ADVANCING ESTABLISHED NATURAL WHITE OAK (*QUERCUS ALBA*) REPRODUCTION THROUGH A MIDSTORY REMOVAL

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ABSTRACT

A midstory release was used to enhance naturally established white oak (*Quercus alba*) seedlings that resulted from a previous bumper acorn crop at the Forest Resources Research and Education Center in Oak Ridge, TN, during the summer of 2020. Total number of species, height classes, and photosynthetically active radiation were collected on the plot level and height and root collar diameter (RCD) were collected on the subplot level over two complete growing seasons. White oak seedlings receiving the release treatment showed significant differences in percent height and RCD growth on the subplot level as well as significant changes in height classes on the plot level following each growing season and from the first to last year of the study compared to the control. The percentage of light received following the midstory removal was not a significant predictor of percent height growth after two growing seasons.

INTRODUCTION

White oak (*Quercus alba*) is a keystone species within our eastern forest ecosystems. A myriad of benefits, including hard mast and habitat for wildlife species, valuable lumber to society, and vital ecosystem services such as soil stabilization, air purification, and the sequestration of carbon are provided by white oak (Cavender-Bares 2016). Oak ecosystems spread across 46 million hectares (Loftis 2004) which makes up over half of eastern forests (Dey 2014b). However, the ability of white oak to successfully regenerate and recruit into the upper canopy is currently threatened.

Due to the vast shifts from historically frequent disturbance regimes over the last century, forest microclimates have been drastically transformed to foster many of the major shade-tolerant oak competitor species. Without the occurrence of frequent disturbances, dense midstory canopies are formed which obstruct light from reaching the forest floor. This has resulted in the competitiveness of white oak regeneration across its historically dominated sites to be drastically reduced.

White oak possesses many physiological adaptations in response to its relationship to disturbance. These adaptions should be utilized to implement successful silvicultural treatments. Decades of scientific studies have documented that adequate size and number of advance reproduction is necessary to regenerate oak (Clatterbuck 2019, Loftis 1990, Sander 1972). A midstory release can be a practical option to recruit seedlings into the future upper canopy (Hackworth and others 2020). By providing these suitable levels of diffuse light to the forest floor, white oak seedling competitiveness should increase. This study investigates growth and development of advance reproduction of white oak from a midstory removal for two growing seasons following a bumper acorn year.

METHODS

Study Site

This study was initiated in the summer of 2020 across the grounds of the Forest Resources Research and Education Center (FRREC) in Oak Ridge, TN. The forest within the study area was

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two-aged and the upper canopy was dominated by white oak. The average diameter at breast height (d.b.h.) for these overstory white oaks ranged from 51 to 90 cm. Their heights ranged from 26 to 37 m. Basal area ranged from 6.5 to 7.8 m^2/ha across all sites.

Species such as hickory (*Carya* spp.), chestnut oak (*Quercus montana*), northern red oak (*Quercus rubra*), and shortleaf pine (*Pinus echinata*) also composed the upper canopy class. The intermediate and midstory canopy classes consisted of American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), sweetgum (*Liquidambar syraciflua*), yellow-poplar (*Liriondendron tulipifera*), black cherry (*Prunus serotina*), eastern redbud (*Cercis canadensis*), dogwood (*Cornus florida*), sourwood (*Oxydendrum arboreum*), and black gum (*Nyssa sylvatica*).

In addition to the substantial amounts of white oak advanced reproduction, mostly from the 2019 acorn bumper crop, there were also seedlings present of species such as maple, hickory, dogwood, oak, sassafras (*Sassafras albidum*), American beech, sweetgum, yellow-poplar, black cherry, shortleaf pine, American holly (*Ilex opaca*), blackgum, eastern redbud, umbrella magnolia (*Magnolia tripetala*), locust (*Robinia* spp.), and elm (*Ulmus* spp.). Estimated ground coverage in these closed canopy stands was sparse, <20 percent. Heavy leaf litter, rocky topsoil, and coarse woody debris were all present on the forest floor. Soils were predominately composed of well-drained Fullerton-Pailo complex with varying slopes ranging from 5 to 35 percent (USDA NRCS 2023). All plots were homogenous in their soil profiles, vegetation and tree species compositions, abundance of white oak advance reproduction, and site productivities.

Study Installation and Design

Plots were subjectively placed in areas containing large quantities of white oak advance reproduction in the summer of 2020. A total of twenty-six 2-m by 2-m plots and fifty-two 0.5-m by 0.5-m subplots were installed prior to receiving the designation of control or release treatment. Three to four plots were installed at four release treatment locations while one to four were installed at seven control locations, but each plot always contained two subplots within it. Both plots and subplots were evenly divided into control and release treatment groups. The total area representing all 26 plots was 104 m^2 and the subplot total area was 13 m^2.

The four plot location areas received a midstory removal treatment in the summer of 2020 that averaged 0.04 to 0.08 ha. Midstory tree species that produce copious amounts of seed annually such as maple, American beech, yellow-poplar, and black cherry were targeted by felling and/or girdling with a chainsaw. In addition, stumps were treated with a 50-percent glyphosate solution to deter sprouting. One to four dominant or codominant white oak trees were retained at release areas to provide future seed source as well as cast some shade on seedlings. The basal area remained within the range of 6.5 to 7.8 m^2/ha in both the release and control treatments, suggesting that the midstory release did not remove overstory basal area. Age, diameter, and height of overstory trees remaining after the midstory treatment were measured.

Data Collection

Growth and light measurements taken in June to July of 2020 served as a baseline to compare each of the two complete growing seasons (2020–2021 and 2021–2022). Woody species were counted within each plot. Seedlings within the plot were further categorized into height classes (<30.5, 30.5 to <70, 70 to <91.4, and 91.4 to 122 cm). Nonwoody ground vegetation composed less than 5 percent of the ground coverage and was not measured.

An aluminum tag with a unique identifier was attached with galvanized wire at the base of each seedling within the subplots. Seedling heights were measured from the ground to the apical bud using a meter stick. Digital calipers were used to measure root collar diameter (RCD) where the base of the seedling stem met the soil. These measurements were taken prior to the application of the release treatment in June through July of 2020 and were repeated at the end of the next two growing seasons in September through October. Subplot species with missing tags were assumed to be either missing or dead and removed from the data.

An AccuPAR model LP-80 ceptometer (Meter Group®, Pullman, WA) was implemented to collect photosynthetically active radiation (PAR) measurements on control and release plots. These measurements were taken twice a year from 2020 to 2022 during July through August on two overcast-free days, with the exception of control plot location 11, which was not installed until the fall following the summer release cut.

The ceptometer was calibrated prior to the start of each year's data collection and light measurements were taken at sternum height (1 m) above the ground during solar noon from 12:00 to 2:00 p.m. Eastern Time. Prior to taking measurements at each plot location, a baseline PAR reading was taken consistently in an exposed, open area of full sunlight at the FRREC adjacent to plots. A total of eight light readings were taken on each plot to order to ensure consistency over 2 days. Four of these PAR measurements were taken from plot center facing outward. The remaining four measurements were taken from each corner facing inward to the plot center.

Data Analysis

Data were analyzed in the R statistical package (R Core Team 2012) with the two complete growing seasons as well as between the first year's baseline measurements and last year (2022). A Wilcoxon test was applied to examine the subplot level effects of the midstory release, comparing average height and RCD between treatments within each growing season as well as the first to the last year, regardless of species. In addition, the average percent height and RCD growth of white oak and maple seedlings were compared between treatments by growing season as well as the first to last year. Seedlings that were missing a tag or were otherwise dead, were removed from the dataset across all years for analysis involving average percent growth, but not for comparisons of average measurements. A *P*-value <0.05 indicated a statistically significant difference. A chi-square test of independence compared plot-level proportional abundance between white oak and maple seedlings by treatment and growing season as well as from the first year to the last year. Proportional changes in white oak and maple seedling height classes between control and release treatments by growing seasons and from first to last year was also analyzed on the plot level. A *P*-value >0.05 indicated proportions were statistically similar.

RESULTS

The average age of white oaks was 122 years with an average height and d.b.h. of 30.5 m and 60 cm, respectively. The site index was estimated to be 21 m at 50 years (USDA NRCS 2023). White oaks composed greater than 70 percent of the total seedlings in the control and release plots initially (2020), maples 18 percent, and miscellaneous species 8 percent (fig. 1). Red maple and sugar maple were grouped together into a maple category for the analyses. Through subsamples, red maple composed approximately 70 percent, and sugar maple 30 percent, of the maple category.

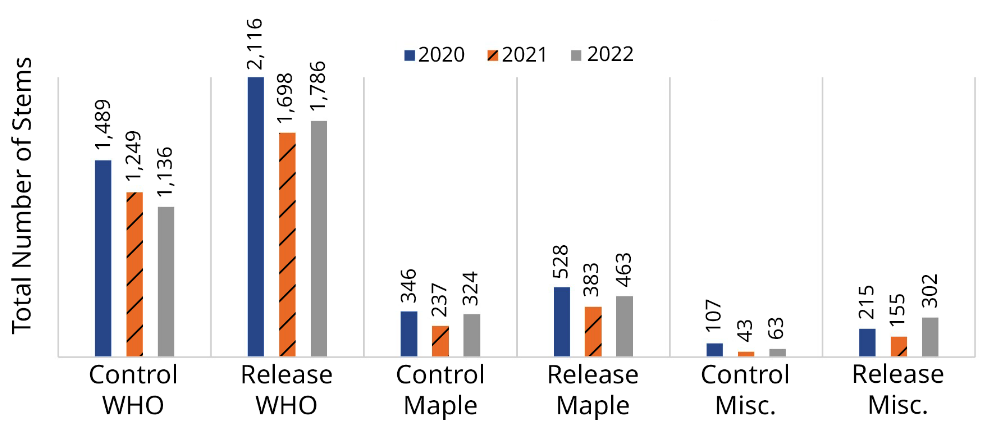

Figure 1—Plot level abundance by treatment and year for white oak (WHO) and maple. Miscellaneous species included chestnut oak, black cherry, hickory, sassafras, beech, northern red oak, black oak (*Quercus velutina*), black gum, dogwood, sweetgum, elm spp. , locust spp., and sourwood.

Only white oak and maple were considered in this research due to their abundance. A total of 782 seedlings were tagged across 52 subplots during the summer of 2020. At the end of the growing season, in the fall of 2022, there was a total of 557 tagged woody seedlings remaining (table 1). A total of 4,801 seedlings were counted across all 26 plots in the summer of 2020. By the conclusion of this study, in the fall of 2022, there were 4,074 seedlings counted (fig. 1).

Response of White Oak

A total of 624 white oak seedlings were tagged at the start of this study in the summer of 2020. At the conclusion of this study, in the fall of 2022, there were 492 seedlings (table 1). The midstory removal treatment observed proportional changes in white oak seedlings that advanced into the taller height classes on the plot level over the two complete growing seasons as well as from the first to last year (table 2). From 2020 to 2021 (P <0.0001) and 2021 to 2022 (P <0.0001), release treatment height classes did not show similar distribution proportions. This same trend was also observed in the first (P = 0.0112) and second (P = 0.0031) complete growing season in the control treatment plots. Changes in height class distributions between the first base year and last year were also not proportionally similar in control (P <0.0001) or release (P <0.0001) treatment plots. Changes in plot-level height classes were proportionally similar between release and control treatments in 2021 but not in 2022 (P <0.0001).

Table 1—Total number of tagged white oak and maple seedlings by treatment and year on the subplot level

Treatment and species	2020 (baseline)	2021	2022
Release	462	334	312
White oak	354	273	265
Maple	78	47	33
Control	320	275	245
White oak	270	251	227
Maple	30	14	11
Total	782	609	557

The midstory release treatment appeared to affect the average percent growth of white oak height and RCD on the subplot level following each growing season as well as from the first to last year of this study (table 3). When comparing control to release subplot level treatments between 2020 and 2021 (P <0.0001), between 2021 and 2022 (P <0.0001), and between 2020 and 2022 (P <0.0001), the percent height growth of white oak seedlings had statistically significant differences between all of them. Similar effects were also observed between release and control treatments after each growing season (P <0.0001, P <0.0224, respectively) as well as from the first to last year (P <0.0001), on the percent growth of RCD. When each growing season was directly compared, average percent changes of white oak RCD growth were statistically different in both release and control subplot treatments (P <0.0001, P <0.0001, respectively). These same statistically significant differences were also observed in white oak average precent height growth between

Table 2—Number of plot-level white oak seedlings in each height class and percent total by treatment and year

		2020 (baseline)		2021		2022	
Treatment and height class		Number	Percent	Number	Percent	Number	Percent
Release	**<30.5 cm**	2,011	95	1,532	90	1,470	82
	30.5–70 cm	105	5	164	9	282	15
	70–91 cm	0	0	2	1	33	3
	91–122 cm	0	0	0	0	1	1
Control	**<30.5 cm**	1,410	95	1,152	92	1,006	88
	30.5–70 cm	79	5	97	8	127	11
	70–91 cm	0	0	0	0	3	1

There were significant (P <0.05) proportional differences after each growing season for both the release and control treatments. Treatments were significantly different from base year (2020) through 2022.

Table 3—Percent height and root collar diameter growth of white oak seedlings by treatment and year

Year and treatment		Height	Root collar diameter
		~~ *percent* ~~~~~~~	
2020–2021	Control	16.5	12.6
	Release	27.2	50.0
2021–2022	Control	10.2	35.2
	Release	16.5	57.1
2020–2022	Control	27.8	59.5
	Release	48.6	98.3

Sample size is 227 white oak seedlings in the control subplots and 265 seedlings in the release subplots.

There was a significant (P <0.05) seedling percent growth increase for released seedlings in height and root collar diameter for each growth period and treatment.

the two growing seasons for both release and control subplot treatments (P <0.0001, P = 0.0002, respectively).

Response of Maple

There was a total of 108 maple seedlings tagged in the summer of 2020, 30 in control subplots and 78 in release subplots (table 1). In 2021 there were 61 seedlings: 14 control and 47 release. By the end of the growing season in 2022 there were a total of 44 maple seedlings left across all 52 subplots: 11 control and 33 release.

Maple also experienced changes in population distributions within height classes from the midstory removal treatment (table 4). Maple receiving the release treatment had statistically significant changes in population distributions of height classes between 2020 and 2021 (P = 0.0285) and between 2021 and 2022 (P = 0.0044) on the plot level. No significant difference in proportional changes of control height classes was observed when comparing 2020 to 2022. However, there was a significant change in release treatment height classes from 2020 to 2022 (P <0.0001). Control maple did not have any significant changes in proportions in height class distributions after each growing season or from the first to last year. There were also no proportional differences in maple height class populations when comparing control to release treatments in both 2021 and 2022.

No significant differences were observed when average percent height and RCD growth were compared between control or release treatments over the two complete growing seasons as well as between the first and last year (table 5). However, when comparing the first growing season to the second, there were significant differences in release treatment height (P = 0.0015) and RCD (P = 0.0019).

Table 5—Percent height and root collar diameter growth of maple seedlings by treatment and year

Year and treatment		Height	Root collar diameter
2020–2021	Control	80.8	39.5
	Release	44.3	75.4
2021–2022	Control	16.8	38.2
	Release	20.8	44.2
2020–2022	Control	76.8	94.8
	Release	127.7	134.3

Sample size is 11 maple seedlings in the control subplots and 33 seedlings in the release subplots.

There was a significant (P <0.05) seedling percent growth increase for released seedling treatment in height and root collar diameter after two growing seasons (2020–2022).

Table 4—Number of plot-level maple seedlings in each height class and percent total by treatment and year

		2020 (baseline)		2021		2022	
Treatment and height class		Number	Percent	Number	Percent	Number	Percent
Release	<30.5 cm	511	97	358	93	299	92
	30.5–70 cm	17	3	25	7	24	7
	70–91 cm	0	0	0	0	1	1
Control	<30.5 cm	326	94	221	93	299	92
	30.5–70 cm	20	6	16	7	24	7
	70–91 cm	0	0	0	0	1	1

There was a significant (P <0.05) proportional difference in the <30.5-cm height class after each growing season for the release treatment only. The release treatment was significantly (P <0.05) different from base year through 2022.

Photosynthetically Active Radiation (PAR)

Light was not found to be a significant predictor of white oak seedling height in either control or release treatment groups after two growing seasons. Figure 2 depicts the range of percent height growth and percent light received for both control and release treatments. White oak seedlings in the release treatment had a much wider range of percent light received and percent height growth compared to the control group. The majority of control seedlings were clustered within the 3- to 10-percent light received and 2- to 42-percent height growth range and release seedlings were clustered within the 5- to 20-percent light received and 10- to 30-percent height growth.

DISCUSSION

The results of this study support the existing literature which suggests, with adequate accumulation of advanced white oak reproduction, a midstory removal treatment can provide a positive stimulus on abundance, vigor, and growth of seedlings (Dillaway and Stringer 2007, Lockhart and others 2000, Lorimer and others 1994, Motsinger and others 2010). White oak held an advantage across the duration of this study on both the plot and subplot level over its only major competitor, maple (fig. 1, table 1) which was likely attributed to a previous large bumper acorn crop season. This level of abundance is a positive indicator that white oak is in a position to maintain its current advantage over local competitors. If these levels of white oak abundance continue to increase or are

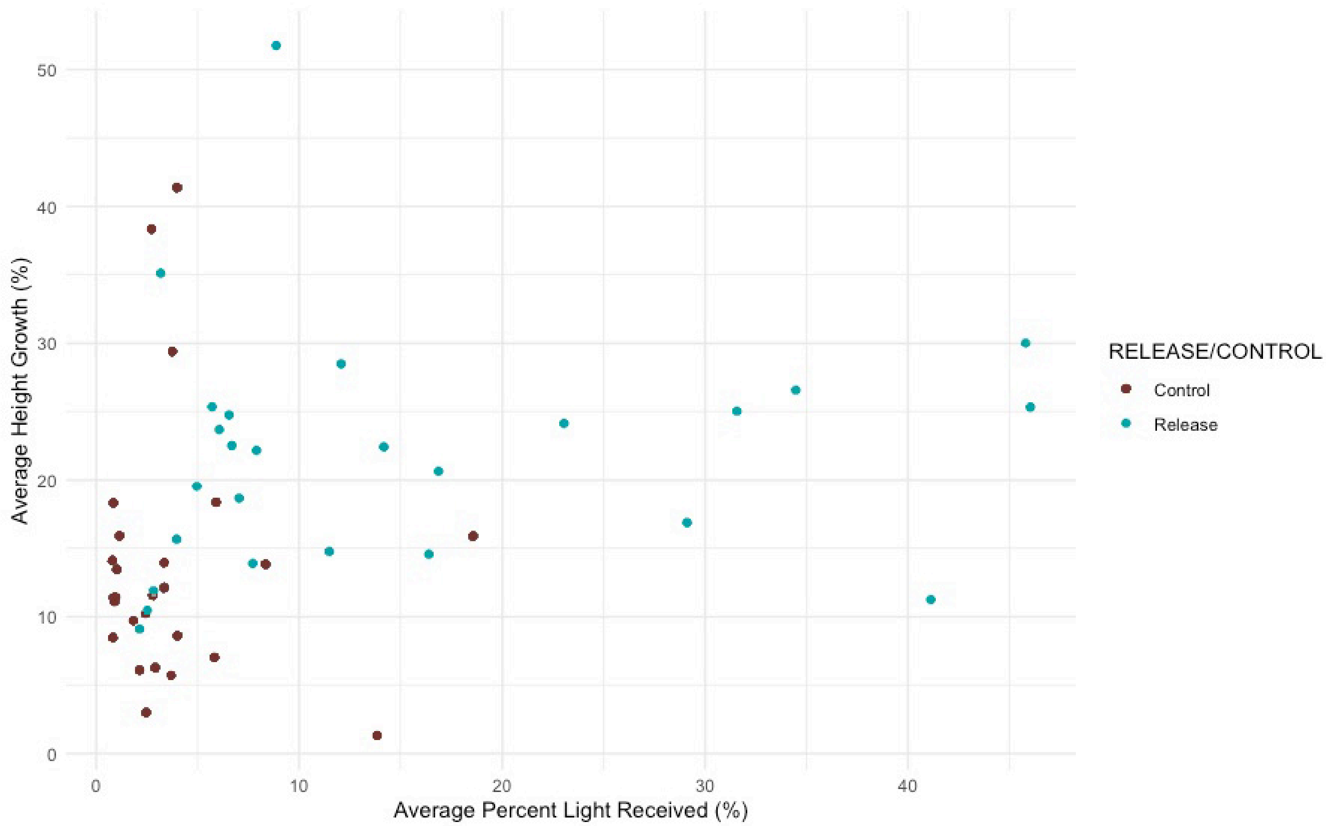

Figure 2—Scatterplot of control and release white oak seedling height growth in response to percent light received. Each point represents average height growth of the two subplots for each plot and the photosynthetically active radiation average of four center plot measurements on one date in 2021 and 2022 (n = 52 plots; 26 control and 26 release).

maintained, unimpeded by competition, the sheer quantity of established white oak seedlings is on track to meet the existing recommendations of Clatterbuck and Hodges (1988), Sander (1972), Sander and others (1976), and Stringer (2016), who suggested having 100–200 large seedlings per 0.4 ha to yield 40–60 mature trees in the future.

The method for plot placement likely caused discrepancies in reported abundance as well. The placement and installation of plots followed the "subjective without preconceived bias" approach described by Clatterbuck (1996), Mueller-Dombois and Ellenburg (1974), and Pfister and Arno (1980) in which the placement of plots was subjectively chosen to sample the landscapes, compositions, and canopy structures present in our study area. This approach allowed areas with abundant white oak advanced reproduction to be sampled and to determine how they would respond to a midstory release. Basal area range measured before and after midstory release and in control treatment were similar, suggesting the midstory release did not create any large gaps in the overhead canopy.

Strong intraspecific competition occurred between advance white oak reproduction (fig. 1). Usually, density of oak saplings is much lower than seedlings, which indicates a bottleneck is occurring between these stages due to competition (Crow 1988, Nowacki and others 1990). Even when white oak is ample in both the overstory and understory, the absence of saplings in the midstory prevents the potential of ingrowth of white oak into the overstory (Clatterbuck 2019, Dey 2014a, Signell and others 2005). A study conducted by Beck (1970) demonstrated that woody and herbaceous competition following an overstory removal cut was not detrimental for the first couple of years but within five growing seasons red oak seedlings were overtopped. A midstory removal or crop tree release could be an effective method to slowly introduce the transmittance of diffuse light through the canopy to continue ascendance of oak into the overstory.

Maple abundance and growth has been observed to quickly catch up to white oak seedlings in response to increasing levels of diffuse light created by a midstory removal. Hartman and others (2005) demonstrated that maple with high abundance overtopped oak in as little as 10 years under a shelterwood system. A study in Kentucky evaluating responses of oak and competitors to a midstory removal reported that red maple had a mean 6-year relative height growth of 459 percent over other oak species and made up 55 percent of seedlings in release treatment plots (Craig and others 2014). Little information is available from the literature on the influence of bumper acorn crops on the success of a midstory release treatment for the growth of white oak advance reproduction and associated competitors. This study provides an opportunity to understand more on the processes involved with successfully culturing large quantities of established white oak reproduction resulting from a bumper acorn crop on average productivity sites. Intraspecific competition among the numerous white oak advance reproduction and the fewer maple may impact maple growth.

For two complete growing seasons since a midstory release, significant shifts in height class distributions of white oak seedlings were observed, which suggests a positive response to the midstory removal treatment (table 2). All plots that received the release treatment had greater relative proportions in the taller height classes after the conclusion of each growing season. Control plots also had increasing height class distribution shifts after each growing season; however, it was less than the release. This is likely due to white oak's intermediate shade tolerance, allowing it to maintain height growth even in lower light levels.

These results are in accordance with the recommendations of Sander (1972), who states that successful oak management can be achieved with an abundance of white oak seedlings with heights >130 cm. After two complete growing seasons no white oak seedlings were in this recommended 130-cm height class. However, if height growth continues at this rate, the 130-cm height class could be achieved in a few years. Percent height and RCD growth of release white oak seedlings on the subplot level were observed to have a response to the increased diffuse light levels created by the midstory removal. There were statistically significant differences in percent height and RCD growth between treatments of white oak seedlings following each growing season as well as from the first to the last year (table 3).

There are limited studies investigating RCD and its influences on successful management. White oak seedlings have a judicious growth strategy when allocating resources below ground during the first year prior to aboveground response (Dillaway and Stringer 2007). In this study as well as a study by (Parrott and others 2012), greater ground line diameters were observed in release treated seedlings. Previous research reports that a midstory removal has direct positive influences on both height and RCD growth, vigor, and abundance of upland oak species for up to 10 years following the treatment (Frank and others 2018, Lhotka and Loewenstein 2013, Lockhart and others 2000, Loftis 1990, Miller and others 2017).

CONCLUSIONS

The response of white oak seedling indicates that there was a positive influence from the increase in light levels created by the midstory removal. In contrast to several other similar studies (Dillaway and Stringer 2007, Parrott and others 2012) investigating the effects of a midstory removal, maple was limited comparatively and did not appear to have serious effects on the competitive success of white oak seedlings after two growing seasons. This suggests that with an abundant accumulation of advanced seedlings provided from a large bumper acorn crop season, white oak can be competitive and find success on average productivity upland sites when diffuse light levels are increased to support increased height growth. Intraspecific competition among the numerous white oak seedlings can also have positive and negative effects on seedling growth.

This research provides a valuable opportunity to understand the preliminary processes involved with bumper acorn crop advance reproduction and the influences that a subsequent midstory removal can have over its recruitment success. White oak was observed to have a positive response in abundance and growth following the midstory removal. Maple growth was also observed to have a positive response to the increased light levels in the release treatments. However, white oak seedling abundance overcompensates the number of maple seedlings by a ratio of 4:1. The midstory release response of maple, though much fewer numbers, was greater than white oak and may necessitate competition control in the future if a crop tree release or shelterwood harvest is implemented.

Alternatively, the overabundance of white oak advance reproduction may discourage the growth of the smaller maple component and influence growth among adjacent white oak stems. Many of the maple present at the plot locations were established prior to the bumper acorn crop season. In addition, maple was only present on a fraction of the plots and subplots. Future studies should investigate both the longer-term growth effects of increased light on large accumulation of bumper acorn advanced white oak reproduction in relation to competitor species such as maple.

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