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THE
PENNSYLVANIA STATE COLLEGE

SPROUTING CAPACITY AND SPROUT DEVELOPMENT
IN
CERTAIN HARDWOOD SPECIES OF CENTRAL
PENNSYLVANIA

By
Ralph A. Vogenberger

THESIS FOR DEGREE OF MASTER OF SCIENCE
IN FORESTRY

June, 1931

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Professor of *Forestry*

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FOREWORD

The author is greatly indebted to Arthur C. McIntyre, Instructor in Forest Research, Pennsylvania State College, who suggested this study, and offered much kind advice and criticism; to Harold J. Lutz, Assistant Professor of Forestry, Pennsylvania State College, under whose direction the study was made, for his assistance in connection with the field work and preparation of the manuscript.

The author also wishes to acknowledge the aid given by George W. Holt, Unionville, Pennsylvania, who furnished information in regard to location and time of cutting of the areas on which the field work was carried out.

Chestnut oak stump, one year after cutting, with a total of 142 sprouts. Nine of these sprouts are dominant and average 6 feet in height. The parent stump is 75 years old, .6 ft. high, and has a diameter (inside bark) of 8.5 inches.

INTRODUCTION

It is a well known fact that most of our hardwood species possess the capacity for sprouting after cutting, and in many cases after burning. The early growth rate of these sprouts is more rapid than the early growth rate of seedlings. Reproduction by sprouts is inexpensive and rapid, and the sprout system of reproduction is relatively simple and easy to practice. These advantages have led many woodlot owners throughout the East to prefer this method of reproduction to slower, and more expensive methods.

For many years iron mining and smelting were important industries in Pennsylvania, and consequently there was a great demand for charcoal. The hardwood forests were cleared off in order to fill this demand, and the succeeding stands were cut again as soon as they were large enough to use. The rotation used was about twenty-five years, and reproduction was obtained largely from sprouts. With the closing down of the iron mines and smelters, the hardwood stands were permitted to grow to older ages, so at present we find stands of sprout origin as old as one hundred years.

There are no accurate statistics available on the amount of timber of sprout origin in this region, but a conservative estimate would be seventy-five per cent. It is actually known that in some cases ninety per cent of the timber is of sprout origin.

Butt rot is a form of defect which is commonly associated with older stands of sprout growth. Wood-destroying fungi attack the parent stump, and decay spreads up into the heartwood of the sprout. Sooner or later a large percentage of the butt log of the

sprout is affected by heart rot. Decay increases with age, and consequently, sprout reproduction is more applicable in stands managed on short than on long rotations. The most important of the products derived from coppice stands are ties, props, posts, poles, and fuel. Although charcoal and fuel were at one time leading products, they are now of minor importance. Chemical wood and pulp wood as well as furniture stock and lumber are other minor products derived from timber of sprout origin. Tannin, in some localities, is an important product obtained from the bark of the various species of oak.

In the region in which this study was made, a fairly good market exists for the major products of sprout stands. The region is situated about half way between the hard coal and the soft coal regions of Pennsylvania, and consequently, ready markets are found for mine ties and props. The railroad companies make constant demands for ties, while posts and poles are in demand by the State Highway Department, farmers, and many other miscellaneous consumers.

This investigation of sprout growth was made primarily because of the fact that sprout timber is of great importance in this region. Much of the timber throughout the region is owned by farmers, and it is hoped that this study will be of particular interest and value to them.

SCOPE OF THE STUDY

The growth of sprouts, like all other forms of plant growth, is influenced by a complex of factors. No attempt was made in this

study to investigate all of the influencing factors. Only those factors were considered which were most readily investigated and which were thought to be most significant and important in the application of silvicultural practice.

This study was limited, as far as possible, to sites which were more or less uniform in regard to such factors as fire, grazing, season of cutting, exposure, soil, and system of cutting.

The object of this study was to determine the following relationships:

1. The relation between the number of dominant sprouts and the total number of sprouts per stump for various species.
2. The relation between the average height of dominant sprouts and the total number of sprouts per stump for various species.
3. The relation between the total number of sprouts per stump and the stump diameter (inside bark) for various species.
4. The relation between the total number of sprouts per stump and the height of stump for various species.
5. The relation between the total number of sprouts per stump and the age of parent stump for various species.
6. The relation between the total number of sprouts per stump and the age of the sprouts.
7. The relation between the number of sprouts per acre and the age of the sprouts.
8. The relation between the average height of the dominant sprouts and their ages.

9. The relation between the average diameter (breast high) of the dominant sprouts and their ages.

DEFINITIONS OF TERMS USED IN THE STUDY

In order to give the reader a precise understanding and to eliminate ambiguity, it appears desirable to define some of the terms used in this study.

Sprout - A shoot developing from an adventitious or dormant bud on an injured tree or on the stump of a tree. Leffelman and Hawley (13), Schwarz (17), and Westveld (21) have used the term "sprout" to designate only shoots which develop from stumps three inches or more in diameter at ground level. To shoots developing from stumps smaller than three inches, they have applied the term "seedling sprout". However, for the purpose of this study, the term "sprout" will be applied to all shoots irrespective of the size of the parent stump.

Dominant sprouts - The largest and most vigorous of the sprouts arising from a stump. These sprouts are probably the only ones that will survive competition.

Sprouting capacity - The ability which a species manifests to produce sprouts.

THE REGION

The region represented in this study is situated in the central part of the Commonwealth of Pennsylvania. The topography consists of rolling limestone valleys separated by long, narrow,

steep, parallel, mountainous ridges of sandstone. The region is drained by numerous creeks flowing into the West Branch of the Susquehanna River. The Moshannon, Bald Eagle, and Penn Creeks, with their tributaries, are the most important of these streams. The elevation of the region ranges from about 1000 feet above sea level as a minimum to about 2500 feet above sea level as a maximum. The winters are quite severe, with temperatures falling as low as 20 degrees below zero, and there is generally a heavy fall of snow throughout the region both in the valleys and on the mountains. The average date of the first killing frost in the autumn is September 30, while the average date of the last killing frost in the spring is May 1. The summers are relatively cool with the summer mean being about 69 degrees F. and the absolute maximum being 96 degrees F. Sudden changes in temperature are common. Rainfall is generally sufficient and well distributed although droughts are common in the late summer and early fall. The timber of this region is generally recognized as a mixed oak type. The chief species predominating in the stands are chestnut oak (Quercus montana), scarlet oak (Q. coccinea), white oak (Q. alba), red oak (Q. borealis), black oak (Q. velutina), red maple (Acer rubrum), hemlock (Tsuga canadensis), white pine (Pinus strobus), and hickory (Hicoria sp.). Just to the north lies the northern hardwood type in which the predominating species are beech (Fagus grandifolia), yellow birch (Betula lutea), black birch (B. lenta), sugar maple (A. saccharum), red maple, hemlock and white pine.

FACTORS UNFAVORABLE TO SPROUT REPRODUCTION

There are many factors which are believed to be detrimental to sprout production and development. Since all of these factors could not be investigated it was decided to eliminate as many of them as possible from the study in order to make the data more comparable. The most important of these factors are discussed below.

Fire, is undoubtedly a factor that has great influence upon sprouting capacity. Fire burns the sprouts to the ground and causes the stumps to produce new shoots. Frequent fires soon destroy sprout production entirely, because the vitality of the stump becomes exhausted. Thus, on areas which are burned over repeatedly, we find large numbers of stumps which have failed to produce sprouts. The stands formed on such areas are open and irregular. Zon (23) has shown that fire also has an effect on height growth of sprouts. His table showing the effect of fire on height growth in stands of sprouts, 11 years old, in the Tennessee River Valley follows:

<u>Species</u>	<u>Average height in feet</u>	
	<u>badly burned</u>	<u>slightly burned</u>
black oak	24.3	25.9
scarlet oak	25.8	27.7
white oak	19.7	21.3

Grazing probably has somewhat the same effect as fire on sprout production. The tender young sprouts are browsed, and although not always killed back to the ground, they are injured and new shoots are produced. Where only the tops have been browsed, the sprouts are hindered in growth and the resulting tree is of poor form.

Late spring and summer cuttings probably result in less vigorous sprout production than winter and early spring cuttings. If the trees are cut during the growing season, the bark is more easily stripped from the stump and consequently, many adventitious and dormant buds are destroyed. Sprouts that are produced late in the season are still tender at the end of the growing season and very susceptible to frost killing. Zon (23) has given in the following table a comparison of the effect of summer and winter cutting upon the growth of two year old dominant sprouts from stumps 32 years old:

<u>Species</u>	<u>Summer cut</u>		<u>Winter cut</u>	
	<u>diameter</u>	<u>height</u>	<u>diameter</u>	<u>height</u>
White oak	0.82"	4.35'	0.71"	4.85'
Black oak	.88	4.94	.94	6.32
Scarlet oak	1.02	4.98	.88	7.20
Spanish oak	1.12	5.83	.84	6.62

In this table, the height growth is shown to be greater for the winter cut, while the diameter growth is greater for the summer cut. Mattoon (14) however, shows in the following table for 1 year old chestnut sprouts that the diameter growth as well as the height growth is greater for the winter cut, but that the average number of sprouts is greater for the summer cut:

<u>Season</u>	<u>Aver. no. sprouts</u>	<u>Aver. height</u>	<u>Aver. diameter</u>
Midwinter	22	6.15'	.42"
May	35	3.5	.23

Brown (4), in an experiment carried out at the Storrs (Connecticut) Agricultural Experiment Station found that the months of June, July, and August were most favorable for the elimination of bushes from pastures, since the sprouting capacity was poorest during that period.

On the other hand, if good sprout reproduction is the object in management, no cutting should be made during this period.

Southern and western exposures are believed to be more or less unfavorable for sprout reproduction. No data has been collected in regard to this condition, but observation and comparison seemed to show that stumps on southern and western slopes were not as vigorous sprouters as those on northern and eastern slopes. Southern and western slopes are generally considered inferior sites because they are constantly exposed to the warm rays of the sun. Moisture content of the soil is generally somewhat lower on these warm slopes, and it is likely that the heat also has an effect on the sprouting capacity of the stumps.

Systems of cutting which do not permit sufficient light to reach the sprouts are unfavorable for sprout development. Oak sprouts are moderately tolerant to intolerant and abundant light is required for their best development. For this reason upper slopes and ridges are more favorable to sprout reproduction than lower slopes and coves, and clear cutting systems are more favorable than other systems of cutting.

Decayed or partly decayed stumps are believed to have an unfavorable effect upon sprouting capacity. This phase was not investigated in this study, but Mattoon (14) has shown the relation of soundness of parent stump to the height growth of sprouts of chestnut. His table is given here, and he explains the high average shown for the poor quality stumps as being due to the fact that no measurements were taken on stumps which were so badly diseased that

no sprouts were produced.

Quality of stump	Length of growth in height in feet			
	1st year	2nd year	3rd year	total
Good	4.88	2.23	1.90	9.01
Fair	4.18	2.20	1.51	7.89
Poor	3.97	2.00	1.23	7.20

METHODS USED IN THE INVESTIGATION

Field methods - In any study of the progressive development of vegetation, the best and most accurate method of investigation is by the use of permanent sample plots, in which the origin and development of the vegetation may be followed and studied from the initial stages clear through to maturity. The one objection to this method however, is the fact that it requires too long a time to secure data, and often results of an investigation are desired quickly. Therefore, a method of alternating areas is most practicable for such a study. This method involves laying out sample plots in which the various stages of development are represented on different areas.

The method of alternating areas was used in this study. The plots laid out were 1/25 acre in size, and rectangular in shape (13.2' x 132.0'). This size and shape was used because it was most satisfactory and convenient for the areas studied. The plots were laid out with a steel tape and a measuring pole 6.6 feet long. The chain was stretched across the area chosen for the location of the plot and then with the use of the pole it was possible to determine the outer limits of the plot.

The data were collected from plots located on areas which had not been burned nor grazed since the time of cutting. It was

not always possible to definitely determine whether or not the area had been grazed, but no plots were established where there was evidence of grazing. Only areas which had been cut over during the winter or early spring were selected in this study, and the information regarding the time of cutting was obtained from the owner of the woodlot and then checked, where possible, by an inspection of the parent stumps. The plots were limited to the northern or eastern slopes of ridges, and to soils varying from a stony loam to a sandy loam. The soil was classified ocularly. The plots were further limited to areas which had been clear cut, and consequently, only even-aged stands were considered.

It was desirable, in order to study development, to lay out plots on areas which had been cut over for various lengths of time. Plots were established and measurements taken on areas which had been cut 1, 2, 5, 10, 17, 22, and 34 years earlier. A total of 53 plots were established which included measurements on 1854 stumps.

The data collected included: species, height, diameter inside bark, age, condition, origin, total number of sprouts, number of dominant sprouts, average height, and average diameter breast high of the dominant sprouts for each stump occurring on the plot. Then location of plot, age class of sprouts (number of years after cutting), and date were also recorded. Measurements taken on each plot were tallied on separate sheets.

Office methods - In handling the data, the first step necessary was to group it according to species and number of years after cutting. Then a further grouping was made according to stump diameter, stump

height and stump age classes. Averages were obtained for each set of measurements in each of the groups and these averages plotted on coordinate paper. Smooth curves were drawn and then tables prepared from values read directly from the curves. No curves or tables are presented where insufficient data did not permit their construction, or where correlations could not be established between certain factors. However, the conditions as they existed are included in a short discussion.

RELATION BETWEEN NUMBER OF DOMINANT SPROUTS AND TOTAL NUMBER OF SPROUTS PER STUMP.

Competition for light and food normally causes high mortality among the sprouts produced, and the dominant sprouts at the end of the first year are probably the only ones which will survive for any length of time.

The aim in this phase of the study was to determine the number of dominant sprouts per stump and the ratio between the number of dominant sprouts and the total number of sprouts per stump.

Measurements were taken on 543 stumps of seven species, one year following cutting. The total number of sprouts and the number of dominant sprouts were recorded for each stump. No distinction was made as to height, diameter, age, or condition of the parent stump, since it was believed that the effect of these factors was more or less compensating and that the combined effect was more important than the effect produced by any single factor. The data were grouped by species into classes based on the total number of sprouts, viz. - 1 - 10, 11 - 20, etc. Averages were computed for the total number

of sprouts and the number of dominant sprouts for each class. These averages were then plotted on coordinate paper with number of dominant sprouts as the ordinate and total number of sprouts as the abscissa. Smooth curves were drawn and Table I was prepared by reading values directly from the curve.

TABLE I. - Relation between total number of sprouts and number of dominant sprouts per stump at age of one year.

		Total number of sprouts										No. stumps	
Species		Dominant	10	20	30	40	50	60	70	80	90	less than 40	total
		sprouts	:	:	:	:	:	:	:	:	:	:	:
chestnut	number	:	2.2	3.1	3.3	3.5	4.4	5.3	6.3	7.2	:	221	240
oak	per cent	:	22.0	15.5	10.6	8.8	8.8	8.8	9.0	9.0	:	:	:
white	number	:	2.2	3.6	4.2	4.5	4.4	4.1	4.2	5.2	5.5	40	44
oak	per cent	:	22.0	18.0	14.0	11.3	8.8	6.8	6.0	6.5	6.1	:	:
scarlet	number	:	2.1	3.4	4.2	5.0	5.2	5.0	5.5	6.8	8.5	87	100
oak	per cent	:	21.0	18.0	14.0	12.5	10.4	8.3	7.9	8.5	9.4	:	:
red	number	:	2.5	4.2	5.5	5.2	4.9	5.5	6.5	:	:	14	17
oak #	per cent	:	25.0	21.0	18.3	13.0	9.8	9.2	9.2	:	:	:	:
black	number	:	2.2	3.2	4.1	4.9	5.5	6.1	:	:	:	4	7
oak	per cent	:	22.0	16.0	13.7	12.3	11.0	10.2	:	:	:	:	:
red	number	:	2.4	3.2	4.0	5.3	6.3	6.5	5.9	4.7	:	121	126
maple	per cent	:	24.0	16.0	13.3	13.2	12.6	10.8	8.4	5.9	:	:	:
hickory	number	:	1.7	2.8	3.9	4.8	5.7	6.5	7.3	:	:	7	8
sp. #	per cent	:	17.0	14.0	13.0	12.0	11.4	10.8	10.4	:	:	:	:

Based on two year old sprouts. * stumps with less than 40 sprouts

A study of Table I brings out certain interesting relations. There is an increase in the number of dominant sprouts as the total number of sprouts per stump increases, but the percentage of dominant sprouts decreases as the total number of sprouts increases. This may be explained by the fact that as the total number of sprouts increases, competition for light and food becomes more keen. The result is that proportionally fewer sprouts are vigorous and dominant.

There is little or no difference in this relationship between the various species studied. Chestnut oak, which is probably the least tolerant species has a slightly lower percentage of dominant sprouts than red maple which is probably the most tolerant of the species studied. An exception to this statement is found in the two upper classes where the data were meager. The data for red oak and hickory are based on 2 year old sprouts and consequently can not be directly compared with that for the other species.

Most of the stumps produced less than 40 sprouts, and only a few produced more than 40 sprouts. Two hundred twenty one chestnut oak stumps produced less than 40 sprouts each and only 19 stumps produced more than 40 sprouts each. In the case of red maple, 121 stumps produced less than 40 sprouts and only 5 stumps produced more than 40 sprouts.

RELATION BETWEEN THE HEIGHT OF DOMINANT SPROUTS AND THE TOTAL NUMBER OF SPROUTS PER STUMP.

It was believed by the writer that the number of sprouts produced by a stump would have an influence upon the height growth of the dominant sprouts, especially during the early years of growth. This phase of the study was carried out for the purpose of determining just what correlation did exist between height growth and total number of sprouts per stump.

The study was made on two year old sprouts because insufficient data did not permit the use of one year old sprouts. Data were obtained on 270 stumps of various species. The total number of sprouts were counted and the height of the dominant sprouts was

measured. No distinction was made as to height, diameter, age, or condition of the parent stump.

The data were grouped by species into classes of total number of sprouts per stump. Averages were computed for the total number of sprouts and the height of the dominant sprouts for each class. These averages were then plotted on coordinate paper with height of dominant sprouts as the ordinate and total number of sprouts as the abscissa. Smooth curves were drawn and Table II was prepared by reading the values directly from this curve.

TABLE II. - Relation of total number of sprouts from stumps of various species and the height of dominant sprouts at two years of age.

Species	Total number of sprouts per stump								number of stumps
	10	20	30	40	50	60	70	80	
	Average height in feet of dominant sprouts								
chestnut oak	5.2	5.5	5.8	5.8	6.1	6.3	6.6	7.1	47
White oak	4.2	4.6	5.0	5.5	5.8	6.0	6.2		43
scarlet oak	4.4	4.9	5.7	6.4	6.4	6.4			40
red oak	4.4	5.8	6.8	6.0	5.7	6.6			17
black oak	4.6	5.0	5.7	6.3					3
red maple	5.1	5.4	5.7	5.9	5.7	5.6			112
hickory sp.	2.5	2.6	2.8	3.0	3.2	3.4			8

The dominant sprouts increase in height as the number of sprouts per stump increases as in shown in Table II. This may be explained by, (1), the same vigor that results in a stump producing a large number of sprouts also causes the sprouts to grow more rapidly in height for at least the first few years, and, (2), competition for

light must be very keen, and rapid height growth results from the attempt of the dominant sprouts to obtain more light.

In a comparison of the effect of total number on height of dominant sprouts in different species, it is shown that chestnut oak gradually loses its high rank in rate of height growth as the total number of sprouts per stump increases. In the case of stumps producing 10 sprouts, chestnut oak shows greater height growth than any of the remaining species; it is closely followed by red maple. In the following two classes chestnut oak falls to second place, being surpassed by red oak. Finally, in the group for stumps with 40 sprouts, chestnut oak falls to fifth place in rate of growth. Due to the small number of stumps producing more than 40 sprouts, the remaining values are not considered. Red maple shows the same general trend as chestnut oak. Scarlet oak and red oak show an opposite trend, while white oak and hickory remain throughout as the slower growing species.

RELATION BETWEEN STUMP DIAMETER (INSIDE BARK) AND THE TOTAL NUMBER OF SPROUTS IN VARIOUS SPECIES.

Diameter of the parent stump was believed to be an important factor which influenced sprouting capacity. Diameter, while probably closely related to age, is much easier to study in its relation to sprouting capacity. It also seems more practical than the age of the parent tree for use in management. Sprouting capacity was measured by the number of sprouts produced, instead of by the height of the dominant sprouts as has been done by Zon (23),^{and} Spaeth (18). Spaeth (18) and Averell (1) have also expressed the sprouting capacity of various hardwoods as the percentage of the stumps that had sprouted.

In this study measurements were taken on 285 stumps of various species. The diameter inside bark was measured because in many cases the bark of the stump was partly or entirely missing, and did not permit measurement of diameter outside bark. The data were grouped by species into one-inch stump diameter classes. Averages were computed for total number of sprouts and diameter of stump for each diameter class. These averages were then plotted on coordinate paper with number of sprouts as the ordinate and diameter of the stump as the abscissa. Smooth curves were drawn and Table III was prepared by reading values directly from these curves. Table III was prepared from data obtained from two year old sprouts because insufficient data did not permit the use of one year old sprouts.

TABLE III. - Relation between stump diameter and total number of sprouts in various species.

stump dia. # inches	chestnut: oak	white: oak	scarlet: oak	red: oak	black: oak	red: maple	hickory: sp.
	Total number of sprouts per stump at 2 years of age						
1	11.1					9.2	
2	14.2	10.5				13.5	
3	15.1	12.8				18.0	5.0
4	15.5	15.5		9.2		23.0	6.0
5	18.5	19.5	6.0	19.2		29.2	7.5
6	21.0	24.5	15.2	26.8		39.3	11.8
7	24.5	32.2	18.6	32.2	15.0	46.0	19.8
8	28.0	36.0	20.0	37.2	15.7	51.8	31.5
9	30.5	34.0	20.2	39.3	18.5		44.0
10	32.3	22.5	21.0	39.2	23.0		56.5
11	33.0	18.8	23.0	37.8	28.5		
12	32.7	16.3	26.3	35.5	35.0		
13		13.5	30.7	32.0			
14		11.3	35.5	28.3			
15		9.5		24.2			
16				20.0			
No. stumps	47	46	45	23	3	112	9

diameter inside bark.

Table III indicates that stumps produce a greater number of sprouts, up to a certain point, with increases in stump diameter. Above this point, there is a reduction in the number of sprouts produced. This reduction is shown for chestnut oak, white oak, and red oak. The remaining species do not show any such downward trend, possibly because of insufficient data. The diameter at which the maximum number of sprouts are produced varies with the different species. For chestnut oak the greatest number of sprouts are found on stumps about 11 inches in diameter. White oak shows maximum production on stumps 8 inches in diameter, and red oak produces the maximum number on stumps with a diameter of 9 inches.

Scarlet oak shows a greater capacity for sprouting than any of the other species. At a diameter of 14 inches scarlet oak is still on the increase in relation to number of sprouts produced. White oak shows the poorest capacity for sprouting since after a stump diameter of 8 inches is attained this species begins to decline in number of sprouts produced.

These data compare favorably with the results reported by Zon (23). He obtained measurements on 1342 white oak and 1306 black oak sprouts and found that the greatest height growth of the dominant sprouts was produced in white oak from stumps 7 to 9 inches in diameter. In black oak he found the most vigorous sprouts on stumps between 10 and 15 inches in diameter.

Spaeth (18) states in the summary of his table on the sprouting capacity of various hardwoods, that after reaching eight inches, white oak, white elm, red maple, and swamp white oak show a marked decline in capacity.

RELATION BETWEEN THE STUMP AGE AND TOTAL NUMBER OF SPROUTS IN
VARIOUS SPECIES.

Measurements were taken on 413 stumps in order to learn the effect of age of parent stump upon sprouting capacity in the different species. Table IV was prepared in a manner similar to that used in preparing the preceding tables. Table IV is based on one year old sprouts with the exception of red oak which is for two year old sprouts.

TABLE IV. - Relation between the stump age and total number of sprouts in various species.

Species	Age of parent stump										No. stumps
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	
	Total number of sprouts one year old										
chestnut oak	1.4	7.6	14.4	20.1	25.0	29.3					239
white oak	3.6	8.8	13.6	17.9	20.3	21.8					48
scarlet oak	2.0	5.2	18.9	23.0	24.9	26.1	26.9				103
red oak #					22.2	23.6	24.8	25.8	26.6	21.4	16
black oak	1.3	3.0	6.5	11.0							4
hickory sp.	1.0	2.0	3.0	4.0	5.3	6.7	8.0	9.4	11.0		3

Based on two year old sprouts.

Table IV indicates that sufficient data were not obtained in order to determine the age at which maximum production occurred. All species (red oak excepted), show a constant increase in number of sprouts with increase in age. Red oak (2 years old) shows a maximum production of sprouts at an age between 91 and 100 years. Greeley and Ashe(9) in their study of white oak state, "In most localities an age of 120 years marks the limits of vigorous sprouting capacity." Foster and Ashe (5) in their study of chestnut oak state,

"The sprouting capacity is determined more by age and vigor than by size. Under the most favorable conditions of growth, vigorous trees sprout until 150 or even 200 years old, or until they are from 16 to 18 inches in diameter. Stunted trees and those growing under unfavorable conditions, as on thin rocky soil or high ridges, sprout feebly when more than 120 years old and 12 to 14 inches in diameter."

RELATION BETWEEN STUMP HEIGHT AND TOTAL NUMBER OF SPROUTS IN VARIOUS SPECIES.

In order to determine the effect of stump height on sprouting capacity measurements were taken on 538 stumps with one year old sprouts, 281 stumps with two years old sprouts, and 357 stumps with five year old sprouts. The total number of sprouts were counted on each stump and measurement was made of stump height. The data were grouped by species and age of sprouts into .5 foot stump height classes. Averages were then computed for the height of stump and total number of sprouts in each class.

No tables or graphs are presented on this study because a correlation could not be established with the data obtained in any of these three age classes. This lack of correlation is probably due to the fact that only a small range in stump height existed. Only four stump height classes were established since all stumps were less than 2 feet in height. Most of the data was for stumps which varied in height between .6 and 1.5 feet.

Zon (22) showed in the following table the relation between the height of the stump and the height of the predominating shoot when one year old:

Table of data:

Ht. of stump, ft.	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
Ht. of predom. shoot, ft.	5.3	4.7	4.3	4.0	3.8	3.7	3.7	3.6

He states, "Stumps 1 foot high show the best results and, from the general tendency of the sprouts to decrease in height with increase in stump height, one may infer that the lower the stump the more vigorous the sprouts."

RELATION BETWEEN NUMBER OF YEARS AFTER CUTTING AND THE TOTAL NUMBER OF SPROUTS IN VARIOUS SPECIES.

This relationship was studied in order to determine and compare the survival of sprouts in the various species, as it might influence the composition of the mature stand.

The total number of sprouts were counted on 1854 stumps which had been cut 1, 2, 5, 10, 17, 22, and 34 years earlier. These data were grouped by species and age of sprouts. An average was computed for the total number of sprouts per stump of each species for each period since cutting. These averages were then plotted on coordinate paper and smooth curves drawn. The curves are presented in Figure 1.

These curves show clearly that the mortality among the sprouts of all species is very high up to an age of about 8 or 10 years, and that the greatest mortality is between the ages of 1 and 5 years. Scarlet oak, however, is the exception, since the curve shows its highest mortality to be during the first 3 years.

Other important facts indicated by these curves are that:-

1. Red maple and chestnut oak have the greatest survival of any of the species over the period of 34 years, and that these two species have a very low mortality after reaching 15 years of age.

2. Black oak and hickory have the poorest survival of any of the species. Too much emphasis should not be placed on these species however, since their curves were drawn from a rather small number of measurements.
3. Red oak has a comparatively high mortality up to an age of about 30 years.

The curves show very definitely why sprout hardwood stands in this region are composed so abundantly of chestnut oak and red maple. As may be seen from the number of stumps of each species measured, the composition of the stands is almost identical with the survival of the various species at the age of 35 years. It is very likely that for older stands of sprouts this correlation would be perfect.

RELATION BETWEEN NUMBER OF YEARS AFTER CUTTING AND NUMBER OF SPROUTS
(ALL SPECIES) PER ACRE.

This study was made in order to show the survival of sprouts of all species on an acre basis. Measurements were taken on 53 plots of 1/25 acre each in size and included a total of 1854 stumps. The plots were distributed over areas which had been cut over 1, 2, 5, 10, 17, 22, and 34 years earlier. The total number of sprouts were counted on each plot and then converted to an acre basis for each of the age classes. The figures were then plotted on coordinate paper and a smooth curve drawn which is presented as Figure 2.

Study of the curve shows that the highest mortality is during the second and third years. Approximately 21,000 sprouts per acre are present at the end of the first growing season whereas approximately 9,000 are present at the end of three years. Between 3 years and 25 years of age there is a decrease of approximately

7,500 sprouts per acre, and from 25 years onward the mortality is comparatively low.

RELATION BETWEEN NUMBER OF YEARS AFTER CUTTING (AGE OF SPROUTS) AND HEIGHT OF DOMINANT SPROUTS IN VARIOUS SPECIES.

This study was made to learn and compare the rate of height growth of the various species. Measurements were obtained from 1715 stumps of various species with sprouts 1, 2, 5, 10, 17, 22, and 34 years of age. Curves were prepared in a manner similar to that used in the construction of Figures 1 and 2. These curves are presented as Figure 3.

A study of the curve will show that:-

1. There is very little difference in the growth rate of the various species during the first few years. The difference in growth rate of the various species becomes more pronounced as the sprouts increase in age. Differentiation begins at about 10 years of age.
2. All species show a rapid growth rate up to about 15 years of age. After that period, the growth rate is not so rapid.
3. Red oak is shown to be a more rapid grower than any of the other species.
4. Hickory is shown to be the slowest growing species of the group, although the curve here presented is based on a small number of measurements.

The results shown by these curves compare favorably with the results obtained by Zon (23), Boisen and Newlin (3), Korstian and Stickel (12), Leffelman and Hawley (13), Graves (7), and Mattoon (14).

RELATION BETWEEN NUMBER OF YEARS AFTER CUTTING (AGE OF SPROUTS) AND
DIAMETER BREAST HIGH OF DOMINANT SPROUTS IN VARIOUS SPECIES.

As a means of further showing the difference in vigor and rate of growth of sprouts of various species, a study was made of the relation between number of years after cutting and the diameter breast high of the dominant sprouts. For this study measurements were taken on the sprouts of 893 stumps which had been cut 5, 10, 17, 22, and 34 years earlier. Curves were prepared and are presented as Figure 4.

The important facts brought out by these curves are that:-

1. The difference in diameter growth becomes more pronounced as the sprouts increase in age.
2. The rate^{of} diameter growth decreases after an age of about 13 years is reached. This was also approximately the period at which the rate of height growth decreased.
3. Hickory shows very slow diameter growth in comparison with the other species.
4. Red oak and black oak, which were shown to have the greatest height growth also show the greatest and most rapid diameter growth.

Results similar to those shown here have been obtained by Zon (23) and Graves (7).

SILVICULTURAL APPLICATION

This study has brought out several important facts which may be applied in the management of sprout hardwood stands. Sprout reproduction may be successfully obtained from most of the hardwood species, but some species are more prolific sprout producers than others. Of the species occurring in this region, those possessing the greatest sprouting capacity were found to be chestnut oak, red maple, scarlet oak and red oak. The species of oak are of great commercial importance and their reproduction should be encouraged. The one serious competitor of the oaks however, appears to be red maple. Due to its high sprouting capacity and its silvical habits, this species has crowded out other more desirable species. White oak and hickory are important species and yet their capacity for sprouting is low, and their growth rate comparatively slow. This indicates that if these species are desired in the final cutting, some other means of reproducing them must be resorted to.

A short rotation is advisable in managing a sprout forest and the products obtained from sprouts should be chiefly minor products such as ties, props, posts and poles. If long rotations are used, much timber is subject to waste due to butt rot, and sprout reproduction is apt to be poor. It has been shown that the sprouting capacity of chestnut oak, white oak, and red oak becomes less after the parent tree has attained a diameter of about 10 inches at stump height.

Stands of oak should be clearcut for sprout reproduction since the oaks are intolerant and require abundant light for best development. The stumps should be cut low and smooth, and care must

be taken not to strip the bark from the stump at the time of cutting. Winter or early spring is probably the best time to cut the timber, since poor reproduction is obtained if the cutting is made during the late spring or summer months. Young sprout stands should be protected from fire and grazing. Fire, of course, will do damage to stands at any age, but greatest damage is done when the sprouts are young. Grazing is not desirable until the sprouts have attained a height of 8 or 10 feet which is equivalent to an age of about 5 years.

The height growth of sprouts is very rapid during the first 15 years. After that period, the growth rate in both diameter and height becomes less. It is probable that a thinning at the age of about 15 years would increase the rate of growth since it has been shown that at this age there are about 2400 sprouts per acre, which average about 20 feet in height and about 2 inches in diameter breast high. This overstocking is probably one of the factors which causes slow growth and poor form among so many of the trees in the mature sprout stand. An important factor that should be considered when a thinning is made is the point at which the sprout arises from the parent stump. The resistance of a sprout to wind and snow damage is largely determined by this factor. A good example of this occurred during a heavy snow storm in the spring of 1929. On the permanent plots established in a stand of 18 year old black locust (Robinia pseudoacacia) at the Pennsylvania State College, many sprouts were damaged by the snow. It was noted that those sprouts arising at or near the top of the stump were more seriously damaged than those arising from the root collar or near the base of the stump.

SUMMARY

A large proportion of the timber of central Pennsylvania is of sprout origin. Most of the products obtained from this timber are in the form of ties, props, posts, and poles which are used locally or transported short distances. The species which are found most abundantly and which have the greatest commercial value are chestnut oak, scarlet oak, red oak, black oak, white oak, red maple and hickory.

A study of the sprouting capacity of these species has brought out the following facts:-

1. There is an increase in number of dominant sprouts as the total number of sprouts per stump increases, but the percentage of dominant sprouts decreases as the total number of sprouts increases.
2. Most of the stumps produce less than 40 sprouts each, of which 5 or less are dominant.
3. The dominant sprouts increase in height as the total number of sprouts per stump becomes greater.
4. The stumps produce a greater number of sprouts, up to a certain point, with increases in stump diameter.
5. Increases in age of the parent tree, up to a certain point, are accompanied by greater numbers of sprouts.
6. There is no correlation between stump height up to 2 feet and the total number of sprouts produced.
7. Red maple and chestnut oak have the greatest survival of any of the species over the period of 34 years; these two species have a very low mortality after reaching 15 years of age.

8. Black oak and hickory have the poorest survival of any of the species.

9. The highest mortality among the sprouts of all species occurs during the second and third years.

10. There is little difference in rate of height growth or diameter growth the first few years. Differentiation begins at about 10 years of age, and from then on the difference in growth rate of both diameter and height of the various species becomes more pronounced.

11. Growth is rapid up to an age of about 15 years. After that period, the rate of growth of all species decreases.

12. Red oak, black oak, and scarlet oak are the most rapid growing species; red maple and hickory are the slowest growing species.

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