# Comparing timber marking versus operator select to thin open longleaf pine stands

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**Author contributions:** BL conceived and designed the research, performed the fieldwork, developed the methodology, conducted the formal analysis, wrote the original draft, and edited later drafts; JS & ML developed concepts, interpreted the data, provided supervision, and critically revised the manuscript.

# Abstract

Open longleaf pine stands in the southeast U.S. are often marked prior to thinning to ensure quality residual trees are left. We present a case study where operator select thinning was applied in a longleaf pine forest where the optimization of water resources was a major goal. Longleaf pine stands were in Trinity County, Texas, U.S.A. Stands were overstocked and had a dense, shrubby understory from years of fire exclusion. Our main objective was to compare the outcomes of operator select versus timber marking, and whether they were different when attempting to create specific stand structure. Additionally, we worked closely with loggers to manage brush in place of traditional forestry mulching. Fourteen inventory plots were sampled pre-thinning, with half marked and the other half left unmarked and harvested by operator select methods. After resampling post-thinning, there was no significant difference in basal area, trees per hectare, quadratic mean diameter, or volume at marked and unmarked plots. Furthermore, QMD increased across all plots, longleaf dominance increased, woody vegetation decreased significantly, and we saw some herbaceous groundcover reestablishment. Our results indicate that close monitoring and feedback with loggers allowed us to circumvent an estimated $194.94 US per hectare cost for timber marking and $1,123.82 US per hectare for traditional mulching services. This amounted to an estimated $923.29 US per hectare reduction in project cost to create open longleaf pine structure. Operator select may be a viable option for initial entry in unmanaged and highly stocked longleaf pine stands of varying age. For our case study, it was a cost-effective approach for creating our desired stand conditions.


**Implications for Practice**

- Where open stand structure is a targeted outcome in longleaf pine forests, operator select thinning can yield similar and satisfactory results in place of timber marking.
- The scenarios where operator select thinning is appropriate might be limited to situations where stand prescriptions are straightforward or initial entries have been prolonged. Furthermore, it requires highly qualified loggers and consistent oversight from forest managers.

- When tasking logging operators to also manage brush during thinning, significant costs savings can be realized by circumventing the cost of timber marking and forestry mulching.

**Keywords:** longleaf pine, operator select, southern pine, timber marking

## Introduction

The reestablishment of longleaf pine (*Pinus palustris* Mill.) within its historic range is a conservation objective of interest across much of the southeastern United States. The longleaf pine ecosystem was estimated to have covered a pre-settlement area of approximately 30 to 38 million hectares (Brockway et al. 2005; Van Lear et al. 2005). Factors such as logging, conversion of land for agricultural or urban uses, and disruption of historical fire regimes led to a reduced modern-day area of approximately 1.2 million ha of longleaf pine (Oswalt et al. 2012).

Longleaf pine restoration has received strong support from government land use agencies, non-governmental organizations, and landowners across the southeast (Randall and Brewitt 2023). These interest groups often cite the environmental benefits of longleaf pine managed for openness and groundcover consisting primarily of grass and forbs (Bragg et al. 2020). This forest structure is associated with high biodiversity that supports several sensitive species (Walker 1993; James et al. 2001), resilience to disturbances like fire and wind damage (Stambaugh et al. 2011; Whelan et al. 2024) and provides valuable ecosystem services. These include benefits such as carbon sequestration (Samuelson et al. 2014) and improved water quality when compared to more developed land uses (Caldwell et al. 2023).

Despite these benefits, open longleaf pine management does not always align well with the objectives of a typical private landowner, often focused on creating revenue from timber harvest. A foremost issue is the slow growth and yield patterns of longleaf pine relative to more productive southern pine species like loblolly pine (*Pinus taeda* L.) (Haywood et al. 2015). The latter are typically even-aged silvicultural systems that use genetically improved seedlings, clearcut regeneration methods, and artificially planted trees. They undergo relatively short rotations of faster growing trees, and generally result in higher economic returns (Dickens and Li, 2023). Conversely, longleaf pine stands that are managed for openness and structural complexity are characterized by multi or uneven-aged silvicultural systems, require longer rotations, have lower stocking and mean annual increment, and are often naturally regenerated (Guldin 2004). This can be difficult, however, with longleaf pine having infrequent and sporadic seed crops (Guldin 2006).

One emerging option for incentivizing open longleaf pine establishment is the generation of water yield benefits associated with the ecosystem's structure. Recent, culminating work suggests that open pine management can increase water yield. This includes longleaf centric work (Brantley 2018; Younger 2023; Liu et al. 2025), and other work demonstrating that stand openness of any southern pine species can increase water yield (McLaughlin et al. 2013; Acharya et al. 2022). One study demonstrated that both scenarios were favorable for increasing water yield, although longleaf pine systems provided a larger benefit and impact (English et al. 2024). Overall, the body of work indicates these opportunities exist but currently may not be economically significant enough to fully incentivize landowner shifts towards longleaf establishment (Susaeta and Gong 2019).

For this study, we were confronted with a unique set of circumstances, where well-established longleaf stands in Southeast, Texas, U.S.A. received funding for restoration efforts associated with water yield benefits. These areas were characterized by dense stocking and significant woody understory due to years of management inactivity. To create the open longleaf pine structure associated with potential water yield benefits, there was a need to thin the stands, remove invasive understory brush, and reintroduce prescribed fire on the site. Thinning longleaf pine stands to historical structure would typically require timber marking, where trained personnel mark which trees to retain prior to timber harvest. In settings where targeted outcomes are relatively straightforward, however, it has been suggested that the loggers can be entrusted with the task of selecting which trees to take (Spinelli et al. 2016). Other case studies have indicated that loggers selecting trees to cut – commonly termed "operator select" – is as reliable or more reliable for realizing stand prescriptions when compared to timber marking (Eberhard and Hasenauer 2021; Mengyuxin 2025). Furthermore, there may be economic opportunities associated with circumventing the cost of timber marking (Love et al. 2018; Callaghan et al. 2019). It was our goal to determine whether operator select could be applied successfully when managing naturally regenerated longleaf pine stands, how it compared to areas that were marked by trained personnel, and quantifying the economic benefits of using operator select at our site.

To facilitate this comparison, we set up fourteen plots in two different aged longleaf stands and marked half the plots to our desired stand conditions before thinning. These included retaining a target BA of 13.77 $m^2$ $ha^{-1}$, shifting species composition towards longleaf pine and away from other southern pine, and reducing woody understory to promote reestablishment of herbaceous groundcover. To support our analysis, plots were inventoried before and after thinning. Close coordination and feedback were provided to loggers when applying operator select. Additionally, we also compensated loggers to spend extra time severing brush in place of traditional mulching. Our null hypothesis was that there would be no significant difference in inventoried metrics at marked and unmarked plots following timber harvest. We also compared costs when using this approach versus one where timber marking and traditional mulching were used instead.

# Methods

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### *2.1 Study area*

Our 41-hectare (ha) study area was located on Brushy Creek management area in Trinity County, Texas, United States. Brushy Creek falls within the historic range of longleaf pine prior to European settlement (Little 1971), with longleaf pine a dominant to co-dominant pine species in our study area. The area receives 1,117 to 1,371 mm of mean annual rainfall and mean daily temperatures range from 3 to 35 $^{o}$C. Brushy Creek falls within the Pineywoods ecoregion and Southern Tertiary Uplands subregion of Texas

(Griffith et al. 2007), and soil series consist primarily of Colita (Fine-loamy, siliceous, active, thermic Typic Glossaqualfs) and Letney (Loamy, siliceous, semiactive, thermic Arenic Paleudults) at 1 to 5 percent slopes (Soil Survey Staff, n.d.).

We focused our monitoring efforts on two different longleaf pine stands on Brushy Creek, which we will refer to as Stand 5 and Stand 7 (Figure 1). Stand 5 was a mixed, pine dominant forest approximately 54-years-old after averaging core samples from two site trees. Pre-thinning BA was 24.9 $m^2$ $ha^{-1}$, trees per hectare (TPH) was 227, quadratic mean diameter (QMD) was 42.8 cm, and volume was 321.8 M tons $ha^{-1}$ (Table S1). Longleaf pine (44%) and loblolly pine (50%) were codominant pine species, with sparse amounts of shortleaf pine (*Pinus echinata* Mill.) and slash pine (*Pinus elliottii* Engelm.). Small amounts of hardwood species found on the site included southern red oak (*Quercus falcata* Michx.), post oak (*Quercus stellata* Wangenh.), water oak (*Quercus nigra* L.), black hickory (*Carya texana* Buckley), various elm species (*Ulmus* spp.), blackgum (*Nyssa sylvatica* Marshall), and sweetgum (*Liquidambar stryaciflua* L.). The understory was primarily made up of yaupon holly (*Ilex vomitoria* Sol. ex Aiton), followed by smaller amounts of American beautyberry (*Callicarpa americana* L.), wax-myrtle (*Myrica cerifera* L.), and sweetgum saplings. Stand 5 contained very little herbaceous groundcover.

Stand 7 was an approximately 30-year-old, even-aged longleaf pine (83%) plantation with a small amount of loblolly pine (12%). Pre-thinning BA was 24.7 $m^2$ $ha^{-1}$, TPH was 402, quadratic mean diameter (QMD) was 28.5 cm, and volume was 249.7 M tons $ha^{-1}$ (Table S2). Stand 7 was relatively dense in stocking compared to Stand 5, contained relatively less mixed hardwood, and had a similar understory structure comprised primarily of yaupon holly. Similar to Stand 5, Stand 7 had little to no herbaceous groundcover following years of woody encroachment.

### *2.2 Inventory Plot Sampling and Data Collection*

#### *2.2.1 Sample Design*

The number of inventory plots and their spacing was generated using an unbiased systematic sampling design established by the U.S. Forest Service (FSVeg Common Stand Exam 2015). We determined the number of plots following a minimum rule of one plot per 4 ha, assuming the stand is reasonably homogenous. This amounted to 9 plots for Stand 5 (27 ha) and 5 plots for Stand 7 (14 ha). Plot spacing was calculated using the following equation:

$$Plot\ Spacing = \sqrt{\frac{Stand\ Area\ (ha) \times 10{,}000\ m^2 ha^{-1}}{Number\ of\ Plots}} \tag{1}$$

Once plot spacing was calculated, we created a square grid at that spacing for each stand and anchored it to Plot 77 in Stand 5 and Plot 49 in Stand 7. These two plots were the locations of additional water monitoring equipment and provided a good reference location to base our grid on. A 90% confidence interval was used when calculating the sampling error of both pre-thinning and post-thinning inventories, with a target percentage error of less than 20%. Forest METRIX Pro software (New Hampshire, US) was used to collect inventory data and provided real-time feedback on percent error as plots were completed, allowing us to identify whether we had reached our error threshold.

*2.2.2 Inventory Data Collection*

Inventory datum were collected in March of 2024, and re-collected post-thinning in September of 2024. Thinning and brush management were carried out in August of 2024. A variable radius point sample was taken for all ≥13.9 cm DBH (DBH = 1.37 m) trees using a 2.29 $m^2$ $ha^{-1}$ BAF prism. A 3.59 m fixed radius plot was installed for recording vegetation and grass cover. In the variable radius point, each tree's species, status (dead or live), DBH and height were recorded. Total tree height, or height from the base of the stem to the top of the crown, was measured using a Haglof EC II-D clinometer (Haglöf Sweden AB, Långsele, Sweden). Estimates of wood products and volume were made by categorizing each tree's merchantability into three major categories accepted by local mills: pulpwood, chip-n-saw (CNS), and sawtimber. Product specifications and volume rules were only created for pine species because they were the dominant species to be merchandised. Pulpwood was limited to ≥13.9 cm DBH and volume calculated using the Doyle Tons rule; CNS was measured between 24.1 to 31.6 cm DBH and sawtimber ≥31.7 cm DBH, with both CNS and sawtimber volumes calculated using the International ¼ tons rule (Mesavage and Girard 1946; Parker 1998). All volume calculations were converted and reported in metric tons ha$^{-1}$.

When quantifying groundcover classes of woody brushy or grass, we assessed a fixed radius area of 40.47 m$^2$ in size. This was done by measuring a 3.59 m radius from plot center in four cardinal directions, estimating the percentage of each plot quadrant covered in either class, and adding those four estimates for total coverage of brush or grass. One or both cover types could occupy up to 100% of each quadrant or 25% of the total plot. Other potential groundcover classes, like tree stumps and bare ground, were not considered.

Inventory and vegetation plot data were collected, and later plot reports were generated using our Forest METRIX Pro software. Outputs that were used for analysis include BA, TPH, QMD, and volume. Also considered in our analysis was the percent cover of woody brush and grass groundcover, and trees species composition before and after thinning.

### *2.3 Silvicultural Treatments and Harvest Operations*

Prior to thinning, half of our fourteen total plots in Stand 5 and 7 were marked to a target BA of 13.77 m$^2$ ha$^{-1}$. Marked plots were originally intended to be every other plot, except for plot 67 and 76, which were reversed in error. To determine the extent of the marked area from plot center, every tree falling within the variable radius plot using a 2.29 m$^2$ ha$^{-1}$ BAF prism was either marked or unmarked to our target BA. Additionally, the marked area was delineated using red and white flagging so that operators knew when they were entering and leaving marked areas. Leave trees were marked so that large and healthy longleaf pine were to be retained as often as possible (Figure 2). This was done using orange marking paint that was applied around the entire circumference of the bole at 1.37 m, and a butt mark on the lowest point of the tree to identify potential instances of leave trees being cut. Where trees were marked, loggers were instructed to cut everything but the predetermined trees, whereas trees cut in unmarked plots were entirely dictated by loggers. This enabled a comparison of our desired outcome (marked plots) versus the outcome of operator select (unmarked plots).

Additionally, loggers were compensated for spending extra time using the feller buncher or sawhead to remove the brush component of the understory. This entailed more time navigating around the stand and between trees to sever, or "mow", brush just above the ground with the sawhead feller. The brush component was generally comprised of approximately 1-3 m tall yaupon holly. While this approach did not masticate brush like when using a traditional forestry mulcher, it did kill and lay down standing woody fuels. This structural change is important for open longleaf pine management later, where the reduction of these fuels enables effective reintroduction of prescribed fire (Hanberry et al. 2018).

### *2.4 Analysis of Stand Structure and Project Costs*

An analysis of post-thinning inventory metrics comparing marked and unmarked plots was conducted using a student t-test in RStudio, version 2024.04.2 Build 764. Before carrying out statistical tests, a Shapiro Wilks test of normality was used on eight individual datasets, including: basal area ($m^2$ $ha^{-1}$), TPH, QMD (cm), volume (metric tons $ha^{-1}$), woody groundcover (% cover), and grass groundcover (% cover) in marked and unmarked plots. Despite a small sample size for groups ($n$ = 7), there was not enough evidence to reject the possibility of our data being normally distributed at a $\alpha = 0.05$ significance level ($p > 0.05$). We also conducted Levene's test for equality of variance amongst paired groups. For paired groups of marked and unmarked plots, we were unable to reject the possibility of equal variances at a $\alpha = 0.05$ significance level ($p > 0.05$) and therefore determined a two-tailed student t-test at a $\alpha = 0.05$ significance level to be an appropriate statistical test for our data. We acknowledge that analyzing at the plot level constitutes pseudoreplication. This is an operational case study, not a replicated experimental design, and is not presented as such. Upon further review, we combined data for Stands 5 and 7, despite their age and structural differences. It did not appear that their differences significantly impacted the outcome of the analysis.

When analyzing the economics of marked versus operator select harvests, we compared our real project cost of $200.52 US dollars per hectare for brush management to recent cost estimates for management alternatives in the southern U.S.A. (Maggard and Natzke 2024). These cost averages included timber marking the stands at $194.94 per hectare and forestry mulching at $617.76 per hectare. Also considered were real costs for mulching services provided by a vendor in other areas of the Brushy Creek project ($933.37 per hectare), and proposed costs from another vendor who did not provide mulching services ($1,235.53 per hectare). No statistics were possible for this analysis (n = 1).

## Results

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### *3.1 Plot and Stand Structure Shifts*

Our results indicate that there was not a significant difference of means in major forest attributes following forest thinning, regardless of whether a plot was marked or not marked (Figure 3). We rejected the alternative hypothesis for BA ($t(12) = 0.57$, $p = 0.58$), TPH ($t(12) = 1.97$, $p = 0.07$), QMD ($t(12) = -1.43$, $p = 0.18$), volume ($t(12) = -0.22$, $p = 0.83$), woody vegetation ($t(12) = -0.64$, $p = 0.53$), and grass vegetation ($t(12) = 0.16$, $p = 0.88$) when comparing groups of marked and unmarked plots.

We also analyzed marked and unmarked plots prior to thinning to confirm whether there were significant differences in the groups. We observed similar results across all variables, except for BA ($t(12) = 3.04$, $p = 0.01$) and TPA ($t(12) = 2.33$, $p = 0.04$), which had a significant difference in means between marked and unmarked groups (Figure S1). Marked plots were 33% higher in BA and 70% higher in TPH and 33% higher in BA.

In this project, the retention of longleaf pine was a major objective during thinning. We observed slight measurable increases in longleaf pine dominance across both Stand 5 and Stand 7 (5.78%), with marked (8.42%) and unmarked plots (3.14%) contributing to this change (Table S1 and S2). Additionally, we measured a 5.28% reduction in loblolly pine, a less desirable overstory pine species for our management objectives. In 6 unmarked plots where both loblolly pine and longleaf pine were present pre-thinning, we measured a 9.18 $m^2$ $ha^{-1}$ reduction in longleaf pine BA and a 27.54 $m^2$ $ha^{-1}$ reduction in loblolly pine BA. None of the plots had a larger reduction in longleaf than loblolly, indicating loggers were successfully identifying and leaving longleaf pine when using operator select.

A target BA of 13.77 $m^2$ $ha^{-1}$ was achieved in Stand 5 (13.77 $m^2$ $ha^{-1}$) and Stand 7 (16.32 $m^2$ $ha^{-1}$ BA), with the latter having marginally more residual BA post-thinning. Average post-thinning BA was 15.73 $m^2$ $ha^{-1}$ in marked plots and 15.08 $m^2$ $ha^{-1}$ in unmarked plots. Increases in QMD indicate that on average larger diameter trees were retained during thinning, although a small amount of this effect may be attributable to an additional growing season between measurement periods. We observed increases in QMD across all marked ($\bar{x}$ = 2.54 cm) and unmarked plots ($\bar{x}$ = 3.59 cm), except for unmarked plot 76 in Stand 5 (no change) and marked plot 56 in Stand 7 (-0.25 cm). Woody vegetation was consistently reduced across every plot after thinning, with an average reduction of 38.92%. The percentage of grass cover was either unaffected in a small number of plots ($n$ = 4 of 14) or increased in the remaining plots, with an average increase of 10.71%. For all our vegetation results, we note that data was collected a month after thinning and does not account for hypothetical resprouting into the following year. In this context, we've aimed to quantify the immediate response to treatment using the sawhead feller.

### *3.2 Comparison of Project Costs*

Using averages of recent forestry practice costs in the southern U.S. we estimated the costs to timber mark Stands 5 and 7 at $7,992.54 (Maggard and Natzke 2024), compared to no cost when using operator select. In addition to considering the averages for mulching costs in the south, we factored in our own pricing for mulching services on Brushy Creek. This amounted to an estimated costs of $928.88 per hectare or $38,084.28 to traditionally mulch Stands 5 and 7. This is compared to our project's real incurred cost of $8,221.55 or $200.53 per hectare to thin and manage brush using the sawhead feller. The total predicted cost to timber mark and traditionally mulch Stands 5 and 7 was $46,076.82 or $1,123.82 per hectare. This translates to a potential project savings of $37,855.27 or $923.29 per hectare.

## Discussion

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Our key findings were that operator select versus marked tree thinning did not result in significantly different BA, TPH, QMD, residual volume, woody vegetation, and grass vegetation ($p > 0.05$ for all metrics). This was facilitated by clear communication of what our desired stand outcomes were (i.e. retain larger longleaf pine), and consistent feedback with loggers on whether their work was satisfying these goals. Operationally, this required at least weekly visits, but often multiple visits to the field each week to monitor logging progress. When comparing post-thinning outcomes in both marked and unmarked plots, we observed increases in QMD and longleaf pine species composition in both plot types. This indicated that in unmarked areas, loggers were successfully leaving desirable longleaf pine trees and removing less desirable loblolly pine trees. We also achieved outcomes at or near our targeted residual basal area in marked and unmarked areas. Overall, it was our conclusion that open longleaf pine structure can be created using operator select, but it might be contingent on significant amounts of standing volume being available, which was the case on Brushy Creek. This creates a situation where there is less room for error when operators are selecting trees to leave or cut.

Similar to this conclusion, it has been previously established that straightforward stand prescriptions might not require timber marking (Spinelli et al. 2016). Furthermore, the forestry industry in the southern U.S.A. regularly uses operator select in highly uniform, pine plantation settings (Coble and Grogan 2016). The use of operator select in longleaf pine management, however, is not as readily available. As of this reading, we were unable to locate studies that analyzed the results of operator select in the longleaf pine ecosystem. Examples of different silvicultural methods implemented with timber marking were well documented (Brockway et al. 2014; Cannon et al. 2022), but not a comparison of outcomes in unmarked and marked scenarios.

Relevant studies in European forests are more numerous, including studies focused on comparing differences of harvest productivity in marked and unmarked stands. Results are varied, with no significant difference in efficiency amongst marked and unmarked areas but increases in residual tree damage in unmarked areas in one study (Holzleitner et al. 2019). Another study observed increases in harvest efficiency within marked areas, along with decreases in desired tree density in unmarked areas (Vahtila et al. 2024). Finally, Eberhard and Hasenauer (2021) used the tree growth model MOSES to simulate long-term outcomes of operator select, marked stands, and random tree selection in Norway spruce forests. They concluded there was no significant difference between operator select versus marked tree scenarios, with operator select representing a significant cost efficiency. The variety of outcomes appear to indicate that project objectives, regional considerations, and several other factors all contribute to whether operator select is appropriate for a specific site.

In addition to improving overstory structure on Brushy Creek, our use of the sawhead feller to manage understory fuels resulted in notable reductions in brush cover (36-40%) and small increases in herbaceous cover (6-13%). This was an important management objective because successful restoration efforts in an open longleaf pine system are reliant on groundcover fuels that allow low-intensity, repeated intervals of fire (Gilliam and Platt 1999; Outcalt and Brockway 2010). Timber marking and thinning, followed by traditional mulching is an expensive management technique relative to our approach, estimated at $923.29 more per hectare. This estimation could vary, however, with mulching cost being highly variable depending on vegetation type, density, and other factors. Also, our cost efficiencies were the result of pairing brush management and harvest operation, allowing us to opportunistically reduce brush management at a cost not normally sustainable without the timber harvest.

An important caveat when using our approach is that brushy understory fuels are not masticated, as is the case with traditional mulching. This results in relatively coarse fuels, and a post-thinning fuel type that requires a cautious first entry prescribed fire. Additionally, fuels not treated with subsequent control methods planned on Brushy Creek, such as fire or herbicide, would readily resprout and reestablish themselves over time. Despite this, our methods could serve as one potential strategy in a landscape where brush management conventions are evidenced to have little impact at larger scales (Scholtz et al. 2021).

Our conclusion is that operator select can be a viable option for managing the outcomes of a thinning harvest in the southeast U.S. longleaf pine ecosystem. We also documented successful outcomes in stands of varying age. However, it is important that the harvest operation be closely supervised, and consistent and prompt feedback provided to loggers during the operation. Furthermore, not all scenarios are appropriate for our approach, with timber marking required when creating more complex longleaf stand structure, such as in group or patch selection regeneration methods (Cannon et al. 2022). For our study, high densities of standing volume allowed for a relatively straightforward harvest prescription, with goals of maintaining larger, quality longleaf pine trees. Stand openness, achieved from managing brush at a significant cost discount, also enabled our goal of managing towards a forest structure conducive to reintroducing fire and increasing water resource benefits.

## Declarations

**Availability of data and material:** Data can be made upon reasonable request to the corresponding author.

**Competing interests:** The author declares that they have no competing interests.

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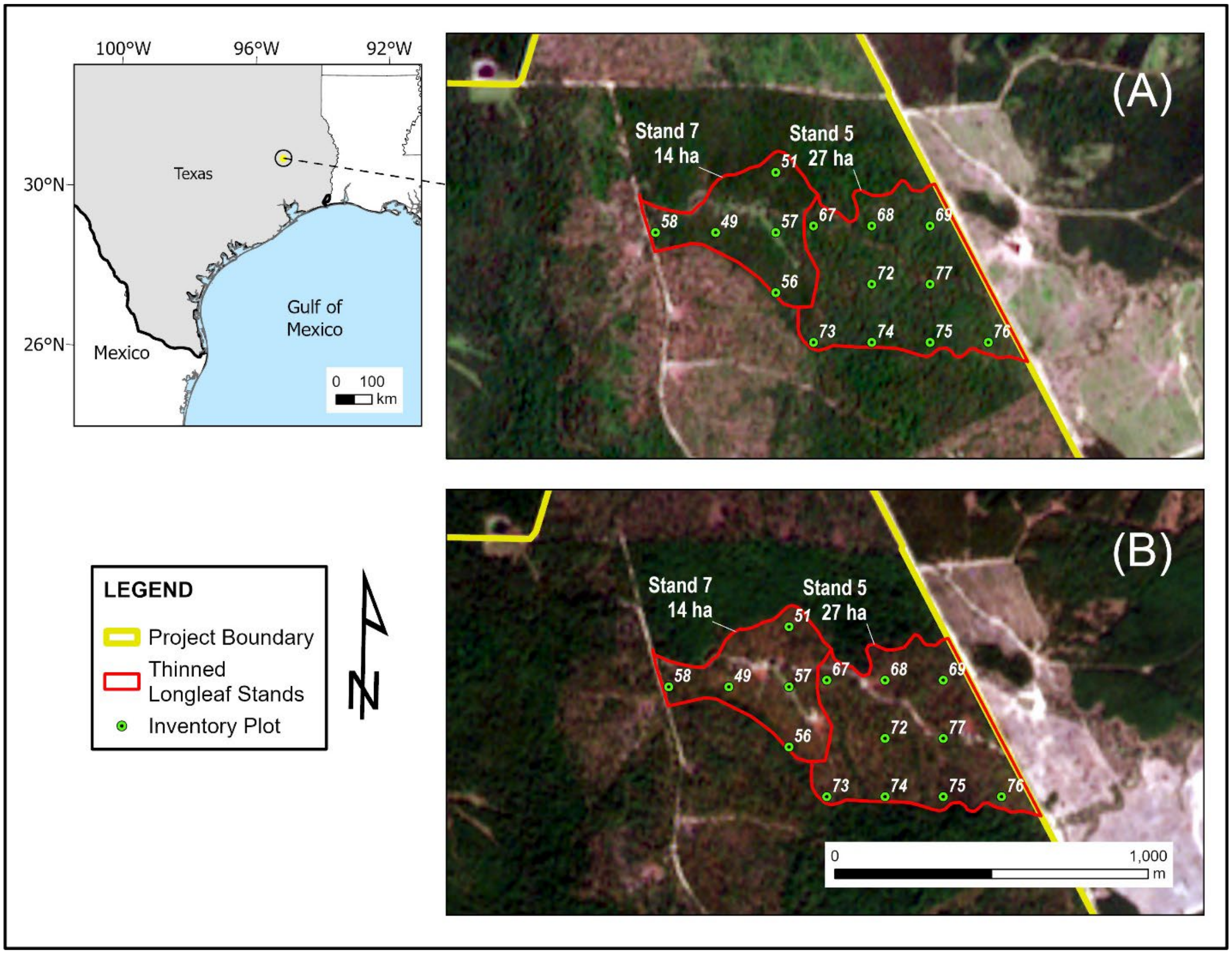


**Fig. 1.** A map of the project area using aerial satellite imagery of (a) prethinning and (b) post thinning.

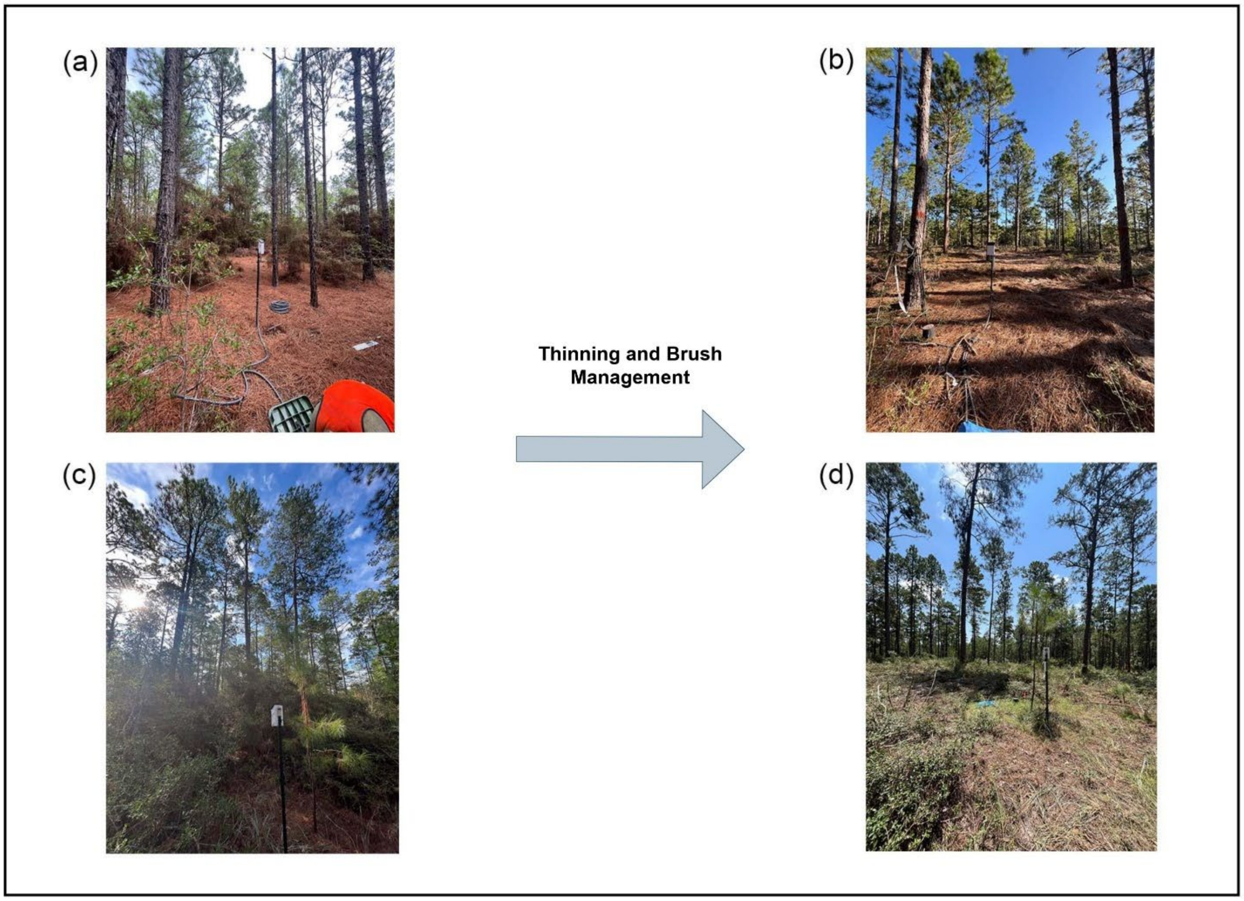


**Fig. 2.** Examples of (a) pre-thinning and (b) post-thinning at Plot 49 in Stand 7, and (c) pre-thinning and (d) post-thinning at Plot 77 in Stand 5. Both plots were marked, with some orange marking paint visible in the Stand 7 post-thinning image.

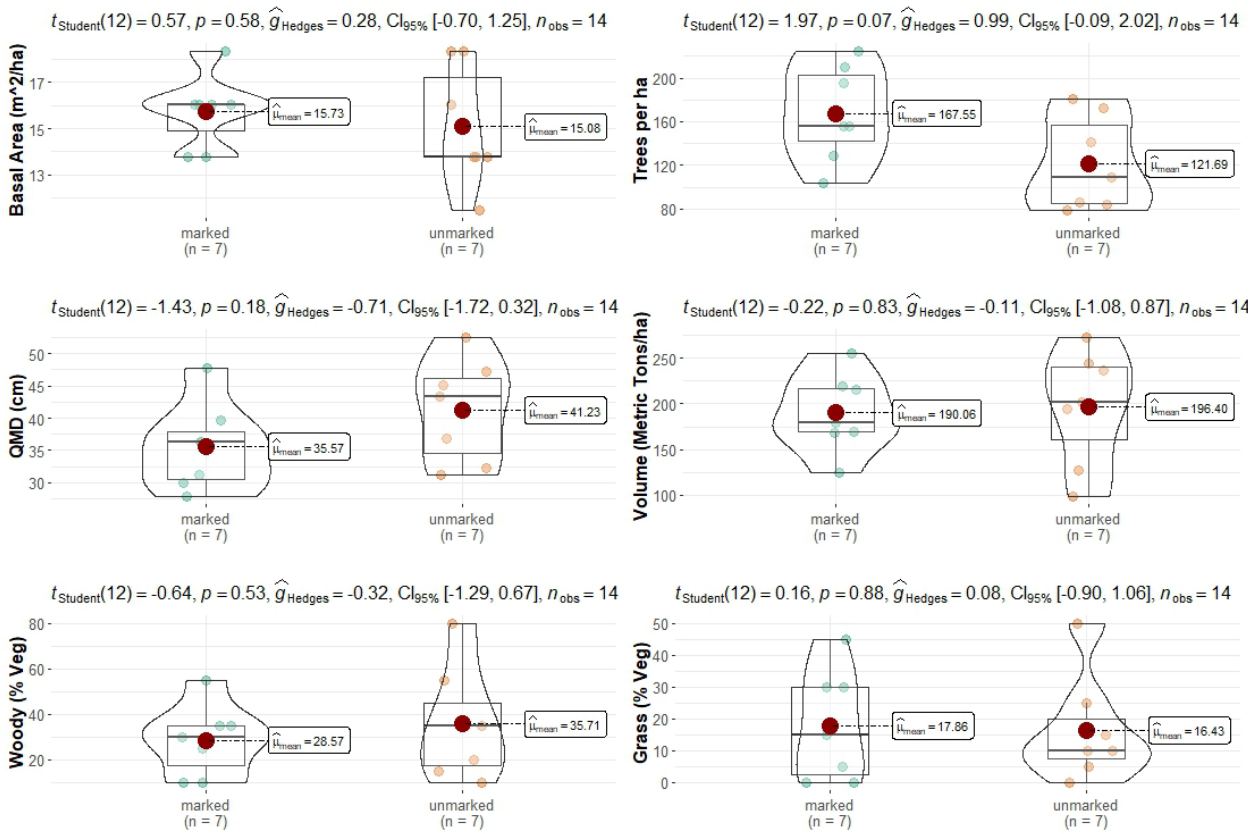


**Fig 3.** Results of Student T-test on post-thinning inventory data where BA ($m^2$ $ha^{-1}$), TPH, QMD (cm), volume (metric tons/ha), woody groundcover, and grass groundcover in marked and unmarked plots were compared. Both violin and box plot visualizations are presented, along with the metrics' average for marked and unmarked groups.

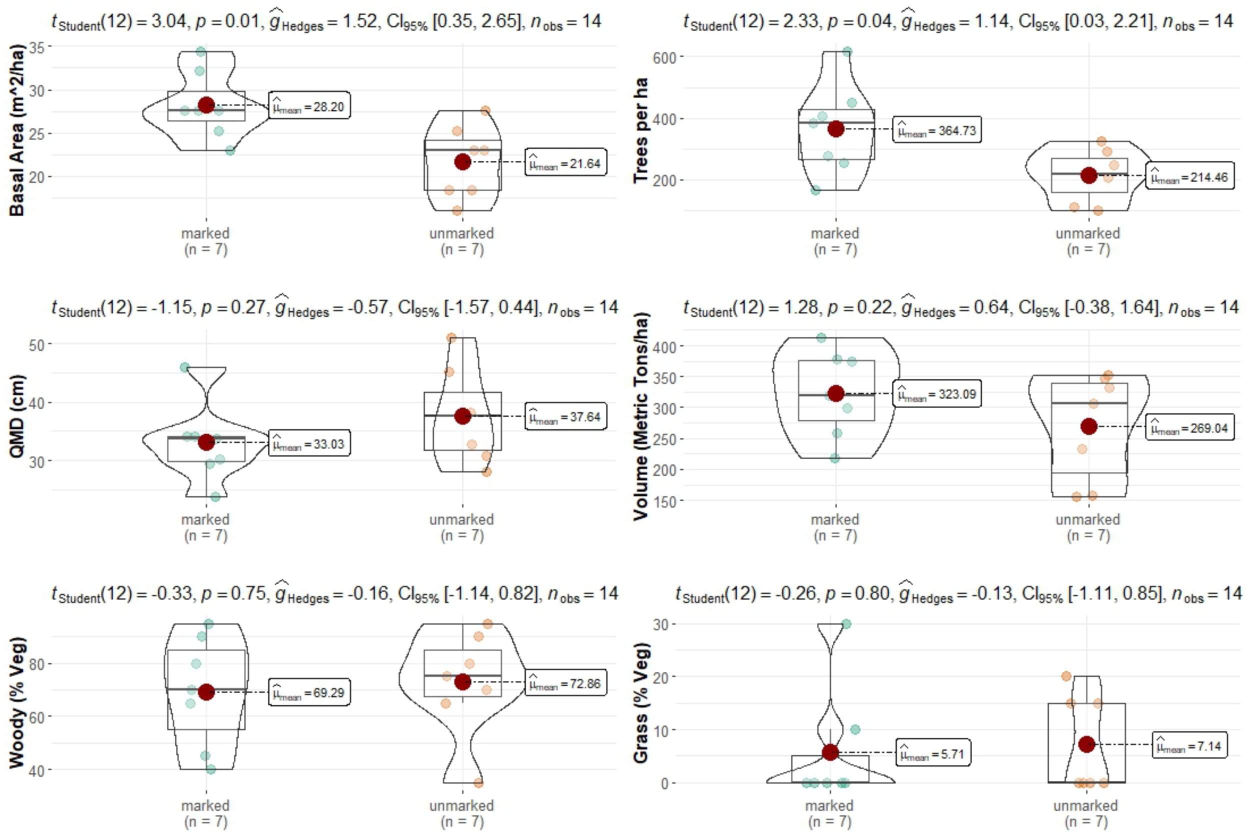


**Fig. S1.** Results of Student T-test on pre-thinning inventory data where BA ($m^2$ $ha^{-1}$), TPH, QMD (cm), volume (metric tons/ha), woody groundcover, and grass groundcover in marked and unmarked plots were compared. Both violin and box plot visualizations are presented, along with the metrics' average for marked and unmarked groups.

**Table S1.** Before and after inventory and vegetation data in Stand 5 following operator select thinning and brushy management. *Plots that were marked prior to thinning.

| Plot # | BA ($m^2$ $ha^{-1}$) | | TPH | | QMD (cm) | | Volume (M tons/ha) | | LLP (% BA) | | Lob (% BA) | | Woody (% Veg) | | Grass (% Veg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After |
| **67*** | 34.43 | 16.06 | 385.19 | 128.40 | 33.76 | 39.59 | 413.37 | 215.43 | 93 | 86 | 7 | 14 | 90 | 35 | 0 | 0 |
| **68*** | 22.95 | 16.06 | 254.32 | 155.56 | 34.01 | 36.29 | 218.79 | 168.58 | 50 | 57 | 40 | 29 | 70 | 25 | 0 | 30 |
| **69** | 22.95 | 16.06 | 207.41 | 108.64 | 37.56 | 43.40 | 306.22 | 243.90 | 20 | 14 | 80 | 86 | 95 | 80 | 0 | 5 |
| **72** | 22.95 | 18.36 | 111.11 | 83.95 | 51.02 | 52.54 | 346.79 | 272.59 | 60 | 75 | 40 | 25 | 75 | 35 | 15 | 50 |
| **73** | 25.25 | 13.77 | 219.75 | 79.01 | 38.07 | 47.21 | 353.07 | 201.75 | 27 | 33 | 73 | 66 | 90 | 35 | 0 | 10 |
| **74*** | 25.25 | 16.06 | 276.54 | 155.56 | 34.01 | 36.29 | 319.67 | 218.79 | 45 | 57 | 55 | 40 | 65 | 30 | 30 | 30 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **75** | 27.54 | 18.36 | 323.46 | 172.84 | 32.74 | 36.80 | 331.32 | 236.95 | 8 | 13 | 83 | 88 | 70 | 20 | 15 | 15 |
| **76** | 16.06 | 13.77 | 101.23 | 86.42 | 45.18 | 45.18 | 232.91 | 193.91 | 43 | 50 | 43 | 33 | 80 | 55 | 20 | 25 |
| **77*** | 27.54 | 18.36 | 165.43 | 103.70 | 45.94 | 47.72 | 374.14 | 254.43 | 50 | 75 | 33 | 13 | 80 | 35 | 10 | 45 |
| **Stand** | 24.99 | 16.32 | 227.16 | 119.33 | 39.14 | 42.79 | 321.82 | 222.91 | 44.00 | 51.11 | 50.44 | 43.78 | 79.44 | 38.89 | 10.00 | 23.33 |

**Table S2.** Before and after inventory and vegetation data in Stand 7 following operator select thinning and brushy management. *Plots that were marked prior to thinning.

| **Plot #** | **BA (m$^2$ ha$^{-1}$)** | | **TPH** | | **QMD (cm)** | | **Volume (M tons/ha)** | | **LLP (% BA)** | | **Lob (% BA)** | | **Woody (% Veg)** | | **Grass (% Veg)** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After |
| **49*** | 27.54 | 13.77 | 617.28 | 224.69 | 23.86 | 27.92 | 258.69 | 124.64 | 92 | 100 | 0 | 0 | 40 | 10 | 0 | 5 |
| **51*** | 27.54 | 16.06 | 404.94 | 209.88 | 29.44 | 31.22 | 298.15 | 178.89 | 100 | 100 | 0 | 0 | 45 | 10 | 0 | 15 |
| **56*** | 32.13 | 13.77 | 449.38 | 195.06 | 30.20 | 29.95 | 378.85 | 169.70 | 36 | 50 | 64 | 50 | 95 | 55 | 0 | 0 |
| **57** | 18.36 | 11.47 | 246.91 | 140.74 | 30.71 | 32.23 | 156.25 | 99.08 | 100 | 100 | 0 | 0 | 65 | 15 | 0 | 10 |
| **58** | 18.36 | 13.77 | 291.36 | 180.25 | 28.17 | 31.22 | 156.69 | 126.66 | 88 | 83 | 0 | 0 | 35 | 10 | 0 | 0 |
| **Stand** | 24.79 | 13.77 | 401.98 | 190.12 | 28.48 | 30.51 | 249.73 | 139.79 | 83.2 | 86.6 | 12.8 | 10 | 56 | 20 | 0 | 6 |