# STAND AND INDIVIDUAL TREE GROWTH OF MATURE RED OAK AFTER CROP TREE MANAGEMENT IN SOUTHERN NEW ENGLAND: 5-YEAR RESULTS

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**Abstract.**—In winter 2003-04, four oak management study areas were established in Connecticut. Each study area had three 0.62-acre treatment plots: B-level thinning, crop tree, and unmanaged. Each plot was located within a 3- to 5-acre area with similar treatment. The mature red oak sawtimber stands had no prior management and were 80 to 112 years old; upper canopy oaks averaged 17.2 inches in diameter at breast height. All trees larger than 4 inches were permanently numbered and measured annually for 5 years. Basal area was reduced from 138 $ft^2$/acre prior to harvest to 77 and 72 $ft^2$/acre on the B-level and crop tree management plots, respectively. For all size classes combined, basal area growth over the next 5 years was greatest in the crop tree plots, followed by B-level thinning, and finally unmanaged controls. Concurrently, sawtimber basal area growth did not differ among treatments and averaged 1.3 $ft^2$/acre/yr, suggesting management can maintain stand volume growth rates. Relative to 5-yr diameter growth of upper canopy oaks on unmanaged plots (0.9 inches), diameter growth increased by 29 percent on B-level thinning and 54 percent on crop tree management plots to 1.1 and 1.3 inches, respectively. Diameter growth increase was related to degree of crown release. Completely released trees grew more than partially released trees, which in turn grew more than trees that were not released.

## INTRODUCTION

The northeastern and north-central United States has more than 13.3 million acres of 80-yr or older oak-hickory forests (Smith and others 2009). Many of these holdings, especially those less than 50 acres, are managed by family forest owners for non-commodity amenities, such as aesthetics, privacy, and wildlife (Butler and Leatherberry 2004). While owners of these mature oak forests may consider management practices, such as crop tree management, that retain non-commodity amenities to offset ownership costs (e.g., taxes and insurance), there are few guidelines beyond initiating regeneration prescriptions.

Few recent studies have focused on releasing mature oaks (> 80 yr old), in part because of earlier reports that mature trees exhibit little response to thinning (Sander 1977, Hibbs and Bentley 1983, Dale and Hilt 1989). However, most early thinning studies in sawtimber stands were areawide, low thinnings. Low thinning, with its emphasis on removing smaller trees, would not release residual trees sufficiently (on two or more sides) to initiate a positive growth response (Lamson and others 1990). More recent work has shown that high thinning, removing upper canopy competitors on at least two sides, increases diameter growth of 70- to 94-yr-old upland oaks (Smith and others 1989, Smith and Miller 1991, Miller and Stringer 2004, Ward 2008).

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The objective of this study was to compare the response of 80- to 110-yr-old oak sawtimber to B-level thinning and crop-tree management at both the stand and individual tree levels over a 5-yr period.

## STUDY AREAS

In winter 2003-04, four oak management study areas were established in Connecticut in cooperation with the Division of Forestry, Connecticut Department of Environmental Protection and the Metropolitan District Commission. These mature red oak sawtimber stands had no prior management or management limited to removing dead and dying trees for local firewood harvests.

Stand ages ranged from 79 to 112 yr old (Table 1), with some scattered oaks 130 to 195 yr old as a legacy of charcoal cutting and pasturing in the 1800s. Site indices ranged from 60 to 67 ft. Stands averaged 51 sawtimber oaks per acre with a mean diameter of 17.2 inches. Red maple, black birch, and hickory accounted for 63 percent of the remaining 18/acre upper-canopy trees. Stocking ranged from 106-124 percent (Gingrich 1967) with an average of 106 $ft^2$/ac of sawtimber (≥11.0 in. diameter at breast height [d.b.h.]) and 33 $ft^2$/ac of poletimber (4.0-10.9 in. d.b.h.) (Table 2). Oak accounted for 82 percent of upper canopy basal area.

**Table 1.—Mean (standard error) initial tree characteristics in an oak management study for four study areas in Connecticut. Crop trees include trees inside and outside fixed area plots, oak and non-oak sawtimber only include trees inside fixed area plots.**

| | Study areas | | | |
|---|---|---|---|---|
| | Hamden | MDC | TunxisD | Winsted |
| **Crop-trees** | | | | |
| D.B.H. (in) | 20.2 (0.3) | 21.2 (0.3) | 21.5 (0.4) | 20.8 (0.3) |
| Buttlog grade | 1.2 (0.1) | 1.0 (0.1) | 1.0 (0.1) | 1.0 (0.1) |
| Tree height (ft) | 82 (0.6) | 83 (0.8) | 84 (0.6) | 91 (0.7) |
| Sawlog length (ft) | 40 (0.7) | 45 (0.8) | 41 (0.8) | 50 (0.8) |
| Live crown ratio (%) | 30 (0.6) | 31 (0.7) | 32 (0.8) | 28 (0.6) |
| N | 87 | 87 | 84 | 77 |
| **Oak sawtimber** | | | | |
| D.B.H. (in) | 16.3 (0.3) | 18.1 (0.5) | 17.0 (0.4) | 17.4 (0.4) |
| Buttlog grade | 2.1 (0.1) | 1.5 (0.1) | 1.8 (0.1) | 1.4 (0.1) |
| Tree height (ft) | 78 (0.7) | 83 (0.9) | 83 (0.8) | 90 (0.7) |
| Sawlog length (ft) | 33 (1.1) | 42 (1.4) | 37 (1.2) | 48 (1.0) |
| Live crown ratio (%) | 30 (0.7) | 30 (1.0) | 29 (0.7) | 26 (0.5) |
| Tree age (yr) | 95 (0.4) | 112 (3.8) | 90 (3.7) | 79 (0.5) |
| N | 98 | 70 | 114 | 96 |
| **Non-oak sawtimber** | | | | |
| D.B.H. (in) | 14.3 (0.7) | 13.8 (0.4) | 14.0 (0.5) | 14.8 (0.8) |
| Buttlog grade | 3.1 (0.2) | 2.5 (0.2) | 3.1 (0.2) | 2.8 (0.2) |
| Tree height (ft) | 74 (1.7) | 77 (2.0) | 70 (1.5) | 80 (1.6) |
| Sawlog length (ft) | 27 (2.4) | 32 (1.7) | 21 (1.8) | 33 (3.0) |
| Live crown ratio (%) | 39 (2.4) | 41 (2.8) | 46 (3.9) | 40 (3.8) |
| N | 31 | 44 | 30 | 23 |

**Table 2.—Mean (standard error) basal area ($ft^2/ac$) of residual and harvested trees by management type and initial tree grade.**

| | Management prescription | | |
|---|---|---|---|
| | Uncut | B-level | Crop tree |
| Initial levels | 145 (28) | 137 (38) | 132 (23) |
| **Harvested trees** | | | |
| Grade 1 sawtimber | -- | 19 (8) | 29 (5) |
| Grade 2 sawtimber | -- | 10 (3) | 7 (20) |
| Other sawtimber | -- | 23 (6) | 12 (3) |
| Poletimber | -- | 9 (2) | 13 (2) |
| Total harvested | -- | 61 (18) | 61 (11) |
| **Residual trees** | | | |
| Grade 1 sawtimber | 67 (11) | 45 (7) | 36 (3) |
| Grade 2 sawtimber | 16 (4) | 3 (3) | 5 (2) |
| Other sawtimber | 27 (7) | 12 (5) | 8 (2) |
| Poletimber | 36 (6) | 17 (5) | 23 (5) |
| Total residual | 145 (28) | 76 (20) | 72 (12) |

# METHODS

## PLOT ESTABLISHMENT AND DATA COLLECTION

Each of the four study areas was divided into three 3- to 5-acre blocks. Blocks were randomly assigned one of three treatments (management prescriptions): B-level thinning, crop tree release, and unmanaged controls. All harvests were conducted as commercial thinning operations. The goal for the crop tree release plots was to reduce stocking to levels similar to an appropriate thinning treatment. Harvesting on three of the plots was completed prior to the 2004 growing season. Harvest on the fourth plot was completed in early August 2004. Stand ages were determined by sanding stumps of at least 15 harvested upper canopy oaks and counting rings.

A minimum of 25 crop trees (~10/acre) were selected and measured in each treatment block at each study area before treatment assignment. Therefore, there were crop trees on all treatment blocks, but only those on the crop tree release blocks were completely released. Crop tree density was low because stands averaged 51 sawtimber oaks per acre prior to treatment. Selection criteria for crop trees were: red oak group (*Quercus rubra* or *Q. velutina*), codominant or dominant crown class, at least 17 ft to first fork, diameter ≥ 18 inches, and grade 1 butt log. Composition of crop trees was 91 percent northern red oak and 9 percent black oak. Crop trees were banded at 4.5 feet and systematically numbered with orange paint. Diameters were recorded to the nearest 0.04 inches. The following data were also recorded for all crop trees: species, crown class, tree-grade (Alerich 2000), live crown ratio (rounded to the nearest 10 percent), total height (ft), and saw log height (ft). Heights were estimated using a laser hypsometer at approximately a 45° angle of total height. The degree of release was assessed within 1 year of cutting in 10-percent increments. Trees that were not released were assigned a release factor of 0.

A 164-ft x 164-ft (0.62-ac) plot was permanently established within each block to monitor changes in stand basal area and volume growth. All trees ≤ 4-inch diameter within each plot were permanently banded at

4.5 feet and systematically numbered with red paint. Data collected for crop trees were also recorded for these trees. A total of 1,742 stems (all species) were measured prior to treatment. Diameter and crown class of all live trees were measured annually during the dormant season.

### STATISTICS

Multiple regression analysis was used to examine the effects of study area and treatment on 5-yr stand basal area (ft$^2$/ac) growth. Tukey's HSD test was used to test differences in basal area growth among factors. Differences were judged significant at $P \leq 0.05$. Two-factor (study area, treatment) analysis of variance with initial diameter as a covariate was used to examine the overall effect of treatment on diameter growth. Tukey's HSD test was used to test differences of tree growth among diameter classes. All differences were judged significant at $P \leq 0.05$. Because of small sample sizes across treatments and plots, the effect of treatment on diameter growth was not examined for non-oak sawtimber (n=85) and oak poletimber (n=39). Oak sawtimber was split into six diameter classes for analysis: 11.0-13.9 in, 14.0-16.9 in, 17.0-19.9 in, 20.0-22.9 in, 23.0-25.9 in, and ≥ 26.0 in. For each size class, the effect of treatment on 5-yr diameter growth was determined using a two-factor (study area, treatment) analysis of variance. Similar procedures were followed to assess the influence of degree of release on diameter growth after trees were split into six release classes: 0, 10-40, 50-60, 70-80, and ≥ 90 percent.

## RESULTS AND DISCUSSION

Initial stocking averaged 113 percent, ranging from 106-124 percent. Residual stand stocking after harvesting averaged 62 percent on B-level thinning plots and 60 percent on crop-tree plots. Harvesting reduced the number of sawtimber oaks from an initial 51 per acre to only 27 and 22 per acre on B-level and crop tree plots, respectively.

Harvesting removed an average of 61 ft$^2$/ac (44 percent) of stand basal area on both the B-level thinning and crop-tree plots (Table 2). Both treatments reduced poletimber basal area by 36 percent. However, the distribution of harvested sawtimber basal area differed among the treatments. Harvesting reduced tree-grade 1 basal area by 44 percent on crop-tree plots and 30 percent on B-level thinning plots. On the crop-tree plots, 60 percent of harvested sawtimber basal area was from tree-grade 1 stems, compared with only 36 percent on the B-level thinning plots. In contrast, nearly half of the sawtimber basal area harvested on B-level thinning plots was from grade 3 or poorer stems.

### STAND GROWTH

Stand basal area growth averaged 8.3 ft$^2$/ac for the 5-yr period after harvesting (Table 3) and did not differ among treatments (F=1.000, df=2, P=0.431). Basal area growth of oak sawtimber (F=0.259, df=2, P=0.780), and perhaps more important, grade 1 oak sawtimber (F=0.052, df=2, P=0.950) did not differ among treatments. For the 5-yr period after harvesting, both managed and unmanaged stands average 6.1 ft$^2$/ac for oak sawtimber, of which 4.8 ft$^2$/ac were grade 1 oaks. This result was unexpected because while initial oak stocking averaged 68 percent, residual oak stocking was only 41 and 34 percent on B-level and crop-tree plots, respectively. Earlier studies have reported that stand volume growth following complete release can be maintained for 14 yr or longer (Beck 1987, Dwyer and Lowell 1988, Ward and others 2005).

**Table 3.—Mean (standard error) 5-yr basal area growth (ft²/ac) by size class, species group, and management prescription.**

| | | Management prescription | | |
|---|---|---|---|---|
| Size Class | Species Group | Uncut | B-level | Crop tree |
| Sawtimber (> 11 in.) | Non-oak | 0.3 (1.1) a[‡] | -0.4 (1.1)* a | 0.6 (0.2) a |
| | Oak | 6.7 (2.0) a | 6.0 (0.6) a | 5.6 (0.4) a |
| | All species | 7.0 (2.3) a | 5.6 (0.7) a | 6.3 (0.5) a |
| Poletimber (4-11 in.) | Non-oak | 0.2 (0.3) a | 2.5 (0.6) b | 3.9 (0.3) b |
| | Oak | -0.3 (0.1) a | 0.1 (0.1) a | -0.2 (0.3) a |
| | All species | -0.1 (0.2) a | 2.6 (0.6) b | 3.6 (0.6) b |
| Total (> 4 in.) | Non-oak | 0.6 (1.3) a | 2.1 (1.3) a | 4.5 (0.4) a |
| | Oak | 6.3 (2.0) a | 6.1 (0.6) a | 5.4 (0.5) a |
| | All species | 6.9 (2.2) a | 8.2 (0.7) a | 9.9 (0.9) a |

‡Row values followed by the same letter are not significantly different at $P < 0.05$.
*Negative values indicate mortality was greater than growth.

Previous reports noted that general thinning increased stand basal area growth (Gingrich 1971, Dwyer and Lowell 1988, Ward 1991), but recommended against thinning in stands more than 70 yr old (Sander 1977, Hibbs and Bentley 1983). The current study found that B-level thinning did not decrease stand basal area growth in stands up to 115 yr old (Table 3). That managed stands had half the sawtimber oaks of unmanaged stands and had similar basal area growth rates (Table 3) suggests oak volume growth was shifted onto the larger, higher-quality residual stems. This conclusion assumes that higher quality trees were selected as residuals and saw log length did not increase more in unmanaged than managed stands.

Less information is available for stand growth following crop tree management. Stand basal area growth was increased by crop tree management in poletimber oak stands in Missouri (Dwyer and Lowell 1988) and sawtimber oak stands in Kentucky (Miller and Stringer 2004). Multi-age crop tree management in oak sawtimber stands resulted in high volume growth in Connecticut (Ward and others 2005). The initial cutting for a shelterwood prescription can result in a residual stand structure that is similar to crop tree management, especially in the larger diameter classes. Several studies have shown that stand volume growth can be maintained following a shelterwood or deferment cut (Beck 1987, Smith and others 1989, Ward and others 2005).

An alternative to initiation of regeneration prescriptions in mature oak sawtimber stands would be useful for large landowners with a management goal of developing a more balanced age structure (e.g., state forestry agencies) and small family forest owners wanting to simultaneously maintain large trees and income from harvesting. Based on this study, both crop-tree and B-level thinning can be used in 100-yr or older oak sawtimber stands to generate income without sacrificing volume growth, assuming that merchantable volume is correlated with sawtimber basal area. Other studies have reported that crop tree management improved (Dwyer and Lowell 1988) or had no adverse effect on quality of residual trees (Miller and Stringer 2004).

## INDIVIDUAL TREE GROWTH

### Treatment Effects

In the following section, "oak crop trees" refers to the 25 crop trees that were selected and measured in each treatment block at each study area before treatment assignment and "oak sawtimber" refers to all other oak sawtimber trees. The maintenance of stand basal area growth in managed stands (Table 3) after a significant reduction of basal area (Table 2) indicates there was increased diameter growth of residual trees (Fig. 1). Relative to unmanaged controls, both B-level thinning and crop-tree management increased diameter growth of non-oak poletimber ($F=122.33$, $df=2$, $P<0.001$), oak sawtimber ($F=11.90$, $df=2$, $P<0.001$), and oak crop trees ($F=57.62$, $df=2$, $P<0.001$). In addition, 5-yr diameter growth of crop trees on the B-level thinning plots (1.2 ±0.04 in.) was less than that of crop-tree management plots (1.4 ±0.04 in.). The possibility that the degree of release, rather than the plot-wide treatment, is the causal mechanism of increased growth is examined below.

During the 5-yr period, diameter growth of completely released crop trees averaged 0.28 in/yr compared with 0.19 in/yr for unreleased trees (Fig. 1). Similar growth responses were reported for 54-yr-old red oaks in West Virginia (Lamson and others 1990), 61-yr-old red oaks in Arkansas (Graney 1998), 70- to 75-yr-old white oaks in Kentucky (Miller and Stringer 2004), 75- to 80-yr-old red oaks in West Virginia (Smith and others 1989, Smith and Miller 1991), and 74- to 94-yr-old red oaks in Connecticut (Ward 2008).

In other words, completely released trees will gain an extra inch in diameter relative to unreleased trees 11 years after treatment if these growth rates continue. Extended periods (>10 yr) of increased growth for sawtimber-sized oaks after release have been reported (Sonderman 1984, Beck 1987, Graney 1998, Perkey and Onken 2000, Ward 2008). Thus, the upper limit at which northern red oaks respond to release can be extended to at least 115 years.

Unexpectedly, only 1 year elapsed before diameter growth increased for completely released crop trees (Fig. 1a). While some studies have reported a more delayed growth response for red oak sawtimber (Graney 1998, Meadows 1998, Ward 2008), diameter growth of 85-yr-old oaks increased immediately after release in North Carolina (Beck 1987).

### Initial Diameter

Both B-level thinning and crop-tree management increased diameter growth of oak sawtimber, as noted above; however, the response varied among diameter classes (Table 4). Treatment had no effect on diameter growth of the smallest (11.0-13.9 in., $F=2.75$, $df=2$, $P=0.076$) and largest (>26.0 in., $F=1.84$, $df=2$, $P=0.191$) diameter classes in the study. This outcome may have been due to small sample sizes rather than an actual lack of treatment effect. Oaks with diameters between 14.0 and 22.9 inches grew more on the crop-tree management and B-level thinning plots than on the uncut control plots. For two diameter classes, 17.0-19.9 and 23.0-25.9 in., oaks on crop-tree management plots grew more than those on B-level thinning plots.

### Degree of Release

Earlier studies have reported that the amount of diameter growth response of oaks is related to the proportion of the crown that is released for saplings, poles, and small sawtimber (Lamson and Smith 1978, Graney 1998, Miller and Stringer 2004, Schuler 2006, Ward 2009). This study extends the response to large oak sawtimber

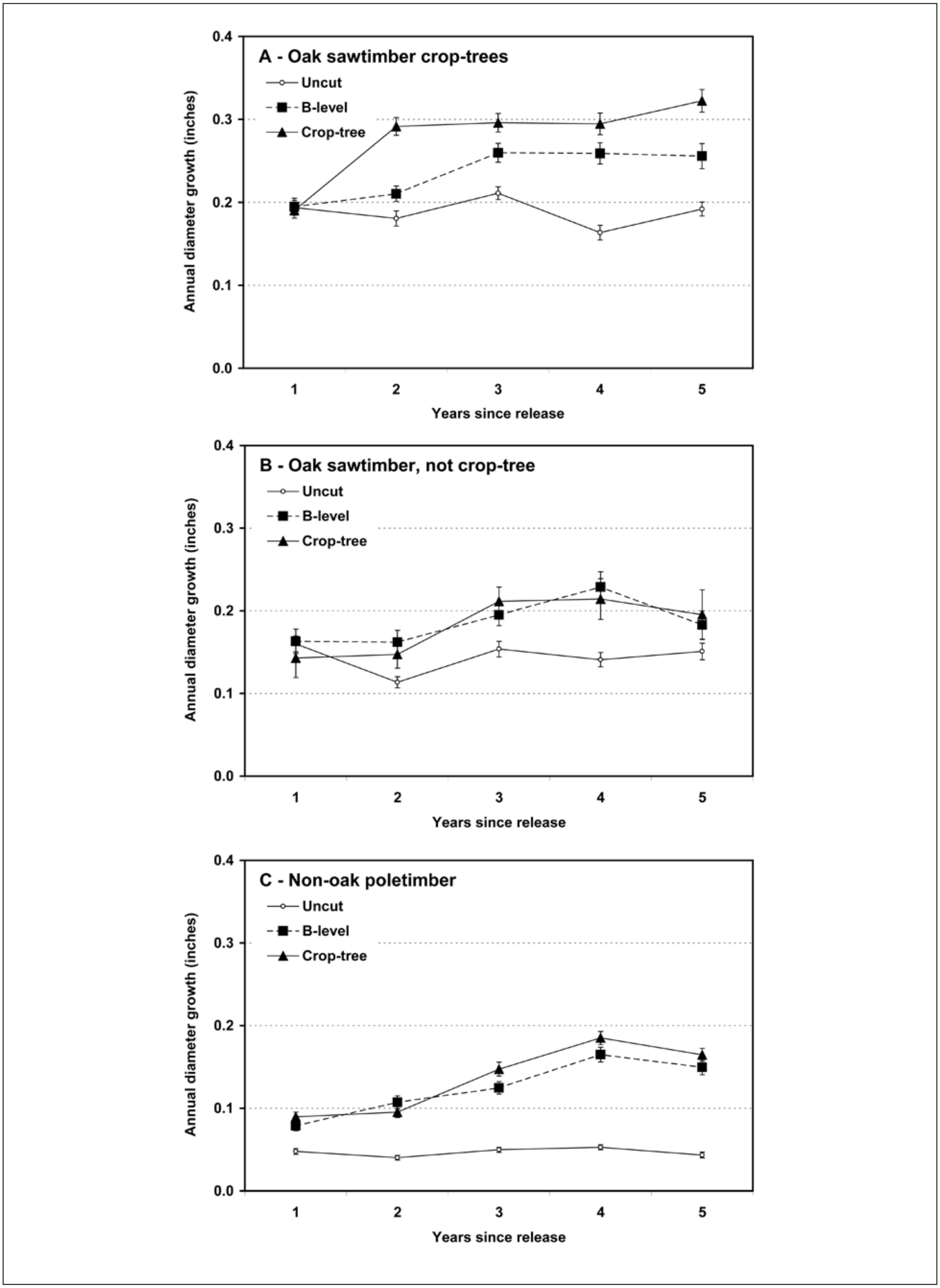


Figure 1.—Mean (standard error) annual diameter growth (inches) by management prescription for (a) oak sawtimber crop-trees, (b) oak sawtimber trees except for crop-trees, and (c) non-oak poletimber.

**Table 4.—Mean (standard error) 5-yr diameter growth (in.) of sawtimber oaks by initial diameter class and management prescription.**

| Diameter | Management prescription | | | Sample size | | |
|---|---|---|---|---|---|---|
| (inches) | Uncut | B-level | Crop tree | U | B | C |
| 11.0-13.9 | 0.58 (0.05) a* | 0.80 (0.08) a | 0.66 (0.11) a | 28 | 10 | 6 |
| 14.0-16.9 | 0.71 (0.04) a | 0.99 (0.08) b | 1.20 (0.09) b | 57 | 16 | 14 |
| 17.0-19.9 | 0.89 (0.04) a | 1.07 (0.04) b | 1.28 (0.04) c | 62 | 53 | 44 |
| 20.0-22.9 | 0.95 (0.05) a | 1.25 (0.05) b | 1.36 (0.05) b | 39 | 47 | 46 |
| 23.0-25.9 | 1.06 (0.08) a | 1.26 (0.10) a | 1.57 (0.08) b | 17 | 14 | 19 |
| ≥26.0 | 0.96 (0.18) a | 1.22 (0.11) a | 1.36 (0.10) a | 3 | 9 | 10 |
| Total | 0.87 (0.02) a | 1.09 (0.03) b | 1.27 (0.03) c | 206 | 149 | 139 |

*Row values followed by the same letter are not significantly different at P < 0.05.

as the diameter growth increase was directly related to the amount of release (Fig. 2a). The observation that a 25-percent (one-sided) release did not increase diameter growth is consistent with studies in West Virginia (Lamson and others 1990) and Connecticut (Ward 2008), indicating that trees should have a canopy release of 50 percent or more (i.e., two or more sides). Releasing trees on two sides increased diameter growth by 26 percent relative to unreleased trees (Fig. 2a).

A greater diameter-growth response was observed when more than half the crown was released. Releasing oak sawtimber by 70-80 percent (three sides) increased diameter growth by 35 percent, and ≥ 90-percent release increased growth by 53 percent, nearly 0.5 in over 5 years (Fig. 2a). Because the increased growth response should continue for 10 years or longer as noted above, diameters of completely released trees may grow nearly 2 in more over 20 years than diameters of unreleased trees, 5.3 and 3.5 in, respectively.

In contrast to oak sawtimber, partial release nearly doubled diameter growth of poletimber (Fig. 2b). Poletimber trees released less than 50 percent grew 0.73 in/5yrs compared with only 0.37 in/5yrs for unreleased trees. While releasing trees 50-60 percent further increased diameter growth to 0.96 in/5yr, poletimber diameter growth was not higher than for trees with ≥ 90-percent release.

## CONCLUSIONS

This study found complete release of large, sawtimber red oak crop trees resulted in significant and sustained increases in diameter growth (Table 4, Figs. 1 and 2) without a loss of stand basal area growth (Table 3). Other studies across a wide geographical range have also reported that releasing oak sawtimber on more than two sides results in increased diameter growth (Lamson and others 1990, Graney 1998, Miller and Stringer 2004, Ward 2008). The upper age limit at which red oaks respond to thinning is at least 115 years on average-quality sites (red oak SI = 65 ft), which allows initiation of regeneration treatments to be delayed in some regions. Therefore, management prescriptions that include releasing trees on at least two sides should be considered when development of stands with a balanced age structure would require that the regeneration cuts in some stands be delayed past economic maturity. Such treatments would be appropriate for private forest owners for whom high forest cover and non-commodity attributes are important considerations, and as an entry to forest management for owners who are hesitant to initiate harvesting.

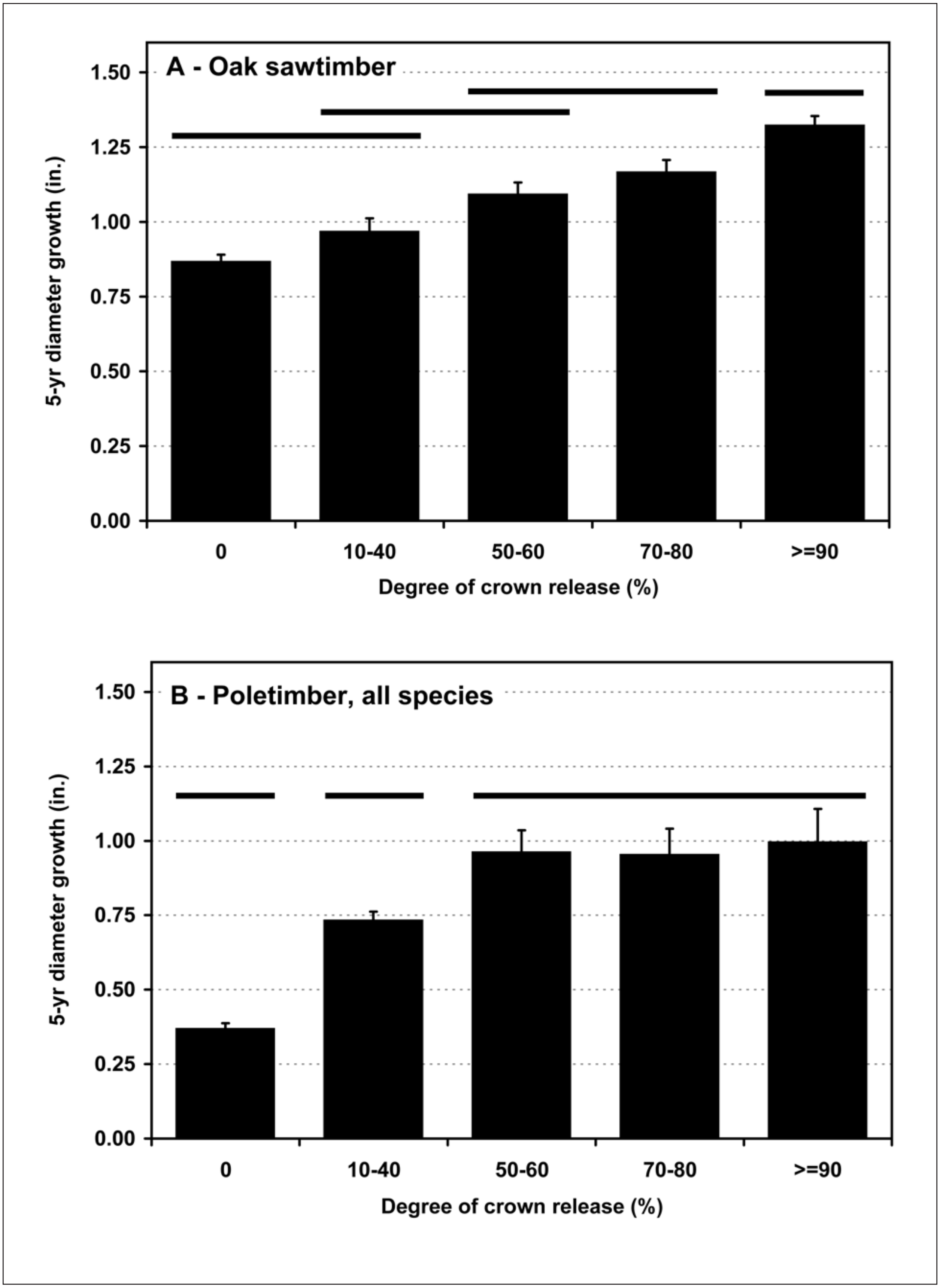


Figure 2.—Mean (standard error) 5-year diameter growth (inches) by degree of release for (a) sawtimber oaks and (b) poletimber trees. Release levels linked by horizontal lines above bars were not found different using Tukey's HSD test at P<0.05.

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