# Development of Loblolly Pine Interplanted One Year After Simulated First-Year Mortality

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## Abstract

A study was installed in the spring of 2007 at Appomattox-Buckingham State Forest to examine the effects of interplanting loblolly pine seedlings in plots with varying levels of simulated seedling mortality in a one-year-old plantation. The original stand density was 450 trees per acre (tpa). Plots with 100 percent, 66 percent (300 tpa), 44 percent (200 tpa) and 22 percent (100 tpa) survival were interplanted at the beginning of the second growing season with enough seedlings to restore the intended 450 tpa stand density. Original and interplanted seedlings were measured annually through the 2015 growing season, and growth and yield models have been applied to the observed diameter distributions to project rotation-length (30 years) productivity and financial outcomes.

Interplanted seedlings have survived and appear likely to remain a part of the stands going forward at all simulated mortality levels, but individually they have never caught up in size (either height or diameter) with the original seedlings, which are one year older. On a volume basis, they are contributing between roughly a quarter (on plots with 66 percent simulated survival) and two-thirds (on plots with 22 percent simulated survival) of total plot volume. None of the interplanted plots has recovered to the volume level of the undisturbed stand growing with the original 450 tpa.

When the current diameter distributions are used to project rotation-length productivity and financial values, only at the highest levels of mortality (i.e., 22 percent survival or 100 original trees per acre) does the added cost of interplanting result in a higher financial value than doing nothing and allowing the surviving trees to grow to rotation. At that high level of mortality, interplanting becomes essentially equivalent to starting over.

## Important Notes

This study represents ideal conditions where an exact planting spacing was maintained because “dead” seedlings were replaced with interplants in the exact same planting location. In practice, the outcome of interplanting would vary depending on the pattern of mortality and the ability of planting crews to maintain a uniform distribution of original and interplanted seedlings. Changing the planting densities could lead to very different product classes (and thereby values) of the resulting stands. Volunteer or wild pine seedlings could also greatly alter the trajectory of the growth response, and, without appropriate competition control or subsequent management, the outcome could vary greatly. And, of course, changing the assumptions (i.e., interest rate, product prices, rotation length) underlying the financial projections could also affect the financial outcome of the interplanting option.

## Introduction

Interplanting refers to the practice of replacing dead or missing seedlings in stands that have suffered varying levels of mortality (or for some other reason are inadequately stocked) after the first growing season. It involves a second investment in seedlings and contract planting. In practice, operational planting crews typically plant a specified number of seedlings per acre to bring the density back to some target level.

The decision to interplant must be based on an accurate inventory of first-year survival; it is critical to know the surviving stem density to correctly define the number of interplanted trees needed to restore the target level. Mortality rarely occurs in a regular pattern, and it is nearly impossible for planters to replace missing seedlings in their exact original location, so the end-product can be a chaotic distribution of original and interplanted trees in patches of varying densities. Because planting density is inversely related to individual tree growth, this leads to more variable long-term productivity.

The VDOF research program has published results from two interplanting studies in Occasional Reports 53 (1980) and 106 (1992). In the 1980 test, results showed that dead seedlings could be replaced after the first growing season with the expectation of reasonable volume growth from the interplanted trees. The 1992 trial involved interplanting specifically on site-prepared cutover sites, and, in that case, interplanting was unsuccessful because the interplanted seedlings had to compete not only with the surviving pines but also with hardwood competition. Both studies indicated that there might be some critical minimum spacing or opening size above which interplanted seedlings could contribute to stand volume. Neither study made any attempt to account for the effects of the added cost of a second planting or the long-term productivity of the stands on financial returns.

In recent decades, the application of improved techniques for site preparation and competing vegetation control have greatly increased early survival and long-term productivity in planted loblolly pine stands in Virginia. Typical planting densities have declined over that time period from more than 700 tpa to 400-500 tpa. Deployment of more uniform, faster-growing and more expensive seedlings has accelerated. These changes have led to the hypothesis that interplanting in today’s stands may be more successful than in the earlier studies because a) an understocked stand would have wide enough openings with minimal competing vegetation to allow the interplants to thrive, and b) the improved genetics increase the chances that the replacement seedlings will grow into dominant or co-dominant trees in the final stand.

## Methods

To test that theory, we installed a study in a one-year-old loblolly pine plantation on the Appomattox-Buckingham State Forest. The initial planting (March 2006) was completed by a contract crew, and the interplanting was done by the research team in April 2007. All seedlings were second-generation open-pollinated seed orchard mix seedlings from the VDOF Garland

Gray Nursery. The existing stand had a surviving pine density averaging 451 trees per acre. We installed tenth-acre square plots in a randomized complete block design with four replications testing four treatments:

1. leave the original planted stand with no simulated mortality or interplanting;
2. reduce density to 300 trees per acre (66 percent survival) and interplant 150 replacement seedlings;
3. reduce density to 200 trees per acre (44 percent survival) and interplant 250 replacement seedlings, and
4. reduce density to 100 trees per acre (22 percent survival) and interplant 350 replacement seedlings.

To accomplish the density reductions, we pinflagged all surviving trees and randomly pulled up enough to reach the target density. We then replaced the trees that had been pulled up with a new seedling of the same genetic mix as those originally planted a year earlier.

Tree survival and heights were measured annually for the first four years after interplanting, after which, diameter (dbh) was added to the measurement protocol and used to calculate basal areas and tree volumes (the latter based on the equation of Tasissa, Burkhart & Amateis [1997. SJAF 21(3)146-152] for total volume outside bark) for each tree. Analysis of variance was used to assess the treatment effects using 0.05 as the critical probability level (Pr>F).

## Results – Age 10 Data

There has been very little additional mortality since the time of study establishment on any of the plots, with survival averaging more than 96 percent for the entire study (including both originals and interplants) since its inception. There are no statistically-significant differences among the treatments in terms of post-interplanting survival. However, diameter, height, basal area and volume have all shown statistically-significant effects of the various simulated survival/ interplanting regimes.

A summary of the most recent individual tree and per-acre metrics is provided in Table 1. Over the duration of the study, the interplanted seedlings have never caught up to the original seedlings in terms of average individual tree size – either height or diameter (Figures 1 and 2). As first-year survival declines to 300, 200 and 100 trees per acre (tpa) (simulating 66 percent, 44 percent and 22 percent survival), the proportion of the current stand volume made up of interplants increases from 23 percent to 44 percent to 69 percent, respectively (Figure 3). In spite of the interplanting efforts, at 66 percent, 44 percent and 22 percent survival, the total volume production has been reduced by 8 percent, 10 percent and 34 percent, respectively, compared to the undisturbed original plots growing with the intended 450 tpa.

So, under the ideal conditions represented in this study – where an exact planting spacing was maintained because “dead” seedlings were replaced with interplants in the exact same planting location – it appears that interplanted seedlings can be established as part of the stand and contribute a meaningful added increment to its overall productivity as measured by basal area and volume for at least nine years after interplanting (10 years after the original planting).

**Table 1. Comparison of original (age 10) and interplanted (age 9) loblolly pine after interplanting at various levels of simulated initial stand survival.**

| | Surviving Trees per Acre at Age 1 | | | |
|---|---|---|---|---|
| | **100** | **200** | **300** | **450** |
| **Original Seedlings (age 10)** | | | | |
| Height (ft.) | 32.0 | 33.6 | 33.9 | 33.3 |
| DBH (in.) | 6.3 | 6.6 | 6.6 | 6.4 |
| Basal Area (ft.$^2$/acre) | 21.6 | 49.5 | 69.8 | 99.9 |
| Volume (ft.$^3$/acre) | 331 | 790 | 1122 | 1579 |
| **Interplanted Seedlings (age 9)** | | | | |
| Height (ft.) | 29.6 | 32.0 | 30.9 | - |
| DBH (in.) | 5.3 | 5.5 | 5.2 | - |
| Basal Area (ft.$^2$/acre) | 49.3 | 40.7 | 21.8 | - |
| Volume (ft.$^3$/acre) | 720 | 633 | 335 | - |
| **Combined Plot Summary** | | | | |
| Basal Area (ft.$^2$/acre) | 70.9 | 90.2 | 91.6 | 99.9 |
| Volume (ft.$^3$/acre) | 1051 | 1423 | 1457 | 1579 |
| Percent of Volume from Interplanted Seedlings | 69% | 44% | 23% | 0% |

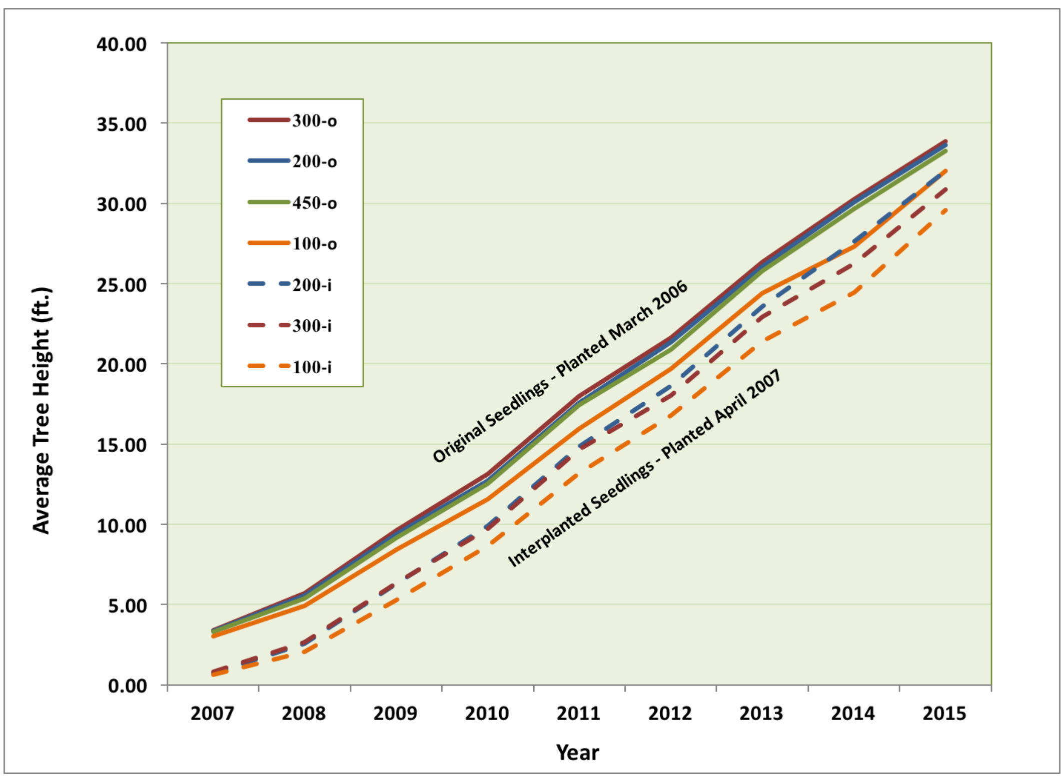


**Figure 1. Average total tree height (ft.) through 10 years after original stand establishment on plots at four levels of simulated first-year mortality and interplanting. Data for original seedlings are designated by an "o" and interplants by an "i" in the legend above.**

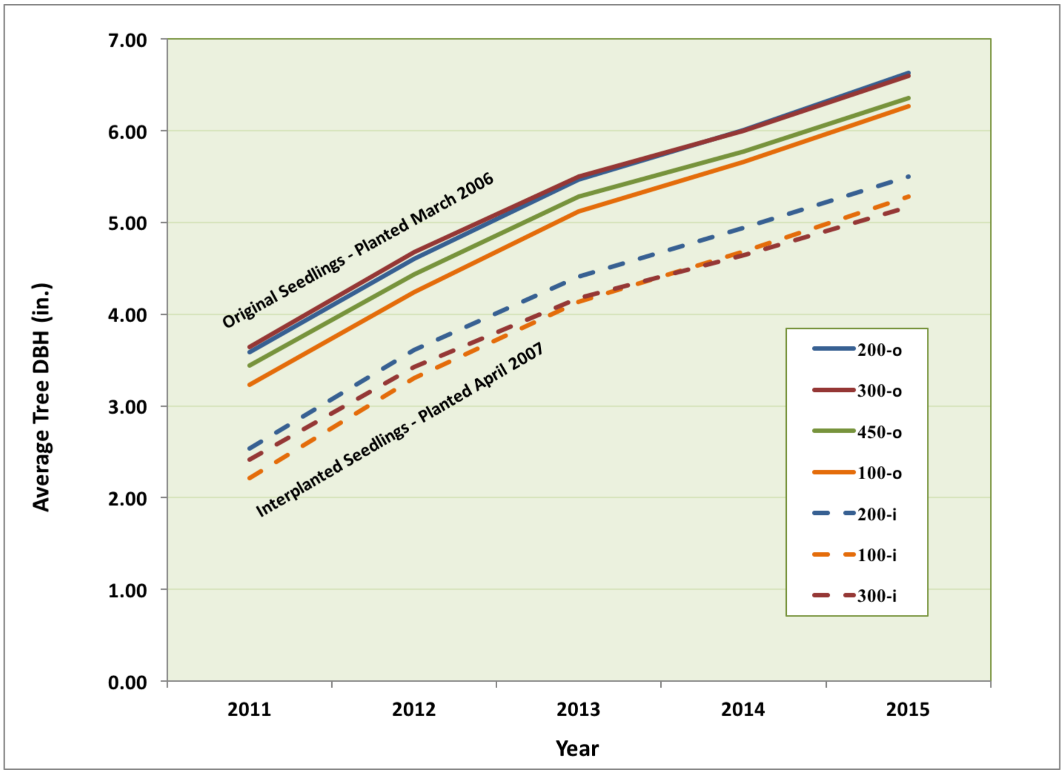


**Figure 2. Average tree dbh (in.) through 10 years after original stand establishment on plots at four levels of simulated first-year mortality and interplanting. Data for original seedlings are designated by an "o" and interplants by an "i" in the legend above.**

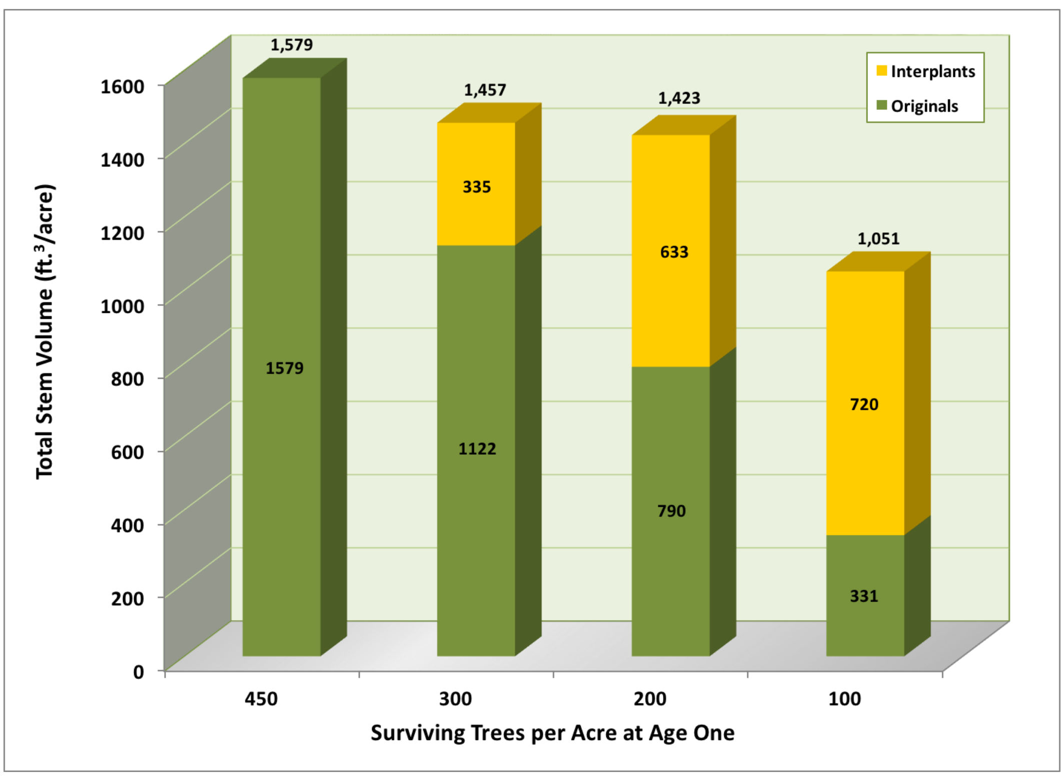


**Figure 3. Average total tree volume (ft.$^3$/acre) 10 years after original stand establishment on plots at four levels of simulated first-year mortality and interplanting.**

## Results – Projected Data

This study design did not include plots with reduced survival but no interplanting. We have no data directly defining how a comparable density of original seedlings (300, 200 or 100 tpa) would have grown in the absence of the supplemental planting. Fortunately, what we *do* have are good data regarding the individual tree growth of each tree in each plot, and, as a result, we can use the observed growth to initialize a growth and yield model to predict how trees would have grown either with or without the interplants. To do this, we used Ptaeda 4.1 – a loblolly pine growth and yield model developed at Virginia Tech through the collaborative efforts of the Forest Modeling Research Cooperative – to "grow" the current plots through a 30-year rotation without thinning. We then applied current product stumpage values per ton for pine pulpwood ($12.10), chip-n-saw ($17.25) and sawtimber ($21.33) from the latest edition (4th Quarter 2016) of Timber Mart-South to the projected fiber yields and discounted them to establishment age at a six percent rate of interest to get an indication of the financial impacts of the interplanting decision. These predicted growth and value results are summarized in Tables 2 and 3. Note that this results in a conservative projection of the original seedlings' growth because the models were initialized using age 10 diameter distributions – after the original seedlings had experienced competition from the interplants for 10 years.

**Table 2. Fiber production (total green tons per acre, outside bark) over a 30-year rotation on plots simulating interplanting following various levels of first-year seedling mortality.**

| Age | All Trees (original + interplanted) | | | | Original Trees Only | | |
|---|---|---|---|---|---|---|---|
| | 450 TPA | 300 TPA | 200 TPA | 100 TPA | 300 TPA | 200 TPA | 100 TPA |
| 11 | 55 | 53 | 50 | 40 | 39 | 28 | 12 |
| 12 | 64 | 62 | 59 | 48 | 47 | 35 | 15 |
| 13 | 73 | 71 | 67 | 56 | 55 | 41 | 19 |
| 14 | 82 | 80 | 76 | 64 | 63 | 48 | 22 |
| 15 | 91 | 89 | 85 | 72 | 71 | 55 | 26 |
| 16 | 99 | 97 | 93 | 79 | 79 | 62 | 30 |
| 17 | 108 | 104 | 101 | 87 | 88 | 70 | 35 |
| 18 | 117 | 111 | 109 | 95 | 95 | 77 | 39 |
| 19 | 124 | 118 | 116 | 102 | 103 | 84 | 44 |
| 20 | 132 | 125 | 123 | 109 | 111 | 91 | 48 |
| 21 | 138 | 132 | 130 | 116 | 118 | 97 | 53 |
| 22 | 144 | 137 | 136 | 122 | 125 | 103 | 58 |
| 23 | 150 | 145 | 143 | 128 | 132 | 110 | 62 |
| 24 | 156 | 151 | 149 | 133 | 138 | 116 | 66 |
| 25 | 161 | 156 | 154 | 138 | 144 | 121 | 70 |
| 26 | 165 | 161 | 159 | 144 | 150 | 127 | 75 |
| 27 | 169 | 164 | 162 | 147 | 154 | 133 | 79 |
| 28 | 175 | 169 | 167 | 152 | 160 | 138 | 83 |
| 29 | 180 | 173 | 171 | 156 | 165 | 143 | 87 |
| 30 | 183 | 177 | 174 | 160 | 171 | 148 | 90 |

**Table 3. Value (dollars per acre, discounted to time of stand establishment) over a 30-year rotation for plots simulating interplanting following various levels of first-year mortality.**

| Age | All Trees (original + interplanted) | | | | Original Trees Only | | |
|---|---|---|---|---|---|---|---|
| | 450 TPA | 300 TPA | 200 TPA | 100 TPA | 300 TPA | 200 TPA | 100 TPA |
| 11 | $347 | $331 | $299 | $218 | $259 | $195 | $79 |
| 12 | $407 | $388 | $354 | $264 | $315 | $242 | $104 |
| 13 | $458 | $436 | $401 | $305 | $366 | $284 | $129 |
| 14 | $499 | $480 | $442 | $345 | $408 | $323 | $151 |
| 15 | $536 | $513 | $477 | $382 | $445 | $357 | $171 |
| 16 | $563 | $541 | $506 | $411 | $467 | $392 | $193 |
| 17 | $590 | $563 | $531 | $437 | $507 | $421 | $211 |
| 18 | $608 | $576 | $556 | $460 | $529 | $444 | $232 |
| 19 | $619 | $586 | $569 | $473 | $549 | $468 | $252 |
| 20 | $628 | $592 | $580 | $488 | $564 | $484 | $268 |
| 21 | $625 | $600 | $586 | $499 | $575 | $495 | $283 |
| 22 | $622 | $597 | $587 | $500 | $580 | $505 | $296 |
| 23 | $621 | $600 | $587 | $503 | $583 | $512 | $305 |
| 24 | $613 | $594 | $581 | $501 | $583 | $517 | $312 |
| 25 | $604 | $589 | $574 | $495 | $580 | $516 | $316 |
| 26 | $588 | $578 | $562 | $491 | $576 | $517 | $319 |
| 27 | $573 | $560 | $546 | $481 | $566 | $514 | $319 |
| 28 | $564 | $548 | $535 | $471 | $559 | $507 | $320 |
| 29 | $552 | $533 | $522 | $461 | $549 | $499 | $317 |
| 30 | $534 | $520 | $504 | $452 | $540 | $491 | $311 |
| | Blue cells highlight maximum present value | | | | | | |

In terms of fiber production, when all the trees on the plots (including interplants) are projected forward (Figure 4), the model predicts modest differences in total green tons per acre yield at age 30 among the survival rates. None of the stands with reduced survival achieves the total productivity of the original stand, but only at the lowest survival rate (22 percent) is there more than a five percent loss of total productivity (Figure 5).

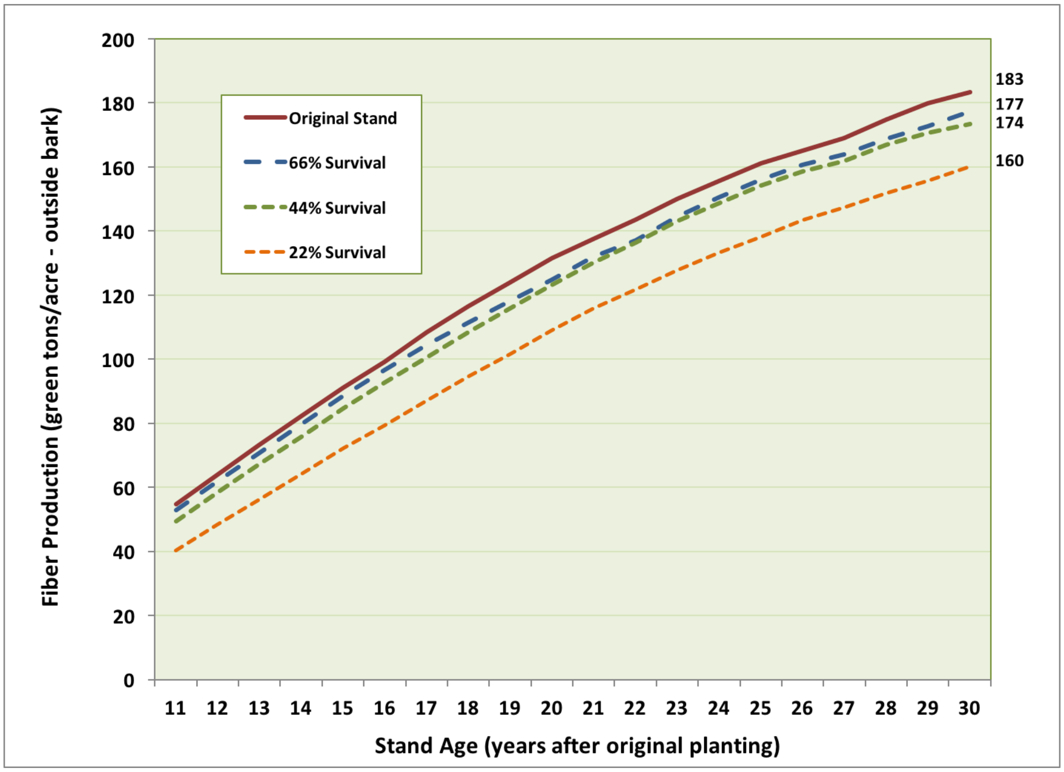


**Figure 4. Projected fiber production (total green tons per acre, outside bark) from age 11 through 30 on plots at four levels of simulated first-year mortality and interplanting.**

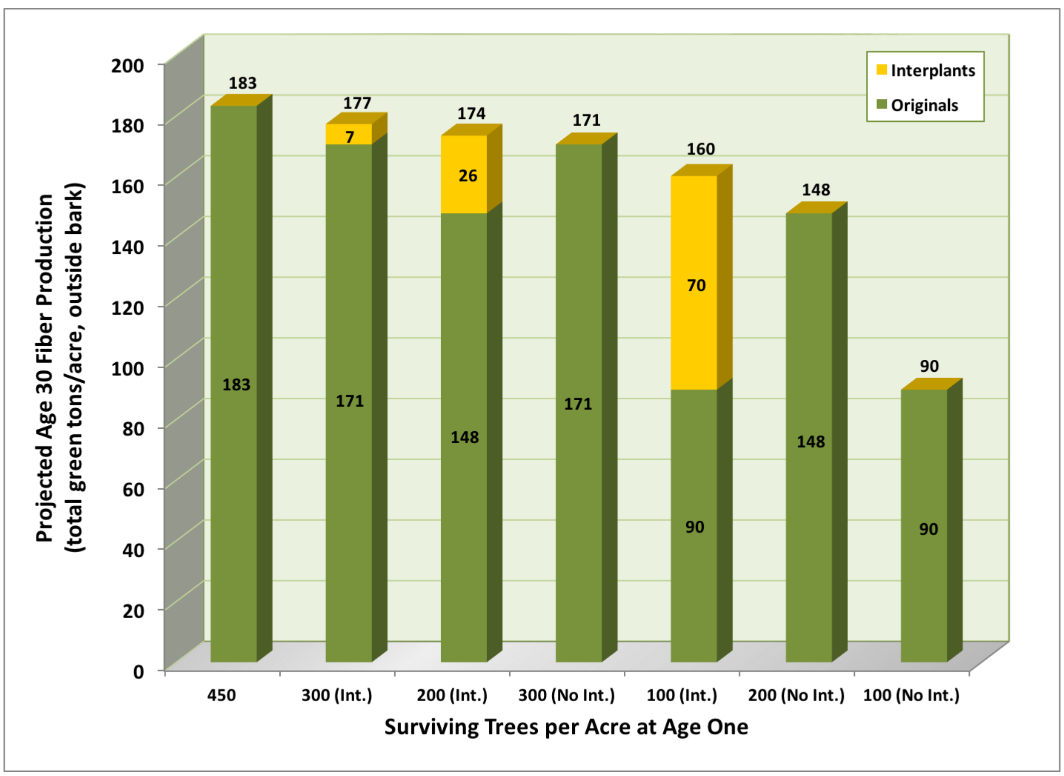


**Figure 5. Projected total fiber production (green tons per acre, outside bark) at age 30 on unthinned plots with varying levels of simulated first-year survival and interplanting.**

In terms of value, the results indicate (Figure 6) that none of the interplanted stands produces value equal to that of the original 450 tpa stand. In fact, by age 30, there is a strong chance that the plots growing at 300 tpa (66 percent survival) would bypass the 450 tpa original stand in total volume *without* interplanting. This is probably because at that lower density the individual trees will grow into the more valuable sawtimber product class more quickly than those growing at 450 tpa. We can estimate the value gained from interplanting as the difference between the peak values of the interplanted plots and those projected to have grown with only the original seedlings. For the 66 percent, 44 percent and 22 percent survival plots, that difference amounts to $17, $70 and $184, respectively. If we estimate the costs of the interplanting (seedlings plus contractor) as $75 per acre and discount that one year at six percent (resulting in a baseline value of $70.75), it quickly becomes clear that only in the very worst survival scenario does interplanting have any chance of paying off.

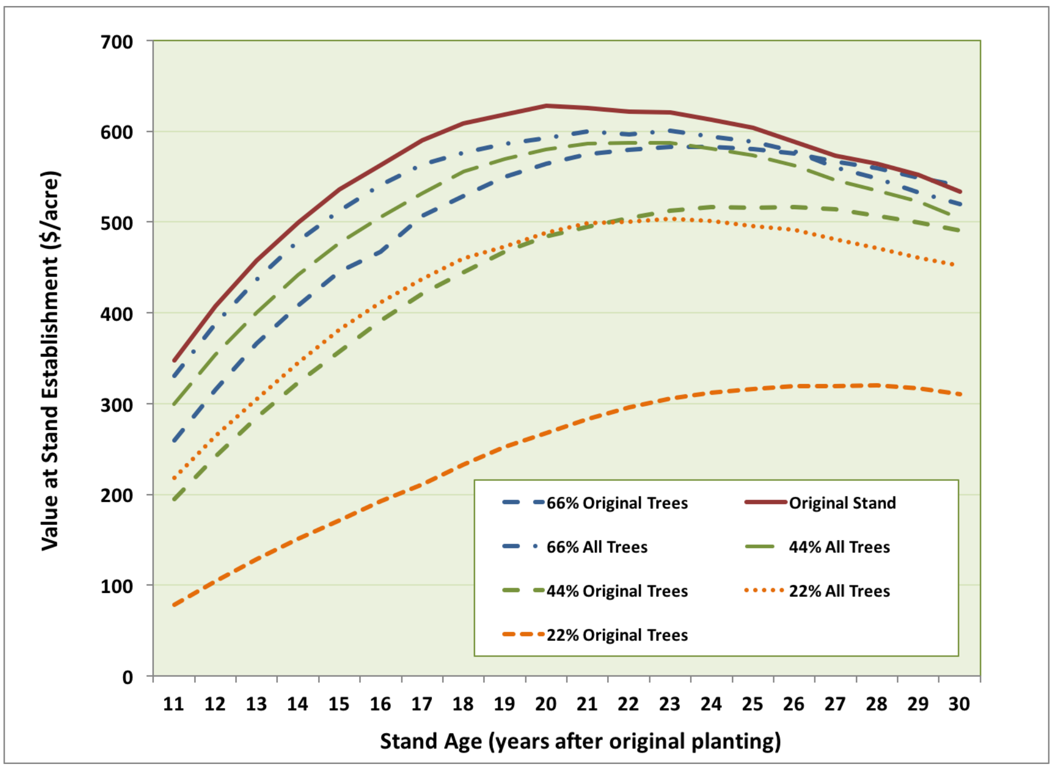


**Figure 6. Projected value (dollars per acre) from age 11 through 30 on plots at four levels of simulated first-year mortality and interplanting. Green lines track value for all seedlings (original plus interplanted) whereas brown lines project only the original seedlings with no interplanting.**

## Conclusions

Based on this study's results through the first nine years, there is evidence that interplanted seedlings can survive and contribute to the long-term productivity of loblolly pine plantations. Individually, the trees do not "catch up" with the originally-planted seedlings in terms of growth – at least through nine years after interplanting. So biologically, supplemental planting of genetically improved seedlings at carefully controlled density and locations in stands with good competing vegetation control can be successful. Financially, however, there is no scenario where interplanting results in a higher present value than doing nothing and allowing the surviving trees to grow at the reduced density unless there are fewer than 100 surviving stems per acre (if no thinning occurs). Mortality must be truly severe for interplanting to pay.

In practice, the outcome of interplanting would differ depending on the pattern of mortality and the ability of planting crews to maintain a uniform distribution of original and interplanted seedlings. Changing the planting densities could lead to very different product classes (and thereby values) of the resulting stands. Volunteer or wild pine seedlings could also greatly alter the trajectory of the growth response, and, without appropriate competition control or subsequent management, the outcome could vary greatly. Changing the assumptions (interest rate, product prices, rotation length) underlying the financial projections would also affect the financial analysis of the interplanting option.

Ultimately, the choice among 1) interplanting; 2) site-preparing and replanting the entire stand, or 3) accepting a lower density stand and moving ahead with no additional investment will depend on the specific investment objectives, assumptions and tolerances of the individual landowner. The best solution is to plan for and achieve adequate survival with the initial planting so that interplanting does not have to be considered.