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Acorn Production in Red Oak

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Acorn Production in Red Oak

by

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Abstract

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Managers of oak forests are often interested in acorn production for oak regeneration and wildlife. Although potential acorn production is genetically controlled, actual production depends on weather, site productivity, wildlife and insect activity, and individual tree characteristics. Crown characteristics such as width, area and dominance, and tree age and dbh are correlated with acorn production.

Manipulation of stand stocking through thinning can increase the amount of oak in the upper crown classes and enhance individual tree characteristics that promote good acorn production. Identification of good acorn producers before thinning or shelterwood harvests can be used to retain them in a stand. Stocking charts can be used to time thinnings and to estimate acorn production for individual stands. Maintaining stocking between A- and B-level ensures complete use of growing space by trees. As stocking approaches the A-level, thinning back to the B-level should maintain oak in the upper crown classes and simultaneously promote maximum development of individual tree characteristics known to influence acorn production. A method for estimating acorn production and preliminary guidelines for acorn management are presented.

Keywords: Red oak, regeneration, acorn production, silviculture, stand stocking, thinning.

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Table of Contents

List of Tables

List of Figures

Introduction

Importance of Acorns

Foresters and wildlife biologists are increasingly becoming interested in managing oak forests for acorn production for both oak regeneration and food for wildlife. Acorns provide food for nearly 200 species of wildlife such as chipmunks, squirrels, turkeys, small rodents, deer, bears, foxes, raccoons, rabbits, waterfowl, woodpeckers, bluejays and other birds (Gysel 1957, Korschgen 1962, Goodrum et al. 1971, Sander 1990, DeGraaf et al. 1992, Auchmoody et al. 1993, Beck 1993, Edwards et al. 1993, Johnson 1994). Many insect species (e.g., *Curculio* spp., *Conotrachelus* spp.) also use acorns. In years of low to moderate acorn production, insects may damage a large portion (50 to 80%) of the crop (Downs and McQuilken 1944, Christisen 1955, Gysel 1957, Sander 1990, Beck 1993).

Natural regeneration of oak largely depends on the presence of adequate numbers of "large" advance reproduction at the time of final overstory removal. Acorn production affects the amount of advance reproduction that becomes established in any given year. However, wildlife and insect consumption of acorns often limits the amount of oak reproduction that becomes established.

In the southern Appalachians, acorn crops of less than 224 kg/ha are usually totally consumed by forest wildlife and insects (Beck 1993). Production of sound acorns exceeds this level only during years with good to bumper acorn crops (Beck 1977). Thus, establishment of oak seedlings occurs primarily in years when the number of sound acorns produced exceeds the demand for acorns by wildlife and insects (Downs and McQuilken 1944, Christisen 1955, Gysel 1957, Christisen and Kearby 1984, Hannah 1988).

Timber harvest and intermediate thinnings can have either a positive or negative effect on the capacity of a stand to produce acorns. Obviously, the removal of all oaks from the overstory or the *high-grading* of oak eliminates or severely reduces the local acorn supply. Shelterwood harvest *from below* in mature stands or thinning young oak stands can be used to maintain or enhance acorn yield. The intent of this paper is to present a method for estimating acorn production and preliminary guidelines for the management of acorn production. Although the emphasis is on red oak (*Quercus rubra* L.), the concepts presented are also applicable to other oaks.

Overview

Acorn Production

Variability in production

Acorn production is highly variable among oak species, individual trees, locations and years (Downs and McQuilken 1944, Christisen 1955, Christisen and Korschgen 1955, Gysel 1957, Sharp 1958, Tyron and Carvell 1962, Beck and Olson 1968, Goodrum et al. 1971, Beck 1977, Christisen and Kearby 1984, Drake 1991, Auchmoody et al. 1993, Sork et al. 1993). In a given area, numbers of acorns produced per year may range from 0 to 620,000/ha (Table 1).

Auchmoody et al. (1993) provided a guide for ranking acorn crops (Table 2). They considered any production greater than about 309,000 acorns/ha to be a good or better crop. Others consider 250,000 acorns/ha or more to be good crops, and bumper crops may yield up to 620,000 acorns/ha (Beck 1993).

Gysel (1957) reported that the 4-year average production of red oak acorns was 75,600/ha on good sites in Michigan. Beck and Olson (1968) stated that acorn

Table 1. Summary of observed acorn production of oaks throughout the eastern United States.[1]

Species/region	Acorns/m² of crown area	Acorns/tree	Acorns/ha	Acorn biomass kg/ha	Source
Mixed oaks Pennsylvania		658-1,081(best) 210-339 (avg.)		802 (bumper) 220 (avg.)	Drake (1991)
Red oak Missouri	9.0 (avg.) 37.8 (bumper)	4,000 (max.)			Christisen and Kearby (1984)
Mixed oaks Missouri	21 (white oak) 23 (black oak)		18,000-265,000	314 (avg.) 60-800 (range)	Christisen and Kearby (1984)
Red oak Missouri	6				Janes and Nichols (1967)[2]
Mixed oaks S. Appalachians				324 (avg.) 1,135 (bumper)	Beck (1977)
Mixed oaks S. Appalachians			16,300-233,800		Beck and Olson (1968)
Mixed oaks S. Appalachians		1,213 (avg.) 2,647 (bumper)			Downs and McQuilken (1944)
Red oak Missouri		364 (avg.) 61-1,033 (range) 3,322 (max.)			Sork et al. (1993)
Red oak S. Appalachian		1,600 (avg. max.)			Downs (1944)
Red oak Pennsylvania			17,300-675,000		Auchmoody et al. (1993)

[1] Values are given for mature, well-developed acorns.
[2] Janes, D.J. and J.M. Nichols. 1967. Acorn production of nine commercial species of oak in Missouri. Unpub. ms. Univ. Missouri. 19 p.

production levels ranged from 16,300 to 233,800/ha in mixed oak stands in the southern Appalachians. Barni (1980) observed average acorn production levels that varied between 27,600 and 99,300/ha in Pennsylvania. Average acorn biomass production over 12 years was 324 kg/ha (about 89,100 acorns/ha) in southern Appalachian oak stands, but this average was heavily influenced by a bumper crop that produced 1,135 kg/ha (about 312,125 acorns/ha) (Beck 1977).

Sork et al. (1993) observed that the 8-year average annual acorn production for individual red oaks varied from 61 to 1,033 acorns. The maximum annual crop size from individual red oaks ranged from 190 to 3,322 acorns. Downs and McQuilken (1944) reported that the 7-year average annual production of oaks was 1,213 acorns per tree in the southern Appalachians, although there was much variability between trees. In a good seed year, oaks produced 2,647 acorns per tree on average. Christisen (1955) studied the production of acorns in Missouri oaks over a 6-year period. He found that in the best year of production, trees in the red oak group (*Erythrobalanus*) produced from 815 to 1,360 sound acorns per tree.

For all oak species, some trees are consistently good producers and others are consistently poor producers (Downs and McQuilken 1944, Christisen 1955, Christisen and Kearby 1984, Sander 1990, Beck 1993). These tendencies are most often attributed to the genetic capability of the tree to produce acorns (Downs and McQuilken 1944, Cypert and Webster 1948, Burns et al. 1954, Sharp 1958, Sharp and Sprague 1967, Christisen and Kearby 1984, Sork et al. 1993).

Frequency of acorn crops

Acorn production is sporadic and unpredictable (Sander 1990, Auchmoody et al. 1993, Beck 1993, Cecich 1993, Johnson 1994). The inherent periodicity for good acorn crops of red oak appears to be 4 years but the actual frequency of good crops may vary because of environmental factors that limit production such as weather, soil fertility, stand density, insects, diseases and wildlife (Christisen and Kearby 1984, Sork et al. 1993). In the red oak group, some good acorn producers may yield well in any given year while others do not (Sharp 1958). Bumper acorn crops occur when all good producers yield a good crop in the same year.

Table 2. Suggested guide for ranking red oak acorn crops (from Auchmoody et al. 1993).[1]

Subjective crop rating	No. acorns/ha	No. acorns/m^2
Bumper	>618,000	>54
Good	310,000-618,000	33-54
Fair	162,000-309,000	17-32
Poor	49,000-161,000	5-16
Trace	<49,000	<5

[1] Based on counts of acorn caps in red oak stands in northwestern Pennsylvania. Average dbh of red oak in these uniform, fully stocked stands ranged from 36 to 56 cm. Red oak basal area ranged from 12 to 22 m^2/ha.

Good to excellent crops of red oak acorns occur on average every 2 to 5 years (Sander 1990). Beck (1977) reported that red oak produced bumper crops at 5-year intervals over a 12-year period in mixed oak stands in the southern Appalachians. During a 21-year study of red oak acorn production in northeastern Wisconsin, Godman and Mattson (1976) observed bumper acorn crops every 7 years on average. However, the interval between some bumper crops was only 2 years. Drake (1991) found that there were 3 bumper crops (> 700 kg sound acorns/ha, or >192,500 acorns/ha) during a 13-year period in Pennsylvania. He reported that only one other year produced mean acorn yields greater than 150 kg/ha (about 41,250 acorns/ha). Red oak comprised 30 to 60% of the basal area in the pole-sized, mixed oak stands he studied.

Factors that affect acorn production

Acorn production is influenced by weather, insects, wildlife, tree age and size, tree crown position, and the tree's inherent capacity to produce acorns. In the long-term, tree characteristics and genetics are probably more important than environmental factors (e.g., weather, wildlife and insects) in determining actual acorn production (Beck 1993).

Acorn yields increase with tree age (Downs and McQuilken 1944, Goodrum et al. 1971). Most oak species begin production when trees are about 20 to 25 years old, but substantial yields do not occur before age 40 or 50 (Reid and Goodrum 1957, USDA 1974, Sander 1990). Open grown trees may begin production earlier than trees crowded in dense stands (Beck 1993). For many oak species, there is a threshold age beyond which acorn production levels off for an extended period. Production then declines with continued increases in age. When trees become senescent, they often experience crown dieback and become poor acorn producers (Goodrum et al. 1971, Huntley 1983).

Other factors being equal, trees of large diameter produce more acorns than trees of small diameter (Moody 1953, Downs and McQuilken 1944, Goodrum et al. 1971, Johnson 1994). For some oak species, including red oak, acorn production increases with increasing diameter to a threshold beyond which production declines (Figure 1) (Downs 1944). Gysel (1957) observed that acorn production of red oak increases rapidly as dbh increased up to 36 cm. In the southern Appalachians, maximum acorn production for red oak occurs in trees with diameters between 41 and 56 cm (Downs 1944).

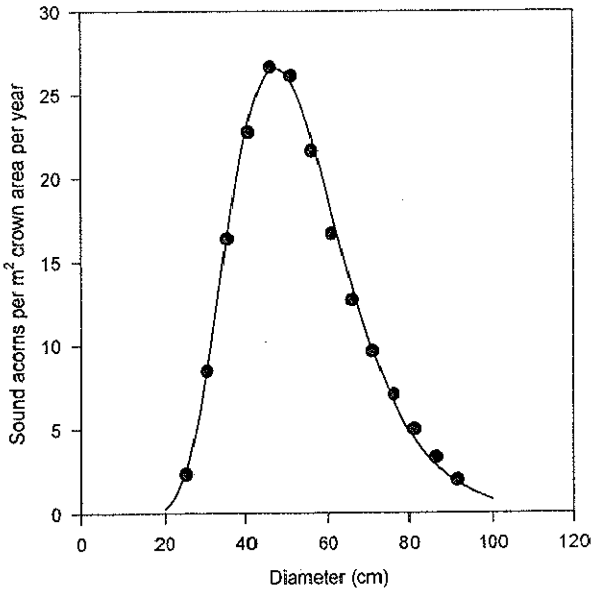

Figure 1. *Observed (solid circles) and predicted (curved-line) production of sound acorns per m^2 of crown area of red oak in relation to dbh (adapted from Downs (1944)). Equation [2] (see page 8) defines the nonlinear regression relationship.*

Production declines rapidly as tree diameter further increases. This may be due to loss of live crown and overall vigor as older trees become senescent.

Crown size, health and class are major factors that influence acorn production (Toumey and Korstian 1937, Downs and McQuilken 1944, Burns et al. 1954, Christisen 1955, Christisen and Korschgen 1955, Reid and Goodrum 1957, Matthews 1963, Christisen and Kearby 1984, Sander 1990, Drake 1991). Acorn yields were larger for oaks with wide crowns and large crown surface areas than for trees with small, narrow crowns (Christisen 1955, Goodrum et al. 1971). Sork et al. (1993) reported that the mean mature acorn crop per tree was significantly correlated with crown area. Downs and McQuilken (1944) stated that total acorn production was related directly to crown size and indirectly to bole diameter. Dominant and codominant oaks, whose crowns receive full sunlight, produced more acorns than the more heavily shaded intermediate or suppressed trees (Sharp 1958, Sharp and Sprague 1967). Drake (1991) found that 96% of dominant oaks and 76% of codominant trees produced acorns, whereas only a small proportion of oaks in the suppressed (e.g., 9%) and intermediate (e.g., 38%) crown classes produced any acorns during a 13-year study period.

Free-to-grow crowns that receive full sunlight have a higher density of live, healthy branches than small, shaded crowns. Acorn production increases as the number of live, healthy branches increases (Verme 1953). Oaks with unhealthy, low-vigor crowns, as evidenced by dead limbs in the upper crown, do not produce acorns in quantity (Sharp 1958). Larger diameter red oaks usually have more foliage and live branchwood biomass than smaller-diameter trees (Loomis and Blank 1981), which may be one reason why acorn production increases with increasing tree diameter.

Bole diameter is a useful indicator of the average acorn production potential of oaks (Downs 1944, Downs and McQuilken 1944). Tree diameter also is correlated with crown width and crown area (Krajicek et al. 1961, Minckler and Gingrich 1970, Sampson 1983, Lamson 1987). This relationship between tree diameter and crown size has been used to develop stocking charts and equations for oak-dominated ecosystems (Gingrich 1967, Sampson 1983, McGill et al. 1991). Loomis and Blank (1981) found that both dbh and the live crown ratio of red oak were significantly related to foliage and live branchwood biomass, which influence the production of acorns. Therefore, tree diameter, an easy-to-measure tree characteristic, is directly related to many of the factors known to influence acorn production including crown size, tree age and crown density.

Stocking and Acorn Production

Maintaining high red oak stocking levels may not ensure acorn production because only a minority of oaks are inherently good acorn producers (Beck 1993). For example, there may be only 50 oaks/ha that are good producers (Johnson 1994). The best approach to maximizing acorn production would be to identify the good acorn producers and provide them with adequate growing space throughout their development. However, doing that would require investments in acorn surveys and periodic thinnings.

It is difficult to identify the inherently good producers without long-term field observations of acorn production. Ideally, observations of acorn production for 5 or more years could be used to identify the good producers. Alternatively, the acorn-producing capacity of individual trees can be assessed in a single year of good to excellent production in a given stand. Longer term observations are preferrable because trees in the red oak group that are good producers on average do not always produce acorns abundantly in the same year (Sharp 1958).

Sharp (1958) outlined procedures for sampling and rating acorn production. To use his method, oaks must be observed from early to mid-August because acorns are large enough at that time to view them through binoculars and acorn predators have not had time to destroy the crop. Acorns of red oak are located beneath the leaves of the current year's growth and, hence, are visible from below. They are attached by short stalks to the previous year's stem growth. A bright sky background makes it easier to view acorns as the observer looks up through the branches. Acorns should be counted on the terminal 60 cm (excluding the current year's growth) of healthy branches in the upper third of the crown. Acorn production of individual oaks can be ranked using the guidelines presented in Table 3. Good acorn producers can be identified using this method over several acorn crops and these trees can then be reserved from harvest.

Christisen and Kearby (1984) provided an alternative method for ranking acorn crops. They used acorn cluster size and the percentage of the crown that contains acorns to assign 1 of 9 acorn productivity ratings to a tree. The uniformity of acorn production on a tree is also an important consideration in their ranking system. The relative size of acorn clusters varies among oak species, as does the spatial distribution of acorns in the crown. For red oak, a large acorn cluster may contain 5 to 7 acorns. Trees in the red oak group seldom have acorns on limbs in the lower half of the crown. Thus, in determining the uniformity of acorns throughout the crown, only the upper half of the crown should be considered.

Even without knowing which oaks are the good acorn producers, oak stocking guides could be used to schedule thinnings that might increase the *potential* of a stand to produce acorns. Growing space requirements of red oak in mixed-species stands have been developed in Wisconsin (McGill et al. 1991) and New England (Sampson 1983), and in oak-hickory stands in the central United States (Gingrich 1967).

As defined by these guides, B-level stocking represents the lowest level of stocking for full site utilization. It also signifies the point where inter-tree competition for growing space begins when trees are uniformly distributed throughout the stand. At this level of stocking, main canopy trees have the maximum amount of growing space that they can use for crown development. For example, the crown areas of red oaks at B-level stocking range from 44 m^2 for trees 30 cm in dbh to 105 m^2 for trees 50 cm in dbh (Table 4). Thus, 227 oaks that average 30 cm in dbh would completely use the growing space on 1 ha, or 95 oaks/ha that average 50 cm in dbh.

Table 3. Ranking of acorn production for individual trees in the red oak group (adapted from Sharp 1958).

Ranking of production	Average number of acorns/branch[1]
Excellent	≥24
Good	16-23
Fair	9-15
Poor	≤8

[1] Based on the terminal 60 cm of healthy branches in the upper one-third of the crown.

A-level stocking represents the maximum density where each tree has the minimum growing space it needs to survive. Competition is greater at the A-level of stocking than at the B-level. Thus, oaks would have smaller crowns at the A-level of stocking than if grown under less dense stand conditions. Full site utilization occurs between A- (100%) and B-level (55%) stocking.

At B-level of stocking, the crown areas of individual oaks are potentially at their maximum. Acorn production of individual trees is optimal but the density of oak is relatively low. As stocking increases above the B-level for a given diameter, the number of potential acorn producers increases, which may lead to an increase in total stand acorn production. However, as stand density increases, inter-tree competition causes oak crowns to become smaller and to have less foliage and fewer fine branches, thereby potentially reducing the acorn production of individual trees. At some threshold stocking, increasing the number of oaks in the stand may cause a net decline in total acorn production because the additional trees may not add enough to total stand production to offset reductions in individual tree production that result from decreases in crown size. There may be an ideal range of stand stocking that maximizes stand-level acorn production but this is not now known.

Table 4. Maximum crown areas of dominant, forest-grown red oaks and tree densities required for full utilization of the available growing space by oaks, i.e., B-level stocking.

Dbh (cm)	Maximum crown area[1] (m^2)	Trees/ha[2]
30	44	227
35	57	175
40	71	141
45	87	115
50	105	95
55	124	81
60	146	68

[1] Calculated using the following equation (adapted from Sampson 1983):

$$CA = 1.477 + 0.4396DBH + 0.0327DBH^2,$$

where CA = crown area of dominant, forest-grown red oak (m^2) and

DBH = diameter breast height (cm).

[2] Calculated by dividing the area in 1 ha (10,000 m^2) by the crown area (m^2) of an individual red oak.

Estimation of Acorn Production

Downs (1944) observed red oak acorn production in relation to dbh over a 7-year period in the southern Appalachians. If we assume that his study stands were fully stocked (i.e., A-level stocking), we can use the main canopy tree area equation developed by McGill et al. (1991) to calculate the crown area of Downs' red oaks.

[1] $CA = 0.55 + 0.148*DBH + 0.02*DBH^2$, where:
CA = crown area per tree (m^2) and
DBH = diameter breast height (cm).

The number of sound acorns per m^2 of crown area is determined by dividing the actual production for a tree of given dbh (Downs 1944) by its crown area (Figure 1).

The relationship between acorn production per unit crown area and tree dbh is defined by the following nonlinear model (R^2=0.9964) (Figure 1):

[2] AP = 3,463,971*EXP(-0.125*DBH - 277.434*(1/DBH)), where:
AP = acorn production per m^2 of crown area for a red oak of given dbh,
EXP = the exponential function, and
DBH = diameter breast height (cm).

Equation [2] was used to estimate total acorn production over a range of density and stocking of red oak (Figures 2 and 3).

The size and number of oaks in a stand influences acorn production as shown in Figure 2. Maximum acorn production occurs between 50 and 60 cm dbh for any given density of oak. When 140 oaks in this diameter range occur per ha, approximately 212,000 to 215,000 sound acorns/ha will be produced on average. Figure 2 can be used as a guide to approximate average production of sound acorns from an inventory of the red oak in a stand and to comparatively evaluate the effects of silvicultural alternatives on acorn supply.

Either stand averages or individual tree data may be used with Figure 2. More precise acorn estimates can be calculated by following the procedures outlined in Appendix I. Acorn production calculated using stand-level average dbh and density of oaks results in conservative estimates because the relatively few, but large diameter (40 to 60 cm) oaks, which are capable of producing large quantities of acorns, are not considered directly. However, estimates based on stand average oak characteristics may be appropriate for regional or landscape-level plannning, especially when detailed stand data are not available. Individual tree characteristics obtained by sampling a stand can be used to more accurately estimate sound acorn production and should be used in developing stand-level prescriptions.

Inventories of 2 upland oak stands, one near Papineau Lake, Bancroft District and the other near Foymount, Pembroke District, were used to estimate sound acorn production. Both stands have a closed canopy of mature (80+ years old), mixed-hardwoods including red oak, sugar maple (*Acer saccharum* Marsh.), beech (*Fagus grandifolia* Ehrh.), red maple (*Acer rubrum* L.), white ash (*Fraxinus americana* L.) and basswood (*Tilia americana* L.). Red oak comprises 30% or more of the basal area in both stands. In either stand, there is little evidence of recent disturbances from either logging or catastrophic events such as fire or wind. Table 5 summarizes average stand characteristics for both stands based on 23 (Bancroft) and 31 (Pembroke) 0.08 ha circular plots in which all trees ≥2.54 cm dbh were measured.

The estimated sound acorns/ha is 31,455 at Bancroft and 61,664 at Pembroke based on stand average oak dbh and density (Appendix I). If, however, individual oak data are used to estimate sound acorn production, then the Bancroft stand can

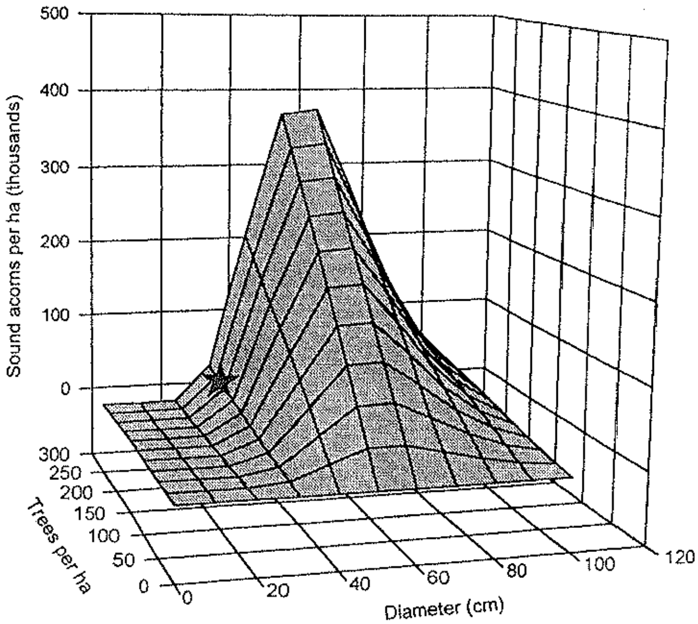

Figure 2. *Relationship between dbh, density (trees/ha) and sound acorn production per unit crown area for red oak. The solid star represents average stand conditions and estimated sound acorn production for 2 oak-dominated stands in the Bancroft and Pembroke Districts.*

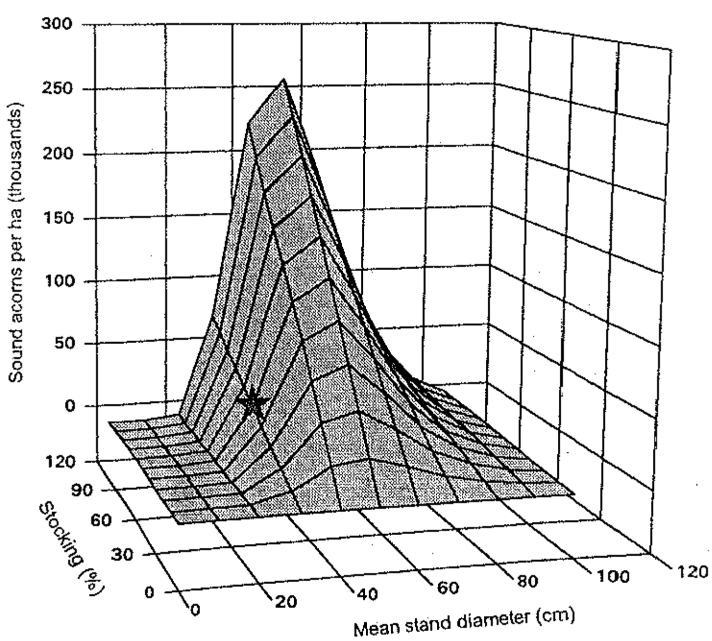

Figure 3. *Relationship between dbh, stocking and sound acorn production per unit crown area for red oak. The solid star represents average stand conditions and estimated sound acorn production for 2 oak-dominated stands in the Bancroft and Pembroke Districts.*

produce 62,444/ha and the Pembroke stand 71,200/ha. These values compare favorably with observed red oak acorn crops in Michigan (Gysel 1957), Pennsylvania (Barni 1980) and North Carolina (Beck 1977).

In these Ontario stands, half of the estimated acorn production comes from 13% of the overstory oaks, whose diameters are ≥40 cm (Figure 4). While only 3% of the oaks occur in the 50 cm and larger dbh classes, they produce 14% of the estimated sound acorn crop. A rather small proportion of the estimated acorn crop (9%) is contributed by oaks with diameters <30 cm, although they represent 58% of oak density.

Stocking is a measure of the amount of growing space occupied by trees on a given site. In red oak dominated forests, the growing space is fully utilized when stand stocking is between 55 and 100%. If a stand is at A-level (100%) stocking and oak stocking is 100%, then it is a pure oak stand. For mixed-species stands, when stand stocking is 100% and the oak comprises 50% of stocking, then half of the growing space is occupied by oak. This latter situation characterizes the 2 oak stands studied in the Bancroft and Pembroke Districts.

The estimated average production of sound acorns for red oak stands, which average 30 cm dbh, ranges from about 78,500 acorns/ha at 100% oak stocking to 43,200/ha at 55% oak stocking (Figure 3). As oak dbh increases to 50 cm, maximum production of acorns (260,300/ha) occurs when oak stocking is 100%. Although these estimates are conservative because they are based on stand average dbh and stocking, they are within the observed range of production over the geographical range of red oak in North America (Table 1).

Table 5. Summary of stand characteristics for 2 mixed-hardwood stands dominated by red oak, Bancroft and Pembroke Districts.[1]

	Basal area (m^2/ha)	Trees/ha	Stocking[2] (%)	Dbh (cm)
		Bancroft		
All species	27.2	645	93	21.0
Red oak	16.2	237	52	28.8
		Pembroke		
All species	28.8	586	96	23.4
Red oak	16.4	203	52	32.4

[1] Based on trees ≥5.0 cm dbh in the intermediate and larger crown classes.

[2] Computed using the main canopy equation for trees ≥5.0 cm dbh in the intermediate and larger crown classes (McGill et al. 1991).

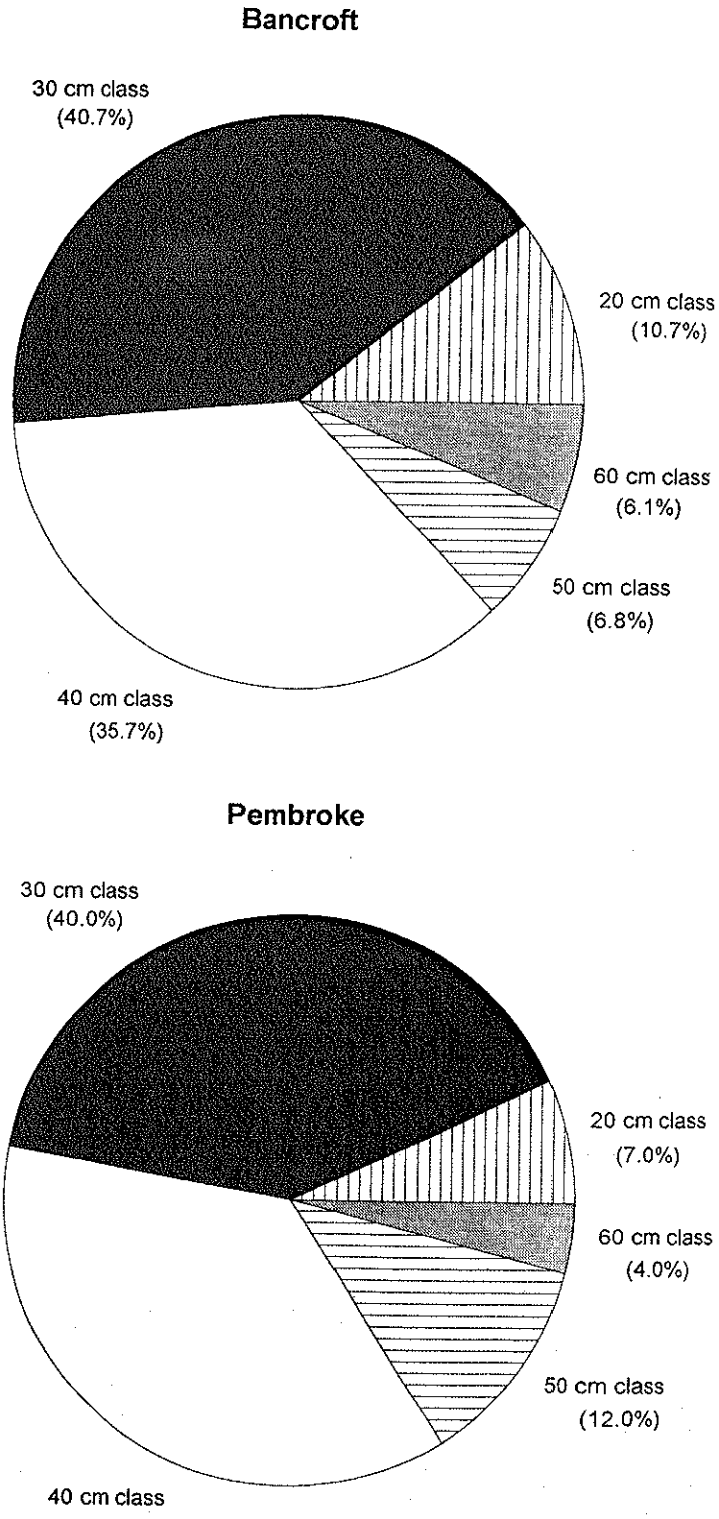

Figure 4. *Proportion of estimated sound acorns/ha in relation to diameter (dbh) classes in 2 upland oak stands on the Bancroft and Pembroke Districts.*

Figure 3 can be used to evaluate silvicultural treatment effects on acorn production. Two oak stands on the Bancroft and Pembroke Districts averaged 94% stocking based on trees of all species that were ≥5 cm dbh and in the intermediate or larger crown classes. Oak stocking in these stands is 52% and the oak averages 30 cm in dbh. These stands can produce about 40,000 sound acorns/ha (Figure 3). Thinning to release crop trees in young oak stands can substantially increase acorn production. Increasing mean stand dbh of oaks from 30 to 40 cm would increase acorn production at 50% oak stocking from 39,235/ha to 113,467/ha (Table 6). When oak stocking is 70% and mean dbh for oak is 40 cm, 158,854 acorns/ha may be produced on average.

Our ability to maximize mean oak dbh is limited by site productivity. Linking site productivity to FEC ecotypes in the future will help define diameter growth potential for specific site conditions. Also, management concerns may influence the desired level of oak stocking. For instance, pure oak stands may experience greater reductions in growth and survival than mixed-species stands following catastrophic events such as gypsy moth outbreaks or oak decline. Therefore, a reasonable goal may be to maintain oak stocking at 30 to 75% on sites of average to fair productivity. On higher quality sites, 10 to 30% oak stocking may be all we can expect without substantial silvicultural inputs. Although we lack detailed guidelines for setting size and stocking thresholds for oak on specific ecotypes, prescriptions for stands with an oak component should define stand characteristics in relation to acorn production targets.

Table 6. Comparison of estimated sound acorn production (per ha) in 2 stands located in the Bancroft and Pembroke Districts and potential acorn yields for hypothetical stands that have larger diameter oaks and higher oak stocking. The shaded area is estimated acorn production based on current average conditions for the Bancroft and Pembroke stands.

Stocking[1] (%)	Mean stand dbh 30 cm	Mean stand dbh 40 cm	Mean stand dbh 50 cm
50	39,325	113,467	130,150
60	47,082	136,161	156,180
70	54,929	158,854	182,209
80	62,776	181,548	208,239

[1] Stocking of red oak in a stand, which is computed using the main canopy equation of McGill et al. (1991).

Management Recommendations

It is not usually possible to control the exogenous factors that affect acorn production such as the weather, or wildlife and insect populatons. However, we can control the amount of overstory oak, its physical characteristics and the inherent capacity of oak in a stand to produce acorns.

When oaks are about 40 or 50 years old, good producers should be identified and maintained in a codominant or better position in the stand. Dominant and codominant oaks will be the best acorn producers. Good acorn producers should be released from competition by thinning so that their crowns are exposed to full sunlight on all sides. This practice will promote crown expansion and increase live branch density, which should increase acorn production. Area-wide thinning is not necessary because the release of good producers is all that is needed to maximize acorn production.

Crop-tree thinning oaks in young stands (7 to 22 years old) increases diameter growth and should increase oak stocking in the upper crown classes as the stand develops (Ward 1995). An additional thinning may be needed to promote the continued growth of intermediate and suppressed oak saplings into the upper crown classes. Discriminating against non-oaks and non-acorn producing oaks in thinning should increase the amount of acorn bearing crown area in the upper crown classes, especially when trees are released at an early age. However, acorn production in young oak stands does not always increase following thinning. Drake (1991) found that acorn production was not significantly increased 10 years after thinning young (e.g., 42 to 58 years old), even-aged oak stands. His results were confounded by 5 years of defoliation by the gypsy moth that occurred after thinning. Acorn production is reduced in oaks defoliated by gypsy moths (Gottschalk 1988).

The stocking chart (McGill et al. 1991) can be used to time thinnings. As a young oak forest develops, thinning should maintain stand stocking between the B- and A-level. This will ensure that the available growing space is fully used by trees. Thinning back to the B-level, as needed, will promote maximum crown development on the residual oak. Oaks maintained at high stocking levels for long periods will have smaller crowns with less dense foliage and fewer live branches than oaks that are released when stand stocking approaches the A-level.

Acorn production is maximized in mature stands when oaks average 40 to 60 cm in dbh and comprise 55% or more of stand stocking on sites with average or better productivity. When initial stocking of oak is less than 55%, practically all upper-canopy oaks should be retained to maximize acorn production. To achieve 55% stocking of red oak when dbh ranges from 40 to 60 cm, there would be approximately 141 to 68 oaks/ha, respectively (Table 4).

Thinning may be less beneficial when managing older stands. Increases in acorn production are limited by the declining biological potential of older oaks, which eventually become senescent. The crowns of older oak are less able to increase in size, mass and area after thinning than are crowns of younger trees. Also, as stands reach maturity and some oaks begin dropping into the lower crown classes, there is less opportunity to increase their growth potential than when they are always maintained in the upper crown classes through periodic thinning (Ward and Stephens 1994).

In older stands, thinning is less likely to result in increases in the absolute amount of oak in the overstory because these trees are more susceptible to decline (Wetteroff 1993).

Oak decline causes reductions in the acorn production of individual trees and decreases in stand production as overstory oaks die. Many oak forests in Ontario are 90 to 110 years old, and oak decline symptoms are often present, especially on sites with shallow soils (Evans et al. 1994, Sajan et al. 1994, Guyette and Dey 1995).

Management of older stands can be done so that acorn production capacity is maintained by either retention of known acorn producers or by leaving oaks in the upper crown classes. When conducting shelterwood harvesting or intermediate thinnings, reserve oaks that: (1) are dominant and codominant, (2) have large, healthy crowns, (3) have abundant foliage and live branches, (4) are between 40 and 60 cm in dbh (in mature stands), or (5) are between the ages of 50 and 100 years. Oaks failing to meet these criteria may be removed in thinnings or harvests. However, non-oaks in the overstory should be removed first. Oaks can be removed without significantly reducing acorn production if the harvested trees: (1) are mature and have intermediate or suppressed crowns, (2) have large, dead branches in the upper crown, (3) have small and narrow crowns, (4) have broken crowns, (5) have partially developed crowns due to competition with neighboring trees, or (6) seldom produce acorns.

In the southern United States, recommendations are to retain from 12 to 25 well-formed oaks ($\geq$ 25 cm in diameter)/ha to provide acorns for wildlife species (Murray and Frye 1957, Strode 1957, Bateman 1959). Downs and McQuilken (1944) suggested leaving 25 good acorn producers (>42 cm in dbh)/ha to accomodate acorn predators and still provide enough acorns for adequate oak regeneration. When reserve trees are smaller (e.g., 30 to 40 cm in dbh), 50 oaks/ha should be left.

Leaving 25 oaks/ha that are 42 cm in dbh would result in a maximum crown cover of 18% (according to Sampson 1983) or 3.5 m^2/ha residual basal area. Retention of 50 oaks/ha that are 30 cm in dbh would result in a maximum overstory canopy cover of 22% or 3.5 m^2/ha residual basal area. This amount of residual overstory should not significantly affect the development of reproduction provided that shade tolerant saplings $\geq$2.5 cm in dbh have been removed during harvest. Miller and Schuler (1995) reported that from 30 to 37 codominant residual trees/ha (4.0 to 5.9 m^2/ha) had no noticeable effect on the development of central Appalachian hardwood reproduction 10 years after a harvest, in which all trees $\geq$2.5 cm in dbh were felled. This low level of residual overstory density and crown cover will not negatively effect long-term development of reproduction. If this relatively sparse residual overstory consists of codominant or better oaks, then acorn production can be sustained for long periods while the new stand is regenerating and developing seed bearing oaks.

Summary

Optimum production of acorns is critical for successful oak regeneration and is important for many wildlife species dependant on acorns as a food source. Production is highly variable among individual trees; some trees are consistently good producers while others are not. The frequency of good acorn crops can be sporadic and unpredicatable, but the inherent periodicity for good crops is 4 years. Biotic and abiotic factors determine the actual level of production in any given year.

Tree age, diameter and crown characteristics influence acorn production. Production increases with increasing age and diameter to a point, beyond which it declines as trees become senescent. Maximum production occurs in oaks that are 40 to 60 cm in dbh and 50 to 100 years old. Oaks with wide, dominant crowns that have large surface areas exposed to direct sunlight can produce large crops.

A method has been presented here for estimating acorn production of stands or individual oaks based on tree dbh and density. The method was developed using empirical acorn production data and stocking relations for red oak. These estimates can be used to evaluate silvicultural alternatives and to assess treatment effects on acorn production.

Estimates of average sound acorn production are 62,444/ha and 71,200/ha for 2 upland oak stands on the Bancroft and Pembroke Districts, respectively. These values compare favorably with observed red oak acorn production in Michigan, Pennsylvania and North Carolina. A large proportion (50%) of acorns are produced by the relatively few, large oaks (≥40 cm dbh) in mature upland oak forests in Ontario. Oaks with dbhs <30 cm account for only about 9% of the estimated acorn crop.

As the level of oak stocking increases in a stand, acorn production increases. Acorn production may be increased through management that results in increased oak diameters and stocking. However, forest health concerns and site conditions influence the amount and size of oak that can or should be grown on a given site. Site productivity physically limits the maximum size and density of oak that can be produced. Oak stocking may be set at levels lower than the maximum site potential to minimize the risks associated with gypsy moth epidemics or oak decline events.

Precommercial thinnings during the first 20 years can increase growth and survival of red oak. At age 40 to 50, good acorn producing trees can be identified. Periodic thinnings, which release crowns on all sides, maintain these oaks in codominant or better crown classes.

Stocking guides can be used to estimate acorn production and to schedule stand treatments. Reduction of stocking from A- (100% stocking) to B-level (55% stocking) and retention of known acorn producers provides adequate growing space for young oaks and maximizes acorn production, while maintaining full use of the site. However, the ideal level of stand stocking that maximizes acorn production is not yet known.

Thinning older stands (e.g., 125 to 200 years old) will have little effect on acorn production because the trees are beginning to decline in vigor. These stands should be prepared for regeneration. General criteria are presented for selecting leave trees in thinnings or shelterwood harvests.

Until now, specific guidelines for management of acorn production have not previously existed in Ontario. Other sources offer recommendations for retaining enough oaks to ensure an adequate acorn supply for regeneration and wildlife. They vary, from 12 to 25 oaks/ha (≥25 cm in dbh); to 25 oaks/ha (≥42 cm in dbh); to 50 oaks/ha (30 to 40 cm in dbh).

Leaving 30 to 37 codominant or dominant oaks/ha (4.0 to 5.9 m^2/ha) for long periods will not inhibit seedling growth or survival provided that all trees ≥2.5 cm in dbh are felled during harvest.

Prescriptions to regenerate red oak by shelterwood harvest can be modified to include leaving a sparse residual overstory of large diameter oaks (18 to 22% crown cover). This will ensure a sustainable, long-term supply of acorns, especially if the reserve oaks are good acorn producers. Stands can be regenerated without complete loss of acorn production. The overstory oaks should be retained at least until the young oaks reach seed bearing age (40 to 50 years). Then, the older trees can be removed during future thinnings or shelterwood harvests.

These preliminary guidelines are intended for management of acorn production in upland, mixed-hardwoods that have a major red oak component (≥30%

oak by basal area). A method is given for estimating acorn production, which is an important consideration when developing prescriptions for oak stands.

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Appendix I

Oak dbh and density are required to estimate sound acorns/ha. Sampling individual oak stands is the most reliable method of data collection and produces accurate estimates of acorn production. Either variable radius plots (prism cruising, 2 m BAF) or fixed area plots (e.g., 0.08 ha circular plot) can be used to sample the overstory. Although only information on oak in the overstory is used in predicting acorn production, other stand data may be collected at the same time for use in prescription development, timber sale preparation or ecosystem classification. The number of plots per stand will vary depending on budget, time, desired precision, stand variability and intended use of the data.

Two methods for estimating acorn production are presented here. First, production is estimated using stand average dbh (cm) and density (trees/ha) of overstory oaks. The second example estimates sound acorn production based on 23 fixed area plots that were systematically located along transects in an oak stand on the Bancroft District.

Example 1: Stand averages

In the Bancroft stand, the average dbh of red oak is 28.8 cm and there are 237 oaks/ha (TPH).

Calculate the crown area for an oak of given dbh:

[1] $$CA = 0.55 + 0.148*DBH + 0.02*DBH^2$$, where
CA = crown area per tree (m^2) and DBH = diameter breast height (cm).
Therefore:

$$CA = 0.55 + 0.148*28.8 + 0.02*(28.8)^2 = 21.401 \text{ m}^2$$

Determine sound acorn production per square meter of crown:

[2] $$APSQM = 3{,}463{,}971.613*EXP(-0.125*DBH - 277.434*(1/DBH))$$, where
APSQM= sound acorns per square meter of crown and EXP = the exponential function
Thus,
APSQM = 3,463,971.613*exp(-0.125*28.8-277.434*(1/28.8)) = 6.2016 sound acorns/ha

Finally, sound acorn production/ha (APROD) is found by:

[3] $$APROD = APSQM*CA*TPH$$
Hence,

APROD = 6.2016*21.401*237 = 31,454.7 ⇒ 31,455 sound acorns/ha

Example 2: Individual tree data

Sound acorn production/ha (APROD) is estimated for each oak measured using the procedure in Example 1. The TPH factor is a constant for fixed area plots and varies with plot size. One tree on a 0.08 ha circular plot represents 12.4 trees/ha. However, the TPH factor varies with individual tree dbh in variable plot sampling. Individual tree estimates are totaled for each plot. Stand production is obtained by averaging plot totals.

For the 23 fixed area (0.08 ha circular) plots in Bancroft, the intermediate products and acorn estimates are presented for a single plot, followed by the plot totals and stand average.

PLOT	DBH	CA	TPH	APSQM	APROD
1	14.3	6.7562	12.4	0.0022	0.18
1	15.4	7.5724	12.4	0.0076	0.71
1	17.4	9.1804	12.4	0.0468	5.33
1	18.0	9.6940	12.4	0.0739	8.88
1	19.3	10.8562	12.4	0.1774	23.88
1	23.5	15.0730	12.4	1.3699	256.04
1	24.2	15.8444	12.4	1.7660	346.97
1	28.0	20.3740	12.4	5.2047	1,314.91
1	28.0	20.3740	12.4	5.2047	1,314.91
1	29.6	22.4540	12.4	7.2802	2,027.02
1	30.7	23.9434	12.4	8.8772	2,635.63
1	33.9	28.5514	12.4	13.9647	4,944.02
1	39.6	37.7740	12.4	22.2428	10,418.46
1	44.2	46.1644	12.4	25.9492	14,854.30
1	46.6	50.8780	12.4	26.5600	16,756.38
1	61.6	85.5580	12.4	17.3593	18,416.80
1	63.3	90.0562	12.4	15.8407	17,689.26
Total					91,013.68

PLOT	APROD	PLOT	APROD
1	91,014	13	45,045
2	51,556	14	102,354
3	32,593	15	64,373
4	58,608	16	15,026
5	50,297	17	73,794
6	92,618	18	54,264
7	89,732	19	69,333
8	52,582	20	59,584
9	45,580	21	84,685
10	21,064	22	114,923
11	56,692	23	43,116
12	67,377		
Stand Average			62,444 ± 25,060