The effectiveness and potential cost-savings of operator select to manage brush and thin longleaf pine stands

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Abstract

We present a case study where loggers thinned and managed brush in longleaf pine stands that went unmanaged for a lengthy period in Trinity County, Texas, USA. Stands were overstocked and had a dense, shrubby understory from years of fire exclusion. Our main objectives were to compare the outcomes and cost-savings of loggers selecting trees to thin, or "operator select", versus timber marking, and whether they were different when attempting to restore longleaf pine stands to an open structure. We also worked closely with loggers to manage brush in place of conventional forestry mulching as a source of additional cost-savings. Twenty-one inventory plots were sampled during prethinning and post-thinning treatment stages, with half marked and the other half left unmarked. The location of unmarked plots was undisclosed to loggers and harvested by operator select methods. We measured no significant difference in forest inventory metrics at marked and unmarked plots following thinning. There was, however, better retention of longleaf pine and removal of loblolly pine in marked areas, and overall precision was higher in marked areas. QMD increased across all plots, woody vegetation decreased significantly, and reestablishment of herbaceous groundcover increased after following thinning with prescribed burning. Using this approach, an estimated $197.53 US per hectare cost for timber marking and $879.34 US per hectare for conventional mulching services was saved. This amounted to an estimated $876.35 US per hectare reduction in project cost to create open longleaf pine structure. When implementing operator select in longleaf pine stands, our results indicate that providing feedback to well qualified loggers can create comparable results to timber marking at a discounted cost, but with small tradeoffs in precision.

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 (USA). The longleaf pine ecosystem was estimated to have covered a pre-settlement area of approximately 30 to 38 million hectares (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 in the pineywoods region of Texas, USA (Randall & 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), 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).

Another recent avenue for incentivizing the establishment of longleaf pine focuses on the water yield benefits associated with open pine management (Susaeta and Gong 2019). Recent, culminating work suggests that open pine management can increase water yield, but these outcomes are often predicated on longleaf pine structure characterized by openness and herbaceous ground cover (Brantley 2018; Younger 2023). For this study, the focus was on effective management strategies for restoring longleaf pine stand in Southeast, Texas, U.S.A., with quantification of water yield being a larger, on-going effort. The areas in question were characterized by dense stocking and significant woody understory due to years of management inactivity. To create this structure, there was a need to thin the stands, remove invasive understory brush, and reintroduce prescribed fire on the site. Additionally, longleaf pine management in the southeast and Texas often focus on uneven aged silvicultural systems, such as patch selection or individual tree selection (Guildin 2006).

Timber marking would be a common approach for creating this structure, 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 comparably reliable for realizing stand prescriptions when compared to timber marking (Eberhard & Hasenauer 2021; Mengyuxin 2025). Furthermore, there may be cost-saving opportunities associated with circumventing the cost of timber marking (Love et al. 2018; Callaghan et al. 2019). The goal of this study was to determine whether operator select could be applied successfully when managing open longleaf pine stands, how it compared to areas that were marked by trained personnel, and quantifying the cost benefits of a scenario where logging operators select trees and manage understory brush simultaneously. Successful outcomes were defined as retaining larger longleaf pine at a target BA and significant reductions in dense understory brush.

To facilitate this comparison, marked and unmarked groups of plots were established on Brushy Creek management area that were inventoried before and after thinning. Close coordination and feedback were provided to loggers when applying operator select in unmarked areas. Another management outcome of interest was reducing woody understory to promote reestablishment of herbaceous groundcover, so loggers were compensated to spend extra time severing brush in place of conventional mulching. The null hypothesis was that there would be no significant difference in inventoried metrics at marked and unmarked plots before and following timber harvest, and the alternative hypothesis was that there would be a significant difference. Additional treatments after thinning, such as prescribed fire, allowed for more long-term assessments of restoration outcomes. A comparison of structural shifts and associated costs were made when using timber marking versus operator select, along with loggers managing brush in place of conventional mulching.

Methods

Study area

The 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 present-day dominant to co-dominant species in the 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 is categorized 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.).

The primary management goals on Brushy Creek were to restore existing areas of longleaf pine to a more open, savannah-like structure. Prescribed fire is an important tool for maintaining the fire-adaptive longleaf pine ecosystem (Heyward 1939; Barnett 1999), but the area had not been burned in approximately 15 to 20 years as of 2023. This contributed to a dense understory brush condition, and additionally, the site was overstocked and could benefit from thinning harvest operations.

Monitoring efforts focused on two different longleaf pine stands on Brushy Creek, which are referred to as Stand 5 and Stand 7 (Fig. 1). Stand 5 (38 ha) 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 S2). Longleaf pine (44%) and loblolly pine (*Pinus taeda* L.) (50%) were co-occurring pine species in Stand 5. Stand 7 (33 ha) 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 S3). For both stands, pre-thinning understory was primarily made up of yaupon holly (*Ilex vomitoria* Sol. ex Aiton), and little-to-no herbaceous groundcover.

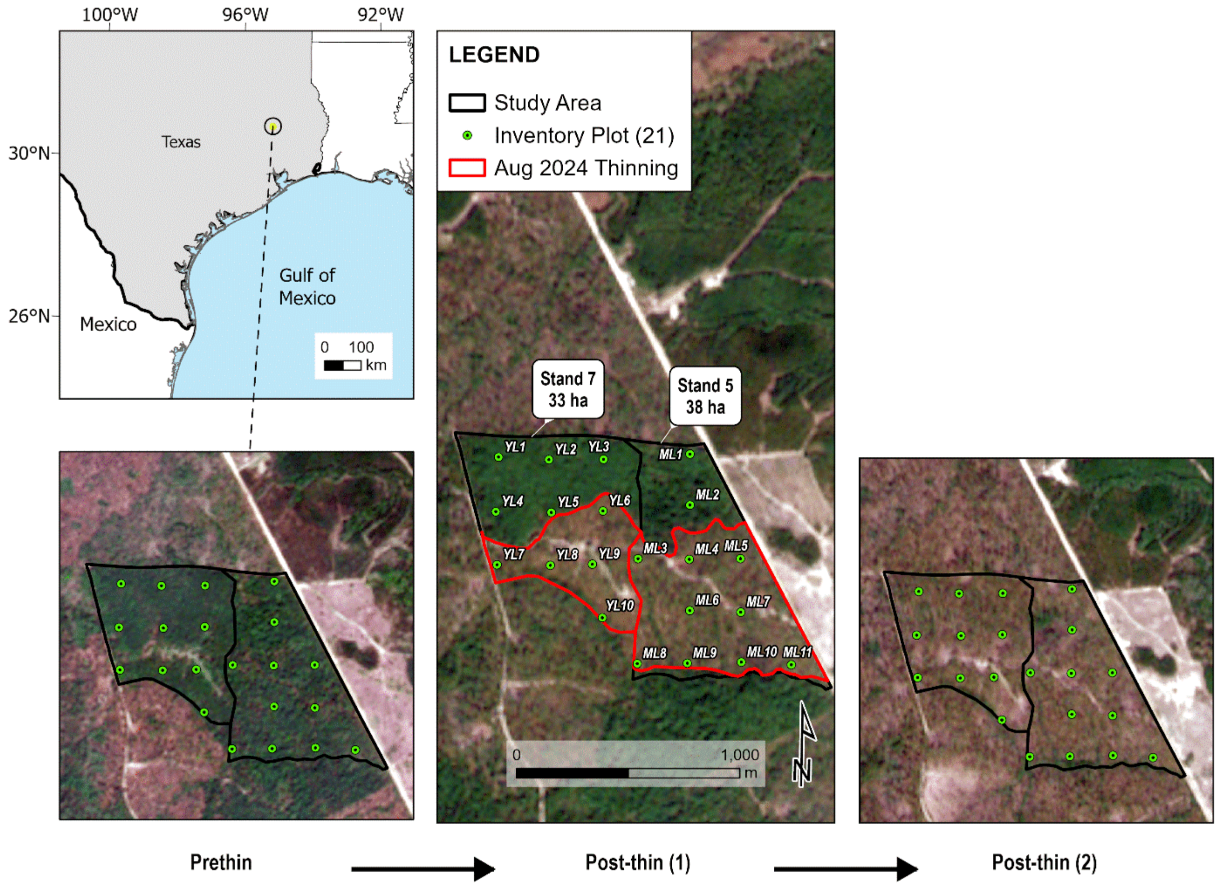

Figure 1 A map of the study area using aerial satellite imagery during pre-thinning conditions, following an initial thinning entry (August 2024), and a second thinning entry where the timber harvest was completed. Inventory plots were set up at 21 locations, and resampled multiple times.

Inventory Plot Sampling and Data Collection

The number of inventory plots and their spacing was generated using an unbiased systematic sampling design established by the US Forest Service (FSVeg Common Stand Exam 2015). FSVeg guidelines use a minimum rule of one plot per 4 ha, assuming the stand is reasonably homogenous. This amounted to 11 plots for Stand 5 (38 ha) and 10 plots for Stand 7 (33 ha). The sampling error of both pre-thinning and post-thinning inventories was calculated using a 90% confidence interval, 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.

Inventory data was collected on three dates: pre-thinning in March of 2024, a first post-thinning in September of 2024 where 14 of 21 plots were resampled, and a second post-thinning in October 2025 where all 21 plots were resampled. The first entry of thinning and brush management was carried out in August of 2024 and covered a partial area of the site where 14 plots were. The second entry occurred in August 2025 and completed the areas where the remaining 7 plots were. A variable radius point sample was taken for all ≥13.9 cm dbh (diameter at breast height = 1.37 m) trees using a 2.29 m^2 ha^{-1} BAF (basal area factor) prism. When quantifying groundcover classes of woody brushy or grass, a fixed radius area of 40.47 m^2 in size was assessed. 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 Forest METRIX Pro software. Outputs that were used for analysis include BA, TPH, QMD, and volume. Also included in analysis later was the percent cover of woody brush and grass groundcover, and trees species composition before and after thinning.

Silvicultural Treatments and Harvest Operations

Hodge Logging, a local logger with strong familiarity with the area, was selected for the project because of their long history and experience doing operator select thinning on public lands around Brushy Creek. Their operators used a 2014 Caterpillar 559C loader, 2019 843L-II wheeled feller buncher, and a 2018 748L-II grapple skidder to conduct thinning operations. Prior to thinning, 10 of the 21 total plots in Stand 5 and Stand 7 were marked to a target BA of 13.77 m^2 ha^{-1}. This amounted to 6 unmarked and 5 marked plots in Stand 5, and 5 unmarked and 5 marked plots in Stand 7. To determine the extent of a marked plot, every tree falling within the variable radius plot using a 2.29 m^2 ha^{-1} BAF prism was either marked or unmarked to the target BA. Marked plots were 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 (Fig. 2). When thinning in marked plots, loggers were instructed to cut everything but the predetermined trees. Routine site visits were conducted during this period, with feedback provided to Hodge Logging at least once a week on whether they were meeting targeted outcomes. With unmarked plots, loggers were unaware of the locations of the plots and based their selection criteria off instructions mimicking marked plot criteria: retain large, healthy longleaf pine as often as possible.

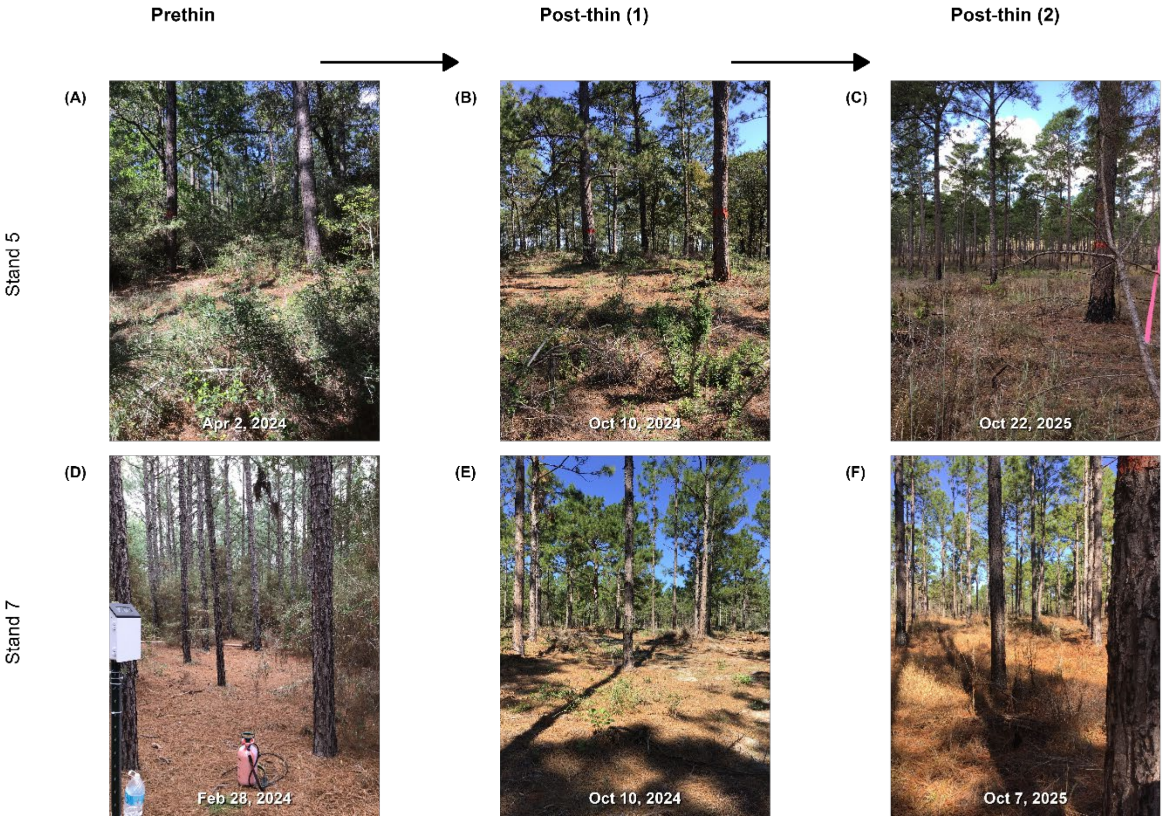

Figure 2 Examples of thinning and brush management outcomes at marked plot ML7 in Stand 5 and marked plot YL8 in Stand 7. Orange "leave-tree" paint was applied to healthy, large longleaf pine, and can be observed in

images (B), (C), and (F). (A & D) Pre-thinning inventories were conducted around March 2024, and plots were resampled after two thinning entries. (B & E) The first post-thinning inventory occurred in October 2024, and (C & F) a second post-thinning inventory occurred in October 2025. A prescribed burn and understory herbicide treatments occurred between these two thinning entries.

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 conventional forestry mulcher, it did top kill and lay down standing woody fuels. Prior to the final resampling of inventory plots in October of 2025, both Stand 5 and 7 were prescribed burned on March 2nd, 2025, and treated with understory herbicide on August 4th, 2025. This enabled an assessment of longer-term effects on vegetation following thinning and brush management (Figure 2).

Analysis: Hypothesis Testing, Stand Structure, and Project Costs

Hypothesis testing was organized into two groups: testing of marked versus unmarked plots from pre-thinning and plots from post-thinning (2). One plot was excluded from analysis in the post-thinning (2) data because it was impacted heavily by the March 2nd, 2025, prescribed fire. Upon further review, data for Stands 5 and 7 were combined, despite their age and structural differences. It did not appear that their differences significantly impacted the outcome of the analysis. In addition to using unbiased systematic sampling when setting up inventory plots, marked and unmarked plots were distributed evenly throughout the grid of 21 plots. These sampling criteria followed a systematic design of independent replicates that avoided pseudoreplication and allowed inferential testing (Hurlbert 1984).

An analysis of post-thinning inventory metrics comparing marked and unmarked plots was conducted using a Mann-Whitney U test at a $\alpha = 0.05$ significance level ($p > 0.05$) in RStudio, version 2024.04.2

Build 764. Before carrying out statistical tests, a Shapiro Wilks test of normality and Levene's test for equality of variances was used on marked and unmarked groups within eight individual datasets: basal area (m^2 ha^{-1}), TPH, QMD (cm), longleaf pine species composition (%), volume (metric tons ha^{-1}), woody groundcover (% cover), and grass groundcover (% cover). Several examples of violations of normality and equal variance were identified at a $\alpha = 0.05$ significance level. This led to the selection of the Mann-Whitney U test, which does not require assumptions of equal variance or normally distribution data. The Mann-Whitney U test also accommodated a small group size ($n = 10$ or 11) by evaluating significant differences in group ranks. Following hypothesis testing, descriptive statistics of inventory data was used to compare the effectiveness of restoration treatments in marked versus unmarked areas.

Inventory results of operator select versus timber marking were compared along with the cost associated with each approach (Table S1). Additionally, a real project cost of $200.52 US dollars per hectare for loggers to manage brush was compared to recent cost estimates for conventional mulching services in the southern USA (Maggard & Natzke 2024). On average, timber marking cost $197.53 per hectare and forestry mulching was $469.13 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

Hypothesis Testing

The study's null hypothesis was that there would not be a significant difference in forest attributes in marked and unmarked plots following longleaf pine thinning. Mann-Whitney U test results indicate that there was not a significant difference of ranks in major forest attributes before (Figure 3) and following forest thinning (Figure 4), regardless of whether a plot was marked or not marked ($p > 0.05$). The alternative hypothesis was rejected and the null hypothesis was accepted for BA (m^2 ha^{-1}), TPH, QMD (cm), volume (metric tons/ha), LLP species composition, woody groundcover, and grass groundcover when comparing groups of marked and unmarked plots.

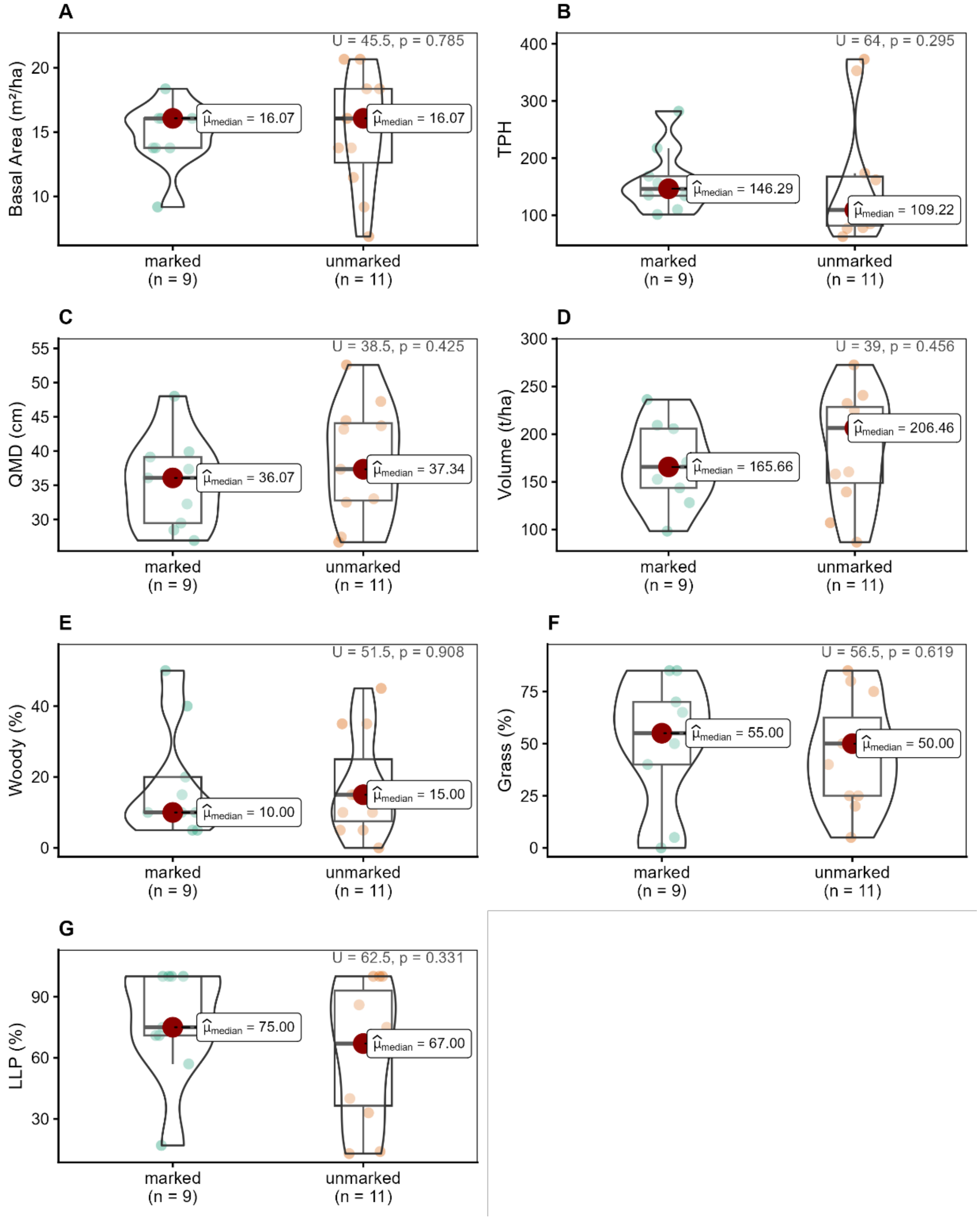

Figure 3 Results of Mann-Whitney U on pre-thinning inventory data where (A) BA, (B) TPH, (C) QMD, (D) volume, (E) woody groundcover, (F) grass groundcover, (G) and LLP species composition in marked and unmarked

plots were compared on Brushy Creek. No significant differences of ranks were observed between marked and unmarked groups.

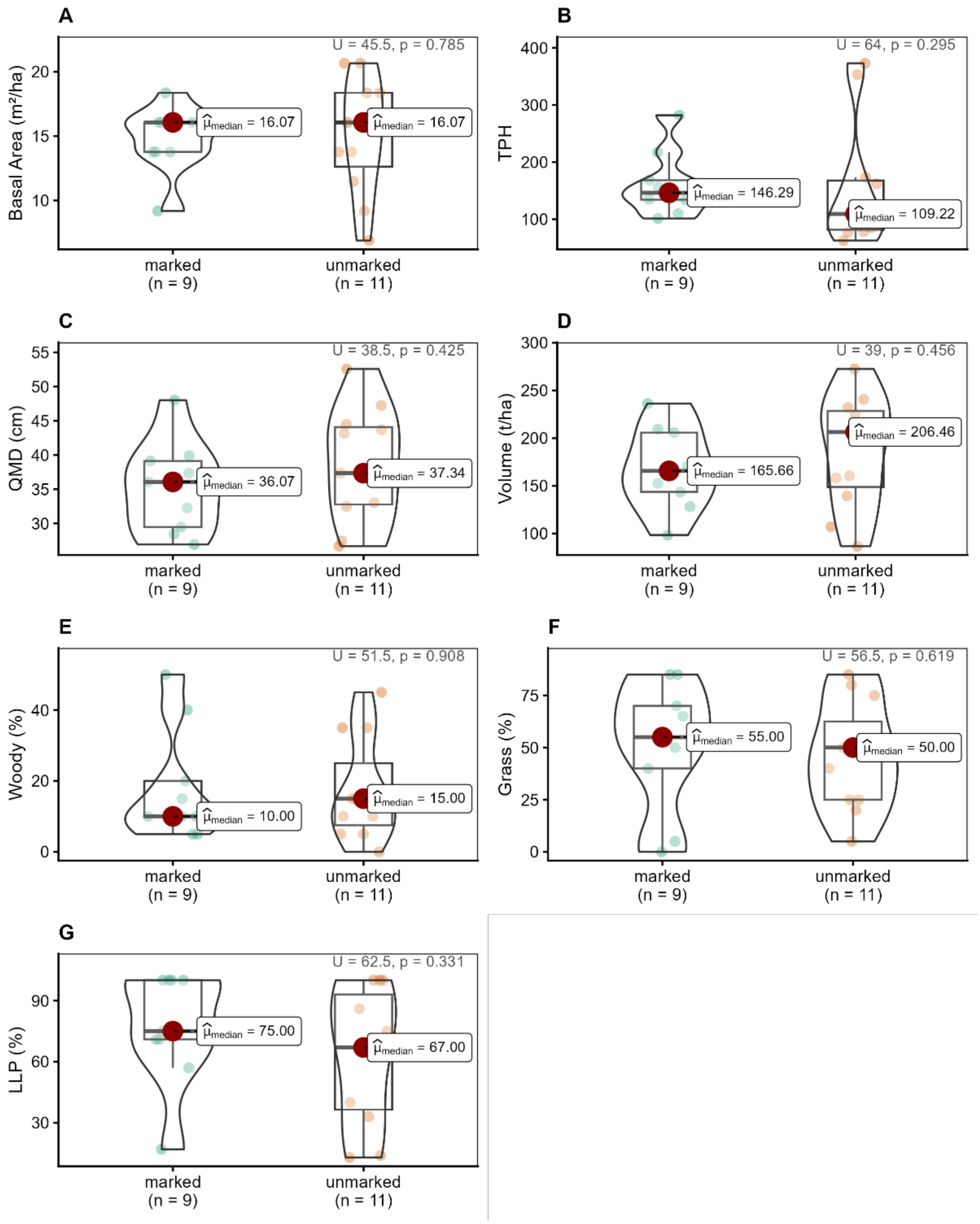

Figure 4 Results of Mann-Whitney U on post-thinning (2) inventory data where (A) BA, (B) TPH, (C) QMD, (D) volume, (E) woody groundcover, (F) grass groundcover, (G) and LLP species composition in marked and unmarked

plots were compared on Brushy Creek. No significant differences of ranks were observed between marked and unmarked groups.

Marked versus Unmarked Forest Structure Shifts

Small measurable increases in longleaf pine dominance were observed in Stand 5 (4.36%) and almost no change in Stand 7 (0.57%) post-thinning (Table S2). Average longleaf pine composition change at marked plots accounted for increases (prethin = 69.20% → post-thin (2) = 76.78%), whereas there were small decreases in longleaf pine composition at unmarked plots (prethin = 66.64% → post-thin (2) = 63.18%) (Table S3). When selecting against, or cutting loblolly, a similar trend was observed. Average loblolly pine species composition decreased in marked plots (prethin = 24.80% → post-thin (2) = 13%) and increased slightly in unmarked plots (prethin = 29% → post-thin (2) = 30.09%) (Figure 5).

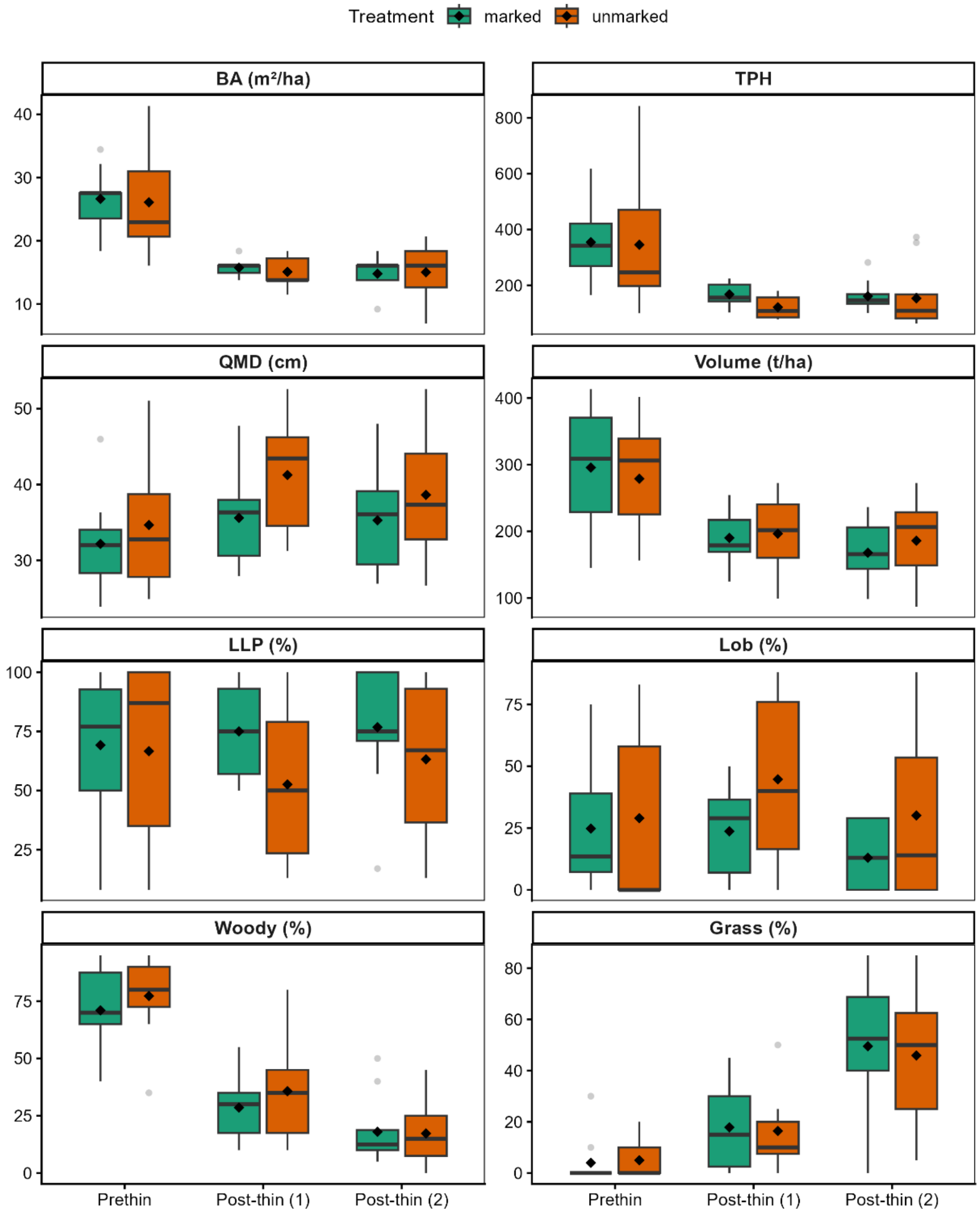

Figure 5 Boxplots of BA, TPH, QMD, volume, woody groundcover, grass groundcover, and LLP species composition for three treatment stages on Brushy Creek.

A target BA of 13.77 m^2 ha^{-1} was achieved in Stand 7 ($\bar{x}$ = 13.77 m^2 ha^{-1}), whereas Stand 5 was above the study's target ($\bar{x}$ = 15.86 m^2 ha^{-1} BA), with the latter having more residual BA at the second post-thinning stage (Table S2). Average post-thinning BA was 14.79 m^2 ha^{-1} in marked plots and 15.03 m^2 ha^{-1} in unmarked plots, indicating marking resulted in a marginally better outcome for achieving target BA. Marked plots were also less variable in post-thinning BA, with a standard deviation (SD) of 2.60 m^2 ha^{-1} and standard error (SE) of 0.87 m^2 ha^{-1} (Table S3). This is compared to an SD of 4.52 m^2 ha^{-1} and SE of 1.36 m^2 ha^{-1} for unmarked plots. When evaluating all variables in the second post-thinning inventory, SE and SD were higher at unmarked plots for six noteworthy attributes: BA, TPH, QMD, volume, percent of longleaf pine, and percent of loblolly pine (Table S3). Increases in QMD were observed across all marked ($\bar{x}$ = 3.1 cm) and unmarked plots ($\bar{x}$ = 3.97 cm), except for unmarked plot ML11 in Stand 5 (-1.52 cm) and marked plot 56 in Stand 7 (-0.25 cm).

First and second post-thinning inventories revealed important changes in groundcover conditions (Figure 5). Woody vegetation experienced a large reduction immediately after thinning in both Stand 5 (79% → 39%) and Stand 7 (69% → 29%) (Table S2). After prescribed burning and herbicide treatments, further reductions were observed, but to a lesser degree in Stand 5 (39% → 13%) and a small increase occurred in Stand 7 (20 → 23%). Grass cover increased in both stands, at both stages, but with a much larger increase following prescribed burning and herbicide treatments. Prethin, post-thin (1), and post-thin (2) changes were 9% → 23% → 63% for Stand 5 and 0% → 6% → 31% for Stand 7.

Comparison of Project Costs

Using averages of recent forestry practice costs in the southern USA, the costs to timber mark Stands 5 and 7 was estimated at $14,024.63 (Maggard & Natzke 2024), compared to no cost when using operator select (Table S3). In addition to averages for mulching costs in the south, recent project costs for mulching services on other parts of Brushy Creek were considered. This amounted to an estimated costs of $928.88 per hectare or $62,433.37 to conventionally mulch Stands 5 and 7. This is compared the project's real incurred cost of $14,236.92 or $200.53 per hectare to thin and manage brush using the sawhead feller. The total estimated cost to timber mark and conventionally mulch Stands 5 and 7 was

$76,458 or $1,076.87 per hectare. This translates to a potential project savings of $62,221.08 or $876.35 per hectare.

Discussion

Key findings were that operator select versus marked tree thinning did not result in significantly different BA, TPH, QMD, volume, longleaf pine species composition, woody vegetation, and grass vegetation ($p > 0.05$ for all metrics). However, targeted forest structure in unmarked areas where operator select was used were less precise than marked areas, as indicated by higher SD and SE in unmarked plots. BA was marginally higher than targets where timber marking was not used, but most notably, a small reduction of longleaf species composition was observed where operator select was used. This is compared to a small increase where timber marking was used. Increases in QMD were achieved in marked and unmarked areas, indicating that loggers were doing an adequate job of selecting larger trees. The results suggest that operator select yielded similar outcomes, but with compromises in precision when compared to using timber marking.

Operator select required clear communication of what the 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. The goal of these interactions was to provide quality-control, while also establishing rapport and trust, a communication dynamic that is not always present between foresters and loggers (Keefer et al. 2003). In one study, foresters most cited reason for marking or not marking a stand was because they trusted the loggers to leave quality, residual trees (Egan and Phillips, 2006). For our study, and others, the relationship between foresters and loggers appears to be primary criteria for whether operator select is possible. Future work should focus on whether the southeast USA has an adequate network of qualified loggers to manage operator select in longleaf pine stands, and whether it can be implemented more programmatically.

The large amount of standing timber on Brushy Creek provided a straightforward decision process for loggers, leading to less opportunity for error. It has been previously established that straightforward stand prescriptions might not require timber marking (Spinelli et al. 2016). The forestry industry in the southern USA regularly uses operator select in highly uniform, pine plantation settings (Coble & Grogan 2016). Documentation of operator select in longleaf pine management specifically, however, is not as readily available. As of this reading, there are limited published works on the results of operator select in the longleaf pine ecosystem. Most case studies in the USA compared timber marking silvicultural practices (Cannon et al. 2022), whereas studies comparing marked and unmarked scenarios were more numerous in Europe. They often focused on timber harvest efficiency, rather than structural outcomes. There were examples of increased efficiency when marking (Vahtila et al. 2024), and no difference in productivity when marking or not in others (Eberhard and Hasenauer 2021). In another case study, there was no significant difference in the trees selected by markers versus operators (Holzleitner et al. 2019). Overall, previous studies suggest that where operator select is used effectively is circumstantial, and depending on the goals for the site, it may not be appropriate for all scenarios. The results of this study are similar, with operator select being appropriate for managing longleaf pine restoration if a high-level of precision is not imperative, and cost-savings is a priority.

The use of the sawhead feller to manage understory fuels resulted in notable reductions in brush cover during both post-thinning treatment phases. Herbaceous groundcover increased a small amount after thinning, followed by a large increase once prescribed burning was reintroduced the site. The indication was that appropriately timed follow-up treatments were important for continuing to accomplish the targeted vegetation shifts. As expected, timber marking was inconsequential to vegetation outcomes: marked and unmarked plots were not significantly different, and there were less examples of higher precision in marked areas in the form of greater SD and SE.

Vegetation shifts were an important management objective for the project. Successful restoration efforts in an open longleaf pine system are reliant on groundcover fuels that allow low-intensity, repeated intervals of fire (Gilliam & Platt 1999). Timber marking and thinning, followed by conventional mulching is an expensive management technique relative to our approach, estimated at $876.35 more per hectare. This estimation could vary across fuel types, however, and is reliant on timber harvest being a necessary management practice. Compared to conventional mulching, brushy understory fuels are not masticated using this approach and resprouting could occur without follow-up treatments. 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).

Conclusion

Our conclusion is that using operator select in place of timber marking can be a conditional option for restoring longleaf pine ecosystems in the Southeastern USA. Some of those conditions include straightforward thinning prescriptions, more time spent providing oversight to well-qualified loggers, and anticipation of lower precision outcomes when compared to marking a stand beforehand. Not all scenarios are appropriate for this approach, with timber marking recommended when creating more complex longleaf stand structure, such as in group or patch selection regeneration methods. Future work should focus on creating more replications across study sites, and the introduction of more loggers to determine if operator select could be implemented more programmatically in longleaf pine projects. Existing projects would benefit from continued monitoring of how successive treatments impact and maintain groundcover that supports prescribed fire. For Brushy Creek, high densities of standing volume allowed for a relatively straightforward harvest prescription, and ultimately, the goals of the project were achieved using operator select. Compensating loggers for brush management services enabled significant cost-savings for the project’s initial stages of management, and when followed with prescribed burning, targeted vegetation shifts were effectively accomplished.

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.

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Declarations

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Author Brett Lawrence served as a consultant to Texan by Nature but has no financial or non-financial interests to declare that are relevant to the content of this article. Additionally, Dr. Matthew McBroom serves as an associate editor of soils and hydrology at *Forest Science* but will have no part in the editorial management of the manuscript. Outside of these disclosures, the authors also have no competing interests to declare.

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Supporting Information

Table S1 A summary of costs for timber marking and mulching according to southeastern US averages (Maggard & Natzke 2024), and real cost for brush management services on Brushy Creek.

Southeastern Regional Costs				
Product	Average cost per ha US. South	Average Marked BA	Average Tract Size (ha)	n
Timber Marking - Pine	$197.53	10.33	4.0	2
Mulching - Single Pass	$469.13	-	52.2	2
Local Costs for Brushy Creek				
Product	Cost per ha			
Mulching (bid and contracted)	$933.37			
Mulching (bid, not contracted)	$1,235.53			
Brush Management by Loggers	$200.52			

Table S2 Inventory results for 21 plots in Stand 5 (Mature Longleaf) and Stand 7 (Young Longleaf) on Brushy Creek. All plots were sampled pre-thinning (March 2024), a subset of 14 were sampled post-thinning (October 2024), and all were resampled after prescribed burning and herbicide treatments (October 2025).

Plot #	**Marked/ Unmarked**	**BA (m²/ha)**			**TPH**			**QMD (cm)**			**Volume (metric tons/ha)**			**LLP(%)**			**Lob (%)**			**Woody (%)**			**Grass (%)**		
		Prethin	Post-thin (1)	Post-thin (2)	Prethin	Post-thin (1)	Post-thin (2)	Prethin	Post-thin (1)	Post-thin (2)	Prethin	Post-thin (1)	Post-thin (2)	Prethin	Post-thin (1)	Post-thin (2)	Prethin	Post-thin (1)	Post-thin (2)	Prethin	Post-thin (1)	Post-thin (2)	Prethin	Post-thin (1)	Post-thin (2)
ML1	marked	27.55	no data	13.77	266.13	no data	109.96	36.32	no data	39.88	359.57	no data	165.66	8	no data	17	75	no data	17	65	no data	10	0	no data	70
ML2	unmarked	22.96	no data	16.07	188.29	no data	103.04	39.37	no data	44.45	255.33	no data	216.10	100	no data	86	0	no data	14	90	no data	45	0	no data	20
ML3	marked	34.44	16.07	16.07	386.72	129.48	134.18	33.78	39.62	39.12	413.37	215.43	209.37	93	86	71	7	14	29	90	35	15	0	0	65

ML4	marked	22.96	16.07	16.07	254.02	155.92	156.42	34.04	36.32	36.07	218.79	168.58	170.59	50	57	57	40	29	29	70	25	5	0	30	85
ML5	unmarked	22.96	16.07	16.07	207.07	108.73	109.22	37.59	43.43	43.18	306.22	243.90	232.24	20	14	14	80	86	86	95	80	15	0	5	25
ML6	unmarked	22.96	18.37	18.37	112.19	84.76	85.00	51.05	52.58	52.58	346.79	272.59	272.59	60	75	75	40	40	25	75	35	0	15	50	80
ML7	marked	27.55	18.37	18.37	165.31	102.80	101.31	45.97	47.75	48.01	374.14	254.43	236.28	50	75	75	17	33	13	80	35	10	10	45	85
ML8	unmarked	25.25	13.77	13.77	220.42	78.09	78.33	38.10	47.24	47.24	353.07	201.75	206.46	27	33	33	73	66	67	90	35	5	5	10	75
ML9	marked	25.25	16.07	16.07	277.25	155.92	146.29	34.04	36.32	37.34	319.67	218.79	205.79	45	57	71	55	40	29	65	30	20	30	30	50
ML10	unmarked	27.55	18.37	18.37	324.70	173.22	173.47	32.77	36.83	36.83	331.32	236.95	240.76	8	13	13	83	88	88	70	20	5	15	15	50
ML11	unmarked	16.07	13.77	11.48	100.57	85.75	76.85	45.21	45.21	43.69	232.91	193.91	160.51	43	50	40	43	33	40	80	55	10	20	25	85
Avg.		**25.04**	**16.32**	**15.86**	**227.52**	**119.41**	**115.82**	**38.93**	**42.81**	**42.58**	**319.20**	**222.92**	**210.58**	**45.82**	**51.11**	**50.18**	**46.64**	**47.67**	**39.73**	**79.09**	**38.89**	**12.73**	**8.64**	**23.33**	**62.73**
YL1	unmarked	34.44	no data	20.66	649.39	no data	352.87	25.91	no data	27.43	217.89	no data	158.26	87	no data	67	0	no data	11	90	no data	35	0	no data	5
YL2	marked	22.96	no data	16.07	426.75	no data	281.95	26.16	no data	26.92	190.54	no data	128.23	90	no data	100	10	no data	0	70	no data	40	0	no data	0
YL3	unmarked	41.32	no data	20.66	842.38	no data	372.88	24.89	no data	26.67	309.35	no data	224.84	100	no data	100	0	no data	0	85	no data	35	0	no data	50
YL4	marked	18.37	no data	9.18	297.02	no data	135.17	27.94	no data	29.46	145.04	no data	98.41	100	no data	100	0	no data	0	90	no data	50	0	no data	40

YL5	unmarked	36.73	no data	9.18	616.53	no data	111.44	27.43	no data	32.51	401.71	no data	107.15	100	no data	100	0	no data	0	75	no data	15	0	no data	40
YL6	marked	27.55	16.07	13.77	404.26	209.05	168.28	29.46	31.24	32.26	298.15	178.89	152.66	100	100	100	0	0	0	45	10	5	0	15	5
YL7	unmarked	18.37	13.77	6.89	291.58	180.39	62.76	28.19	31.24	37.34	156.69	126.66	86.75	88	83	67	0	0	0	35	10	15	0	0	50
YL8	marked	27.55	13.77	13.77	617.27	224.37	217.45	23.88	27.94	28.45	258.69	124.64	143.69	92	100	100	8	0	0	40	10	10	0	5	55
YL9	unmarked	18.37	11.48	13.77	246.12	140.36	161.85	30.73	32.26	33.02	156.25	99.08	139.43	100	100	100	0	0	0	65	15	10	0	10	25
YL10	marked	32.14	13.77	no data	450.47	195.95	no data	30.23	29.97	no data	378.85	169.70	no data	64	50	no data	36	50	no data	95	55	15	0	0	40
Avg.		**27.78**	**13.77**	**13.77**	**484.18**	**190.02**	**207.18**	**27.48**	**30.53**	**30.45**	**251.32**	**139.79**	**137.72**	**92.10**	**86.60**	**92.67**	**5.40**	**10.00**	**1.22**	**69.00**	**20.00**	**23.00**	**0.00**	**6.00**	**31.00**

Table S3 Descriptive statistics for inventory variables on Brushy Creek. Variables include BA, TPH, QMD, Volume, percentage of LLP, percentage of loblolly pine, percentage of woody brush, and percentage of grass. Descriptive statistics are broken into marked and unmarked plots for each variable, and further broken into treatment stages: prethin, post-thin (1) and post-thin (2).

Treatment	Time	Variable	n	mean	sd	se	median	min	max
marked	Prethin	BA (m^2/ha)	10	26.63	4.62	1.46	27.55	18.37	34.44
unmarked	Prethin	BA (m^2/ha)	11	26.09	8.17	2.46	22.96	16.07	41.32
marked	Post-thin (1)	BA (m^2/ha)	7	15.74	1.58	0.60	16.07	13.77	18.37
unmarked	Post-thin (1)	BA (m^2/ha)	7	15.09	2.60	0.98	13.77	11.48	18.37
marked	Post-thin (2)	BA (m^2/ha)	9	14.79	2.60	0.87	16.07	9.18	18.37
unmarked	Post-thin (2)	BA (m^2/ha)	11	15.03	4.52	1.36	16.07	6.89	20.66
marked	Prethin	TPH	10	354.52	129.08	40.82	341.87	165.31	617.27
unmarked	Prethin	TPH	11	345.39	244.92	73.85	246.12	100.57	842.38
marked	Post-thin (1)	TPH	7	167.64	44.10	16.67	155.92	102.80	224.37
unmarked	Post-thin (1)	TPH	7	121.61	43.16	16.31	108.73	78.09	180.39
marked	Post-thin (2)	TPH	9	161.22	56.63	18.88	146.29	101.31	281.95
unmarked	Post-thin (2)	TPH	11	153.43	109.12	32.90	109.22	62.76	372.88
marked	Prethin	QMD (cm)	10	32.18	6.25	1.98	32	23.88	45.97
unmarked	Prethin	QMD (cm)	11	34.66	8.41	2.54	32.77	24.89	51.05
marked	Post-thin (1)	QMD (cm)	7	35.60	6.76	2.56	36.32	27.94	47.75
unmarked	Post-thin (1)	QMD (cm)	7	41.26	8.01	3.03	43.43	31.24	52.58
marked	Post-thin (2)	QMD (cm)	9	35.28	6.73	2.24	36.07	26.92	48.01
unmarked	Post-thin (2)	QMD (cm)	11	38.63	8.31	2.51	37.34	26.67	52.58
marked	Prethin	Volume (metric tons/ha)	10	295.68	89.82	28.40	308.91	145.04	413.37
unmarked	Prethin	Volume (metric tons/ha)	11	278.87	81.23	24.49	306.22	156.25	401.71
marked	Post-thin (1)	Volume (metric tons/ha)	7	190.06	42.61	16.11	178.89	124.64	254.43
unmarked	Post-thin (1)	Volume (metric tons/ha)	7	196.40	63.34	23.94	201.75	99.08	272.59
marked	Post-thin (2)	Volume (metric tons/ha)	9	167.85	43.39	14.46	165.66	98.41	236.28
unmarked	Post-thin (2)	Volume (metric tons/ha)	11	185.92	59.26	17.87	206.46	86.75	272.59
marked	Prethin	LLP (%)	10	69.20	30.75	9.72	77	8	100
unmarked	Prethin	LLP (%)	11	66.64	36.21	10.92	87	8	100
marked	Post-thin (1)	LLP (%)	7	75.00	20.99	7.93	75	50	100
unmarked	Post-thin (1)	LLP (%)	7	52.57	34.45	13.02	50	13	100
marked	Post-thin (2)	LLP (%)	9	76.78	27.82	9.27	75	17	100
unmarked	Post-thin (2)	LLP (%)	11	63.18	33.38	10.06	67	13	100
marked	Prethin	Lob (%)	10	24.80	25.60	8.09	13.5	0	75
unmarked	Prethin	Lob (%)	11	29.00	35.80	10.79	0	0	83
marked	Post-thin (1)	Lob (%)	7	23.71	19.53	7.38	29	0	50
unmarked	Post-thin (1)	Lob (%)	7	44.71	36.94	13.96	40	0	88
marked	Post-thin (2)	Lob (%)	9	13.00	13.51	4.50	13	0	29
unmarked	Post-thin (2)	Lob (%)	11	30.09	34.94	10.54	14	0	88
marked	Prethin	Woody (%)	10	71.00	18.53	5.86	70	40	95
unmarked	Prethin	Woody (%)	11	77.27	16.94	5.11	80	35	95
marked	Post-thin (1)	Woody (%)	7	28.57	15.74	5.95	30	10	55
unmarked	Post-thin (1)	Woody (%)	7	35.71	24.74	9.35	35	10	80
marked	Post-thin (2)	Woody (%)	10	18.00	15.13	4.78	13	5	50
unmarked	Post-thin (2)	Woody (%)	11	17.27	14.55	4.39	15	0	45
marked	Prethin	Grass (%)	10	4.00	9.66	3.06	0	0	30

unmarked	Prethin	Grass (%)	11	5.00	7.75	2.34	0	0	20
marked	Post-thin (1)	Grass (%)	7	17.86	17.53	6.62	15	0	45
unmarked	Post-thin (1)	Grass (%)	7	16.43	16.76	6.34	10	0	50
marked	Post-thin (2)	Grass (%)	10	49.50	29.48	9.32	53	0	85
unmarked	Post-thin (2)	Grass (%)	11	45.91	26.16	7.89	50	5	85