory development; sometimes oak or pine, but all too often, undesirable species that will require treatment (e.g., ground disturbance, even fire) during the regeneration phase. A second thinning may be feasible before step 5.

Step 5: At age 80 to 120, a component of the oak should be mature at 18 to 24 inches, depending on the site and prior treatment. Regenerate as in step 1 above. Especially on sandy sites, a pine understory may have developed and a decision is required whether to release pine or work toward oak.

DAMAGING AGENTS

Perhaps the chief concern in regenerating oak is browsing damage from deer (Williams et al. 2006). Heavy and repeated browsing can alter species composition of the regeneration, moving it toward complete dominance by less palatable species such as beech, black birch, striped maple, and non-native and native invasive plants.

Perhaps the chief concern in regenerating oak is browsing damage from deer (Williams et al. 2006). Heavy and repeated browsing can alter species composition of the regeneration, moving it toward complete dominance by less palatable species such as beech, black birch, striped maple, and non-native and native invasive plants. Possible ways to limit deer damage include (1) regional or on-site herd control, (2) large harvest areas including clearcuts of at least 20-acres or numerous group or patch harvests to overwhelm the herd, (3) complete release to maximize height growth; and (4) large tops left on site following harvest. Expect maximum browsing pressure near deer winter range.

Outside of the acorn-destroying insects, (see Seed Production and Losses), the most serious insect pest of red oak in New England is the gypsy moth (*Lymantria dispar*). Defoliation repeated over a 2 to 3-year period results in growth-loss or mortality, quality-reducing epicormic branching, and seed-crop failures. Several biological and hormonal insecticides are effective against the larvae including *Bacillus thuringiensis*, Dimlin, and Gypchek. In addition, a naturalized fungus (*Entomophaga maimaiga*), possibly originating in Japan, causes significant mortality in years with cool, wet springs, helping to limit rapid buildup of the caterpillar populations. Since oaks are the most favored host, early recommendations (Behre et al. 1936) were to limit stands to no more than ½ oak to exert some silvicultural control over gypsy moth infestations. More recent guidelines suggest that susceptibility to defoliation is low in stands with up to 20 percent oak and other preferred species, moderate with 20 to 50 percent preferred species, and high to very high with greater than 50 percent (Gottschalk 1993). Pines and hemlock, associated with oak, may be heavily damaged.

Although mortality may be only moderate following gypsy moth attack, epicormic branching often is severe, especially on trees with smaller crowns. Under low stand densities, the epicormics may develop and persist. Under higher stand densities, the epicormics will remain small and eventually self-prune; however, even these small epicormics may produce unacceptable defects. To assist in preventing or eliminating epicormics, perhaps the ideal way to grow quality oak in areas threatened by gypsy moth is to (1) maintain a mix of species rather than pure oak, (2) develop large crowns ($^1/_3$ to ½ crown ratio) by repeated thinnings, and (3) maintain fairly high understory stand densities (e.g., hemlock).

Non-native invasives and native nuisance species are often a problem when regenerating pine and oak—especially on the nutrient-rich soils or wet soils (Leak 2014, Campbell et al. 2015). The most competitive are ferns, buckthorn, and mountain laurel. In southern New England, Japanese stiltgrass and Asiatic bittersweet are emerging as non-native invasives of concern. Possible controls include release of established advance regeneration where it is in a dominant position relative to the invasives. Or, apply heavy site preparation during the harvest operation by crushing interfering plants to eliminate some of the understory. Possibly, some chemical control along roads, trails, and stand borders will limit invasion by these nuisance species.

Red oak has many other damaging agents. Numerous defoliators other than gypsy moth attack red oak (Hitchcock 1961) as well as wood borers and cankers that cause serious degrade in wood products. On sandy sites especially, basal cracks and "spider-heart" may develop as a result of a wounding event such as fire. However, in comparison with other species including other species of oak, decay is not a serious problem with red oak (Berry and Beaton 1971). Much of the decay that does occur enters through fire scars, wounds or branch stubs.

WILDLIFE HABITAT CONSIDERATIONS

Around 200 vertebrate species use northern red oak stands, about ¾ of the total numbers of species in New England (DeGraaf et al. 2006). Over 50 commonly occurring species such as northern redbelly snake, wild turkey, eastern towhee, gray squirrel, white-footed mouse, black bear, and white-tailed deer use stands with a significant oak component which provides preferred breeding, feeding or winter use habitat (Appendix A). Oak and oak-pine stands offer a considerable array of foraging and cover habitat features that both the vertebrate and invertebrate communities use. Oak also occurs as an important component in the northern hardwoods forest (Leak et al. 2014).

Red oak produces much more hard mast on a weight basis than American beech, which is the second most important mast-producer in New England.

Acorns

Red oak as well as American beech are two of the primary hard mast producing species in New England providing an important high caloric food supply for the wildlife mentioned above and for species such as wood duck, ruffed grouse, red-bellied woodpecker, blue jay, tufted titmouse, eastern chipmunk, fisher, and gray fox.

Red oak produces much more hard mast on a weight basis than American beech, which is the second most important mast-producer in New England. A 3-year Massachusetts study (1989 to 1991) documented 27,000 to 197,000 sound acorns per acre with dry weights of 69 to 490 pounds per acre (Healy 1997a); ranging from fair to super-bumper crops. During an 11-year period in the White Mountains of New Hampshire (Graber and Leak 1992, Leak and Graber 1993), the maximum production of sound beechnuts was about 348,000 per acre with an estimated dry weight of 227 pounds per acre; beechnut production was poor (or a trace) in about 3 years out of 11.

Thinning was found to increase acorn production per tree, with some indications of an increase in production per acre (Healy 1997a) and especially if the best-producing acorn stems (determined from at least 3 years of prior acorn production observation) were favored in the thinning (Healy et al. 1999).

Over an 11-year period in central Massachusetts, acorn production was observed on 120 sample red oaks, half the trees were in a thinned stand and half were in an unthinned control (Healy et al. 1999). Thinned oaks produced more acorns per tree than unthinned oaks, however the treatment-effect was small compared with the individual and annual variation in acorn production. Half of the total acorns collected during the study came from $^1/_3$ of the sample trees; and 2 of the 11 years produced 55 percent of the total while the five poorest years accounted for only 10 percent of the total collection. When thinning oak stands it is important to recognize and retain the best acorn producing stems to lessen the effect of poor acorn production years (Healy et al. 1999). When maximum acorn production is the primary management goal, Healy et al. (1999) advises that three consecutive years of monitoring individual tree acorn-production are needed to determine the best acorn-producing stems to retain.

Shelterwood cuts that incorporate the best acorn-producing stems in the residual stand can maintain and improve acorn production potential as well as oak regeneration potential.

Thinning 40 to 50 percent of the basal area around potential mast trees improves acorn production, but targeted thinning around known acorn-producing stems gives the greatest benefit to acorn production (Healy et al. 1999). A short-term evaluation of acorn production in shelterwood harvests in central Ontario, Canada that removed 50 percent of the canopy showed the residual oaks produced more acorns than oaks in uncut stands (Bellocq et al. 2005). Shelterwood cuts that incorporate the best acorn-producing stems in the residual stand can maintain and improve acorn production potential as well as oak regeneration potential.

Callahan et al. (2008) found that acorn production was tripled by annual addition of 150 pounds per acre of nitrogen, suggesting that nitrogen fertilization could be used to enhance acorn production.

Higher tannin, phenol, and fat levels are found in red oak acorns than white oak acorns (Servello and Kirkpatrick 1989, Chung-MacCoubrey et al. 1997, and Wood 2005) and influence dietary palatability and digestibility (Smallwood and Peters 1986). White oak acorns tend to have lower fat, tannin and phenol compositions and are more palatable and digestible for a variety of wildlife than red oaks (Duvendeck 1962, Short 1976, Pekins and Mautz 1987, and Kirkpatrick and Pekins 2002).

Animals consuming only acorns often demonstrate negative nitrogen balances (Kirkpatrick and Pekins 2002) because of the low protein content and high tannin levels in acorns. Fall mixed diets (e.g., forbs, hardwood leaves, and acorns) consumed by most herbivores appear to minimize the tannin and phenol effects on negative nitrogen balances in the fall when acorns are consumed (Kirkpatrick and Pekins 2002, Pekins and Mautz 1988).

Browse

Herbivore-foraging in disturbed areas is nutritionally productive as a general rule since leaves and twigs in harvested areas (e.g., regenerating clearcuts, group cuts, shelterwoods, thinnings) and naturally disturbed areas (e.g., microbursts, tornados) have higher concentrations of protein and soluble carbohydrates than the same species' leaves and twigs sampled from uncut forests in New Hampshire (Hughes and Fahey 1991).

The species composition in harvested areas can be a highly variable mixture of oak, pine, red maple, grey birch, aspen, and other conifers (Leak and Yamasaki 2013 a, b). Where white-tailed deer browsing is low, regenerating stem densities can easily range from 12,300 to 24,000 stems per acre five growing seasons post-cut with red and white oak accounting for 7 to 20 percent of the regenerating stems (Yamasaki, unpublished data). Where deer-browsing is high, understory stem density is much lower (DeGraaf et al. 1991).

The digestibility and digestible energy of red oak leaves and shoots is at the low end for common forage components of white-tailed deer diets compared to other leaves and shoots (i.e., red maple, black birch, and wintergreen) (Pekins and Mautz 1988). The nutritional contribution of oak shoots and leaves, as well as other hardwood species, and groundcover vegetation in the summer and fall diets of white-tailed deer becomes more important in years without a hard mast crop.

Insects as Forage

Prey size and abundance, and the ability of potential predators to detect prey on a variety of foliage substrates shape the availability of food resources for insectivorous birds (Holmes and Schultz 1988). Larvae from three families (Noctuidae, Notodontidae, and Geometridae) comprised the majority of the lepidopteran fauna sampled on northern hardwoods foliage at Hubbard Brook Experimental Forest, New Hampshire (Holmes and Schultz 1988) during a non-outbreak period. Differences in avian community structure between oak and maple stands during three seasons of observation (winter, spring, and fall) were greater in the fall because of the acorn mast availability as well as in the spring when insects are gleaned by the influx of insectivorous birds from tree and foliage substrates (Rodewald and Abrams 2002, Rodewald 2003).

Periodic gypsy moth outbreaks in stands with oak offer both black-billed and yellow-billed cuckoos, considered "hairy" caterpillar specialists, opportunities to move around the region for forage (Smith 1985 and Barber et al. 2008).

Gypsy moth outbreaks periodically result in defoliation of most overstory and understory tree foliage, and 2-year observations of severe outbreaks in central Pennsylvania oak stands showed similar bird species richness in severely defoliated and foliated stands (DeGraaf 1987). Avian foraging guilds were similar among defoliated and foliated stands. Abundances of tree-branch and tree-twig nesting guilds decreased significantly in the second year of the study. Thurber et al. (1994) also found that predation rates on artificial nests were higher in areas of gypsy moth defoliation compared with non-defoliated areas.

Periodic gypsy moth outbreaks in stands with oak offer both black-billed and yellow-billed cuckoos, considered "hairy" caterpillar specialists, opportunities to move around the region for forage (Smith 1985 and Barber et al. 2008). Other insectivorous birds can have a direct impact on insect prey (Holmes et al. 1979) as well as indirectly on sapling growth by foraging on lepidopteran larvae (Marquis and Whelan 1994). A captive bird aviary study by Whelan et al. (1989) observed avian predation by both black-throated green and blue warblers, American redstarts, ovenbirds, common yellowthroats, black-and-white warblers, and red-eyed vireos on young gypsy moth larvae (second instar) as well as older instars. As these neotropical migrants return from their wintering grounds in the spring, these species can be an important predation factor in integrated pest management efforts to deal with the occasional large-scale outbreaks (Smith 1985 and 1989).

Small mammals, particularly white footed mice, northern short-tailed shrew, masked and smoky shrews are the principal mammalian predators of gypsy moth pupae (Smith and Lautenschlager 1981), as well as carpenter ants (*Camponotus* sp.), another damaging agent.

Regeneration

Gray squirrels, eastern chipmunks, and especially blue jays are instrumental in moving and planting acorns, sometimes at considerable distances (up to several miles) from the parent tree (Johnson et al. 1997, Johnson and Webb 1989, Darley-Hill and Johnson 1981). Wildlife caching of these nuts below-ground improves nut survivorship and subsequent germination (Johnson and Webb 1989), and underscores the importance of the practice of scarification and burying acorns during fall harvesting as a key element for successful oak regeneration.

Wildlife caching of these nuts below-ground improves nut survivorship and subsequent germination (Johnson and Webb 1989), and underscores the importance of the practice of scarification and burying acorns during fall harvesting as a key element for successful oak regeneration.

Harvesting in conjunction with masting events can produce considerable regeneration—mixed oak (both red and white), white pine, and early successional hardwoods. In southern Maine on the Massabesic Experimental Forest, regeneration appears to take longer to achieve the height growth compared with northern hardwood regeneration at the Bartlett Experimental Forest NH (C. Costello personal observations). In general, the first couple of growing seasons are fairly quiet before early successional birds such as chestnut-sided warblers, prairie warblers, common yellowthroats, Eastern towhees, indigo buntings, and American goldfinches begin to appear (C. Costello, unpublished data). In northern hardwoods, these early successional habitat conditions are ephemeral; birds of young forest patches (3 to 5 acres) are usually gone by the time stands reach 10 to 12 years old. Campbell et al. (2012), working with very small groups averaging $^{1}/_{10}$ acres in size suggest it takes 15 years in the oak-pine stands on the Holt Research Forest in Arrowsic, ME until mature forest birds reoccupy these very small gaps. How long this ephemeral early successional bird habitat lasts in larger stands of mixed oak-pine regeneration is still to be determined.

Thinning Oak Stands

In a study at the Quabbin Reservoir in Massachusetts examining the effects of thinning oak stands with histories of high (25 to 49 deer per square mile) or low (7 to 15 deer per square mile) deer densities, Brooks (1999) found neither thinnings that removed 40 to 50 percent of the basal area nor low or high deer densities affected northern redback salamander numbers.

Thinning even-aged oak stands in another Quabbin Reservoir study resulted in more breeding bird species than in uncut stands regardless of deer density (DeGraaf et al. 1991). Nine species (i.e., red-eyed vireo, hermit thrush, ovenbird, Eastern wood-pewee, veery, American redstart, black-and-white warbler, Eastern towhee, and black-throated blue warbler) comprised 60 percent of the bird observations and were found in both thinned and unthinned stands. The numbers of species and individuals of omnivores and ground gleaners were higher in thinned stands compared to unthinned stands. DeGraaf et al. (1991) expected to see increased problems regenerating mature oak stands in areas of high deer density.

The increased likelihood of regeneration problems in oak stands due to high deer density and browsing, and competing grass and fern cover is covered in Healy (1997b) and Healy and McShea (2002).

Thinning also was found to increase acorn production per tree, with some indications of an increase in production per acre (Healy 1997a) and especially if the best-producing acorn stems (determined from at least 3 years of prior acorn production observation) were favored in the thinning (Healy et al. 1999).

Raptor Nests

Multi-limbed tree crotches or "basket forks" in live hardwood crowns (Figure 13) can make secure forest nest sites for the many raptors that often use oak-pine stands such as sharp-shinned and Cooper's hawks, northern goshawk, red-shouldered, broad-winged, and red-tailed hawks, great horned owl, barred owl, and northern saw-whet owl (Portnoy and Dodge 1979, DeGraaf et al. 2005, 2006). These basket-forked trees may be the first trees removed in stand improvement projects, so observing multiple nests at a particular site indicates an opportunity to retain these trees for the habitat values they offer (Bennett 2010). Structure on the ground is also important. Turkey vultures will nest on the ground in hollow stumps and brushy thickets.

Figure 13.—Northern goshawk nest in a northern red oak, Northwood, NH.

Cavity Trees

Red oak stands provide breeding and shelter cavities for about ¼ of the vertebrates in New England (Healy et al. 1989). A central Massachusetts study of cavity trees in 13 sawtimber-size oak stands found that cavities occurred in 3 percent of the live trees, 3 percent of the dead trees, and 20 percent of the snags (e.g., dead trees greater than 5 inches dbh and greater than 4.5 feet tall). Cavity trees were observed in all tree quality classes (e.g., preferred, acceptable, rough cull, and rotten cull); and 28 percent of live cavity trees were observed in preferred and acceptable quality classes. Cavity trees were 8 percent of the live tree basal area in stands with no previous treatment and 4 percent of the live tree basal area in thinned stands.

Ground searches for cavities in the live crown underestimated the actual number of cavities by 20 percent when compared with visual observations made in the live crown from Swedish climbing ladders (Healy et al. 1989). Sapling and pole-sized trees accounted for roughly ⅔ to ¾ of the live cavity trees in unthinned and thinned stands respectively. Ninety-four percent of observed cavities had small to medium entrance sizes (less than 4 inches) and were used as mammal dens and escape holes by gray squirrels, flying squirrels, and white-footed mice. Six percent of the observed cavities were greater than 4 inches, usually in larger dbh live and dead trees, and useful for larger-bodied woodpeckers and other secondary cavity users such as wood duck, pileated woodpecker, raccoon, fisher, and gray fox.

The wildlife cover value of large-diameter standing snags depends on their size and a longer versus shorter life expectancy (DeGraaf and Shigo 1985, Tubbs et al. 1987). Larger diameter snags stand longer and can provide both foraging and cavity-dwelling habitat than smaller diameter snags (Yamasaki and Leak 2006). Gypsy moth outbreaks can kill trees, create snag habitat, and trigger an ephemeral increase in both snag-occurrence and cavity-nesting bird communities (Schowalter and Whitmore 2002). Additionally, the exfoliating bark of many snags, especially if situated where sunlight can warm the tree bole, offers important nesting and roosting habitats for species such as the brown creeper and myotid bats (Schowalter and Whitmore 2002, DeGraaf and Yamasaki 2001, Sasse and Pekins 1996).

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Coarse Woody Material

Providing coarse woody material or deadwood (after Healy 2002) can be challenging as the decomposition rates in eastern forests are fairly rapid. Measurement of dead bole-wood 23 years after cutting and felling in a New Hampshire northern hardwood stand showed a 90 percent reduction in bole-wood mass (Arthur et al. 1993). Coarse woody material accumulates modestly over time resulting in 12.9 to 19.6 tons per acre in New Hampshire old, uncut northern hardwood stands (Tritton 1980, Gore and Patterson 1986).

Twenty years of observations on coarse woody material recruitment and dead tree availability from prior gypsy moth outbreaks in a central Massachusetts forest (Wilson and McComb 2005) demonstrate that there is considerable mortality of smaller stems over time; and that smaller diameter snags fall sooner to the ground than larger diameter snags. The majority of coarse woody material on the ground was from these smaller diameter classes. The number of larger diameter snags equal to or greater than 12-inches dbh that eventually fell to become larger diameter coarse woody material remained low, ranging from 0.8 to 1.3 snags per acre over the 20-year period. Following the various cavity tree and coarse woody material guidelines in Tubbs et al. (1987), Bennett (2010), and Leak et al. (2014) is recommended.

Providing coarse woody material or deadwood (after Healy 2002) can be challenging as the decomposition rates in eastern forests are fairly rapid.

Wildlife-Related Concerns and Oak Forests

Increases in gypsy moth densities are associated with declines in white-footed mouse density, a major predator of gypsy moth pupae (Elkinton et al. 1996). Increases in white-footed mouse density were also correlated with increased autumn acorn crop densities (Elkinton et al. 1996). White-footed mice appear to regulate gypsy moth populations at low levels while other complex factors regulate gypsy moth populations at higher levels (Elkinton et al. 1996).

Where white-tailed deer densities exceed 26 to 49 deer per square mile in central Massachusetts, northern red oak seedling survivorship is far more problematic in both thinned and unthinned stands than where deer densities are much lower (7 to 15 deer per square miles (Healy 1997b, Rawinski 2014). It is always important to participate in ongoing conversations with state wildlife deer managers over acceptable regional deer densities and harvest targets needed to maintain the ability to successfully regenerate valuable timber species and provide a reasonable hunting experience across the forested landscape.

The emergence of Lyme disease—the spirochete, *Borrelia burgdorferi*, its vector, the black-legged tick (*Ixodes scapularis*), and the various vertebrate hosts of *B. burgdorferi*—as a major public health issue in the northeastern United States (CDC MMWR 2007) and eastern Canada (Ogden et al. 2009) underscores an additional layer of complexity that inserts public health considerations into the already complex relationships associated with the management of biodiversity and oak forests in New England (Ostfeld et al. 2006). Recent investigations point to rodent-host populations and food resources, particularly acorn mast dynamics as major indicators of anticipated Lyme-disease risk (Ostfeld et al. 2006). It is well beyond the scope of this paper to review the Lyme-disease literature but to note that many of those investigations touch on issues of small mammal biodiversity (LoGiudice et al. 2003), forest fragmentation along the urban-suburban-rural human habitation gradient (Ostfeld et al. 2002), non-native invasive plants and exotic insects (Lubelczyk et al. 2004), and deer overabundance (NE Deer Technical Committee 2009) among others, making the management of oak forests a highly interdisciplinary effort.

SPECIAL TOPICS

Red Oak Grade Specifications

Log grade rules vary considerably in different market areas and over time. But it should be useful to provide some idea of the log specifications from multiple sources that define high-value versus lower-value red oak logs. The prices are listed to provide some idea of the range in values between the different grades.

Grade	Top Diameter Inside Bark	Minimum Preferred Lengths (in feet add 6" trim)	Minimum Clear Faces	General 2015 Delivered Log Prices/Mbf
Prime	16	8, 9, 12	3	800
Select	14	8, 9, 12	3	700
1	12	8, 9, 12	3	600
2	10	8	2	500
Tie	15	8	1	400
Pallet	10	8	1	350

Controlling Epicormic Branching

Epicormic branching degrades lumber quality on the mid to lower red oak tree bole where the value resides. Epicormics can be minimized by following a few precautions. After a defoliation event such as by gypsy moth, don't thin or harvest until the stand recovers with 2 to 3 years of full leaf canopy and then thin or harvest lightly by releasing on two sides or less around trees that appear small-crowned or slow-growing—commonly trees in less than a dominant or codominant position. Look for small bud-like marks on the tree bole. Trees vary greatly in their propensity to epicormic sprout, and these bud-like marks indicate that tendency. Some have observed that epicormics develop in the upper bole, just below the live crown. These sprouts have, of course, less impact on log quality than those on the lower bole.

Controlling Deer and Moose Browsing

Browsing is one of the most serious oak regeneration problems. Oaks are highly palatable to both deer and moose while less desirable species (e.g., beech and invasives) may be left untouched. Deer browsing also significantly reduces the overall botanical diversity of a stand (Ward, 2015b). The possible approaches to dealing with excessive browsing include (1) herd control through hunting; (2) leave unlopped tops on the site, or brush barriers around the perimeter of patch cuts (though there are conflicting reports on the effectiveness of these methods); (3) release established oak regeneration completely to encourage the regeneration to grow beyond browsing height; (4) overwhelm the deer and moose with large harvest areas of 15 to 20 acres and larger or numerous groups and patches in a given area; and (5) use individual tree shelters (Ward et al. 2000) or tall wire cages.

Deer and moose browsing is generally worse adjacent to winter cover; in these areas, all the above-mentioned precautions may be needed.

Fire and Herbicides

Fire has proven useful in the mid-Atlantic region for regenerating oak (Brose et al. 2008). Following an initial shelterwood regeneration harvest and, hopefully, prior to an acorn crop, fire can be used to prepare a seedbed by removing unwanted vegetation, reducing litter and humus layers, and possibly reducing small mammal habitat. Fire is also used to free established oak regeneration from competing vegetation. Fire kills many competing species while the oak resprouts from the fire-resistant tap root.

In both northern and southern New England, experience with fire to regenerate oak is limited although there is a long history of maintaining blueberry lands with repeated fires, usually on shallow bedrock or outwash. Small ownerships and suburban development limit the opportunities, but prescribed fire could be explored where feasible.

Herbicides provide another opportunity to eliminate unwanted vegetation following an initial shelterwood regeneration cut prior to an acorn crop. Studies specifically for oak are lacking though herbicide treatment of invasives promotes hardwood regeneration, but only if the deer are excluded in high deer-density areas (Ward personal communication).

Appendix A. Table of common and scientific names of plants used in the text.

acuminate aster (*Oclemena acuminata* formerly *Aster acuminatus*)
hay-scented fern *Dennstaedtia punctilobula*)
running clubmoss (*Lycopodium clavatum*)
raspberry sp.(*Rubus* spp.)
low-bush blueberry (*Vaccinium angustifolium)*
ground-cedar or northern ground-cedar (*Diphasiastrum complanatum* formerly *Lycopodium complanatum*)
treefern or ground, princess or prince's pine (*Dendrolycopodium obscurum* formerly *Lycopodium obscurum*)
Canada mayflower or wild lily (*Maianthemum canadense*)
Wintergreen (*Gautheria procumbens)*
bracken fern (*Pteridium aquilinum*)
Starflower (*Trientalis borealis*)
beaked hazel (*Corylus cornuta*)
Sarsaparilla (*Aralia nudicaulis*)
Woodfern (*Dryopteris* spp.)
buckthorn, common (*Rhamnus cathartica*)
buckthorn, glossy (*Frangula alnus*)
mountain laurel (*Kalmia latifolia*)
Japanese stiltgrass (*Microstegium vimineum)*
Asiatic bittersweet *Celastrus orbiculatus*)
red oak (*Quercus rubra)*
white oak (*Quercus alba*)
black oak (*Quercus velutina)*
white ash (*Fraxinus Americana)*
Beech (*Fagus grandifolia*)
red maple (*Acer rubrum*)
sugar maple *(Acer saccharum*)
striped maple (*Acer pensylvanicum*)
eastern hemlock (*Tsuga canadensis*)
yellow birch (*Betula alleghaniensis*)
paper or white birch (*Betula papyrifera*)
grey birch (Betula populifolia)

Appendix B. Commonly occurring wildlife species with some preference for oak-pine stands in New England (modified from DeGraaf et al. 2005, 2006).

Birds

Turkey vulture (*Cathartes aura*)
Wood duck (*Aix sponsa*)
Sharp-shinned hawk (*Accipiter striatus*)
Cooper's hawk (*Accipiter cooperii*)
Northern goshawk (*Accipiter gentilis*)
Red-shouldered hawk (*Buteo lineatus*)
Broad-winged hawk (*Buteo platypterus*)
Red-tailed hawk (*Buteo jamaicensis*)
Ruffed grouse (*Bonasa umbellus*)
Wild turkey (*Meleagris gallopavo)*
Mourning dove (*Zenaida macroura*)
Black-billed cuckoo (*Coccyzus erythrophthalmus*)
Yellow-billed cuckoo (*Coccyzus americanus*)
Great horned owl (*Bubo virginianus*)
Barred owl (*Strix varia*)
Northern saw-whet owl (*Aegolius acadicus*)
Whip-poor-will (*Caprimulgus vociferous*)
Ruby-throated hummingbird (*Archilochus colubris*)
Red-bellied woodpecker (*Melanerpes carolinus*)
Downy woodpecker (*Picoides pubescens*)
Northern flicker (*Colaptes auratus*)
Pileated woodpecker (*Dryocopus pileatus*)
Eastern wood-pewee (*Contopus virens*)
Least flycatcher (*Empidonax minimus*)
Yellow-throated vireo (*Vireo flavifrons*)
Red-eyed vireo (*Vireo olivaceus*)
Blue jay (*Cyanocitta cristata*)
American crow (*Corvus brachyrhynchos*)
Tufted titmouse (*Baeolophus bicolor*)
White-breasted nuthatch (*Sitta carolinensis*)
Brown creeper (*Certhia americana*)
Blue-gray gnatcatcher (*Polioptila caerulea*)
Eastern bluebird (*Sialia sialis*)
Veery (*Catharus fuscescens*)
Hermit thrush (*Catharus guttatus*)
Wood thrush (*Hylocichla mustelina*)
Gray catbird (*Dumetella carolinensis*)
Brown thrasher (*Toxostoma rufum*)
Blue-winged warbler (*Vermivora cyanoptera*)
Chestnut-sided warbler (*Setophaga pensylvanica*)

Birds (cont.)

Black-throated blue warbler (*Setophaga caerulescens*)
Blackburnian warbler (*Setophaga fusca*)
Prairie warbler (*Setophaga discolor*)
Black-and-white warbler (*Mniotilta varia*)
American redstart (*Setophaga ruticilla*)
Ovenbird (*Seiurus aurocapilla*)
Common yellowthroat (*Geothlypis trichas*)
Canada warbler (*Cardellina canadensis*)
Scarlet tanager (*Piranga olivacea*)
Eastern towhee (*Pipilo erythrophthalmus*)
Chipping sparrow (*Spizella passerina*)
Rose-breasted grosbeak (*Pheucticus ludovicianus*)
Indigo bunting (*Passerina cyanea*)
American goldfinch (*Spinus tristis*)

Amphibians

Northern redback salamander (*Plethodon cinereus*)

Reptiles

Northern redbelly snake (*Storeria o. occipitomaculata*)
Eastern hognose snake (*Heterodon platirhinos*)
Eastern worm snake (*Carphophis a. amoenus*)
Northern black racer (*Coluber c. constrictor*)
Eastern ratsnake (*Pantherophis alleghaniensis*)

Mammals

Virginia opossum (*Didelphis virginiana*)
Masked shrew
Northern short-tailed shrew (*Blarina brevicauda*)
Snowshoe hare (*Lepus americanus*)
Eastern chipmunk (*Tamias striatus*)
Gray squirrel (*Sciurus carolinensis*)
Southern flying squirrel (*Glaucomys volans*)
Northern flying squirrel (*Glaucomys sabrinus*)
White-footed mouse (*Peromyscus leucopus*)
Southern red-backed vole (*Myodes gapperi*)
Red fox (*Vulpes vulpes*)
Gray fox (*Urocyon cinereoargenteus*)
Black bear (*Ursus americanus*)
Raccoon (*Procyon lotor*)
Fisher (*Pekania pennanti*)
White-tailed deer (*Odocoileus virginianus*)

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