HARVESTING PRODUCTIVITY AND DISTURBANCE ESTIMATES OF THREE SILVICULTURAL PRESCRIPTIONS ON THE DANIEL BOONE NATIONAL FOREST, KENTUCKY

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Abstract.—A large-scale silvicultural assessment designed to examine the effectiveness of five treatments in reducing the potential impacts of gypsy moth infestation and oak decline was implemented on upland hardwood forests in the Daniel Boone National Forest in southeastern Kentucky. The study was authorized via the Healthy Forests Restoration Act of 2003. The goal of the treatments was to improve the health and vigor of the stands through five different prescriptions. Three of the treatments required mechanized harvesting to achieve the desired stand condition, one treatment utilized herbicides to treat the midstory vegetation, and the final treatment was an unaltered control. This paper discusses the harvesting productivity and soil disturbance associated with the three mechanized harvest treatments.

INTRODUCTION

A large-scale study was implemented to assess the effectiveness of five different silvicultural treatments in limiting the impacts of gypsy moth and oak decline on the Daniel Boone National Forest in southeastern Kentucky. Oak decline is a naturally occurring condition attributed to advanced tree age and adverse climate and site conditions. The combination of these stresses with the effects of forest pests can lead to the premature death of oak-dominated forest stands. Occurrences of oak decline have been recorded since the early 1900s throughout New England, the Middle Atlantic, and the Southeastern United States. Symptoms of oak decline include a progressive dying back from the tips of the branches and dwarfed or sparse foliage and premature autumn leaf color and leaf drop (Wargo and others 1983).

The gypsy moth is a nonnative pest first introduced to the United States in 1869. Over the past 140 years the moth has slowly spread from its introduction point in Boston, MA, to include the entire Northeast and now the Southern Appalachians. The gypsy moth feeds on tree foliage. Cyclic outbreaks of the insect can result in the defoliation of entire stands. The stresses of gypsy moth and other pests, such as shoestring root rot and the two-lined chestnut borer, in combination with oak decline, can lead to mass mortality of oak-dominant forests (Hoyle 2007).

Previous research suggests that the impact of oak decline and gypsy moth infestations can be limited by preparing the forest before stress introduction. Silvicultural treatments aimed at decreasing competition and increasing regeneration and tree vigor have been shown to lessen the impacts of oak decline and gypsy moth infestations.

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This study implements four silvicultural treatments and a control to test their effectiveness against oak decline and the gypsy moth. The study is being conducted by a multidisciplinary research team composed of U.S. Department of Agriculture Forest Service and university researchers. Research will include studies of not only the silvicultural effects, but also the effects on wildlife, soils, and selection of harvesting methods and equipment. This paper focuses on the production, efficiency, and impacts of the harvesting systems used to implement the silvicultural prescriptions.

STUDY AREAS

The study was implemented on the London Ranger District of the Daniel Boone National Forest in southeastern Kentucky. The harvesting units are located west of London in the Cold Hill area with oak- and hickory-dominated stands ranging in age from 70 to 150 years. The units are generally located on broad ridges with some moderate side slopes (up to 30 percent). Soils are highly weathered, low-fertility Ultisols. Stand density before harvest ranged from 100 to 120 ft^2/ac and 140 to 160 stems/ac.

The study was designed as a randomized complete block on two site types (dry-mesic and dry-xeric) with five treatments (Table 1): shelterwood with reserves, oak shelterwood, B-line thinning, oak woodland, and a control (Schweitzer and others 2008). There are three replicates for a total of 30 units equaling almost 600 acres. Eighteen of the 30 units were mechanically harvested, six of the units were treated chemically, and the remaining six were retained undisturbed as controls. Harvesting began in May 2007 and was completed in August 2009.

METHODS

A mechanical tree-length harvesting system was used to harvest all units. The system consisted of a feller buncher, grapple skidder, and a knuckleboom loader. Trees larger than 23 inches diameter at breast height (d.b.h.) were felled with a chainsaw. All limbing and topping was performed with a chainsaw in the stand. Products removed from the units included hardwood sawtimber and biomass logs. A biomass log was any material greater than 3 inches in diameter, reasonably straight, at least 10 feet long, and not meeting merchantability specifications of a saw log.

The Forest Operations Research Unit of the U.S. Forest Service in Auburn, AL, measured the productivity and efficiency of the harvesting system and its impact on the stand. Due to the number of acres to be treated and the extended time frame taken to complete the harvesting, data recorders were used to capture gross

Table 1.—Treatments on the research study examining sustaining oak systems amid threat of gypsy moth infestation and oak decline on the Daniel Boone National Forest.

Treatment	Prescription
1. Control	No burn, no disturbance
2. Shelterwood w/ Reserves	10-15 ft^2/ac residual BA[a], mechanical harvest
3. Oak Shelterwood	60-75 ft^2/ac residual BA, herbicide treatment
4. Thinning to B-line	Gingrich's Stocking Chart, mechanical harvest
5. Woodland Thinning	30-50 ft^2/ac residual BA, mechanical harvest

[a]BA = Basal area

harvesting data. Detailed observation of the chainsaw limbing and topping component of the harvesting system was not performed. A utilization rate of 50 percent was used for the chainsaw and laborer. The goal was to measure the machine productive time required for the harvesting system to harvest each unit of each treatment. These data along with the amount of timber removed from each unit allowed for the calculation of unit productivity and an estimate of cost and efficiency.

A Yellow Activity Monitoring System (YAMS) activity recorder was fitted to each machine in the harvesting system to capture productive machine hours (PMH). The YAMS recorders are capable of recording 114 hours of productive machine time before requiring a download. Assuming 8 productive hours a day, the recorders have to be downloaded only approximately every 14 working days or every 3 weeks (Thompson 2002). The feller buncher was also equipped with a MultiDAT Jr. data recorder/global positioning system unit (Castonguay Électronique Inc., Pointe-Claire, Quebec) to provide spatial data regarding the cutting pattern and acreage cut per day. Timber volume removed from each unit was calculated from the consumer-scale load tickets which were supplied by the timber purchaser to the Forest Service as part of the timber sale agreement.

Each unit was assessed using the point transect method (McMahon 1995) to measure the site disturbance caused by the harvesting operations. Nine mutually exclusive disturbance classes were used. Each sample point was further classified by a location type (Table 2).

RESULTS AND DISCUSSION

The research study required that the harvesting be completed with a mechanical harvesting system. The harvesting equipment initially consisted of a rubber-tired feller buncher, a tracked swing-to-tree feller buncher, two grapple skidders, and a knuckleboom loader. The rubber-tired feller buncher was equipped with a shear felling head with the assumption that smaller biomass material could be felled more effectively with such a machine. After a few weeks, however, the contractor decided that it was better to do all felling with the tracked feller buncher. To balance system productivity, the rubber-tired feller buncher and one of the grapple skidders were removed from the crew. Later in 2007, the tracked feller buncher was replaced with a similar machine with a disc saw. This machine remained with the crew for the rest of the study. Adverse (wet) weather conditions resulted in the extension of the harvesting well beyond the desired completion date of the end of the second growing season (winter 2008). The wet weather and the resulting slower harvesting productivity led to the decision to add a second harvesting crew (contractor 2) in June 2008. The second harvesting

Table 2.—Disturbance classes and location types used to describe harvesting impacts.

Disturbance Class	Location
Undisturbed	Landing
Disturbed w/ litter in place	Primary skid trail
Litter removed & topsoil exposed	Secondary skid trail
Litter removed & mineral soil exposed	Stand area
Litter & soil mixed	Road
Soil exposed > 4 inches	Other (stream bed, streamside management zone)
Non-soil (e.g., stumps, rocks, logs)	
Logging slash	
Soil deposited on top of ground	

contractor was equipped similarly to the first. In early 2009, the first harvesting crew (contractor 1) stopped participating in the timber harvesting. The equipment models and operating cost for both crews are listed in Table 3. System costs were calculated using the machine rate method (Miyata 1980, Brinker and others 2002) and include ownership, operating costs, and labor costs, but do not include profit and overhead.

In an effort to complete the harvesting by the end of the second growing season, the harvesting crews were allowed to work through the normal winter shutdown period (December to April). The crews were closely monitored and not allowed to exceed site disturbance limits set by the Forest Service. Working through the winter months did speed up harvesting but included extended periods of idle time when conditions were too wet.

In 2007, when harvesting began, productivity measurement was complicated by constantly changing personnel and equipment in the harvesting system. The addition of the second harvesting contractor also complicated the process of measuring productivity by doubling the number of machines to monitor. Of the 18 units harvested, nine were completed by contractor 1, eight were completed by contractor 2, and one unit was started by contractor 1 and finished by contractor 2. Table 4 summarizes harvesting results by unit.

The shelterwood with reserves units averaged 27 acres and took an average of 10 weeks to harvest. The woodland thinning and thinning to B-line units averaged 28 and 26 acres in size and took an average of 7 and 6 weeks respectively to harvest. Figure 1 illustrates time to harvest by treatment. Woodland thinning Unit 20 took 4 months to harvest. This unit was started by contractor 1 and then later finished by contractor 2. The unit was the largest unit in the study (48 ac) and consisted of several long, thin ridge tops which contributed to the extended time to harvest.

Tons per acre removed varied, as expected, by treatment with an average of 77 tons/ac on the shelterwood units, 25 tons/ac on the B-line thinning units, and 42 tons/ac on the woodland thinning units. Table 5 shows the removal percentage for each treatment. The thinning treatment, which had the lowest tons per acre removed, also had a much lower percentage of basal area (BA) removed compared to the percentage of

Table 3.—Harvesting system machine types and estimated costs.

Machines	SMH[a]	PMH[b]
Contractor 1		
1999 John Deere 648G Grapple Skidder	$34.65	$53.31
1999 Timberjack 2618 Tracked Feller-Buncher	$43.12	$66.34
2007 John Deere 335 Knuckleboom Loader	$48.76	$75.01
Chainsaw	$0.80	$1.60
Manual Laborer (Wage + fringe benefits)	$12.36	$24.72
System	$139.69	$220.98
Contractor 2		
1998 John Deere 648G Grapple Skidder	$34.65	$53.31
1998 Timberjack 608 Tracked Feller-Buncher	$43.33	$66.67
1985 Hawk Knuckleboom Loader	$23.56	$36.24
Chainsaw	$0.80	$1.60
Manual Laborer (Wage + fringe benefits)	$12.36	$24.72
System	$114.70	$182.54

[a]SMH = Scheduled Machine Hours, [b]PMH = Productive Machine Hours

Table 4.—Summary of harvesting data.

UNIT	TREATMENT[a]	CONTR.[b]	AREA (AC)	TIME (WKS)	TONS REMOVED	TONS/AC	PMH[c]	TONS/PMH
2	2. Shelter	1	31	9	2,136	68.9	501	4.26
12	2. Shelter	2	16	9	1,523	95.2	458	3.33
29	2. Shelter	1	30	7	1,510	50.3	356	4.24
35	2. Shelter	1	29	12	2,865	98.8	641	4.47
16	2. Shelter	1	27	10	2,207	81.7	510	4.33
32	2. Shelter	2	27	13	1,858	68.8	572	3.25
18	4. Thin	2	21	4	526	25.1	197	2.68
21	4. Thin	1	27	4	409	15.2	193	2.12
25	4. Thin	2	17	4	540	31.8	164	3.30
33	4. Thin	1	26	5	593	22.8	312	1.90
11	4. Thin	2	21	7	532	25.4	237	2.25
17	4. Thin	2	43	10	1,283	29.8	384	3.34
4	5. WThin	1	20	5	1,079	53.9	256	4.22
19	5. WThin	2	28	6	997	35.6	258	3.86
22	5. WThin	1	27	4	907	33.6	239	3.80
23	5. WThin	2	19	5	706	37.2	228	3.10
15	5. WThin	1	28	5	1,025	36.6	222	4.61
20	5. WThin	1/2	48	16	2,653	55.3	716	3.71

[a]Treatments, see Table 1. [b]Contractor, see Table 3. [c]Productive Machine Hours.

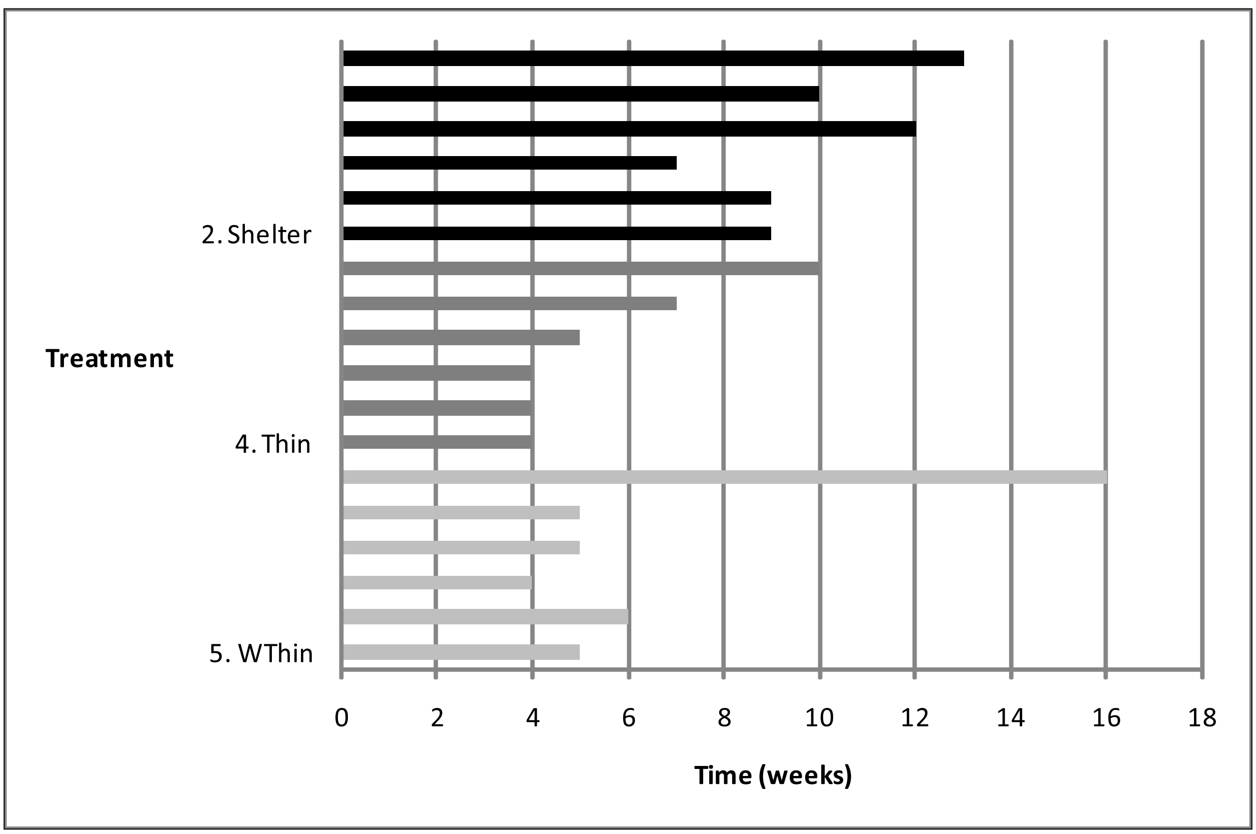

Figure 1.—Gross time to harvest units by treatment.

Table 5.—Percentages of basal area (BA), stems/acre (SPA), and biomass removed.

	Percent Removed		Percent Removed (tons)	
Treatment	BA (ft^2)	SPA	Biomass	Saw logs
2. Shelter	78	87	54	46
4. Thin	32	60	78	22
5. WThin	43	68	65	35

stems per acre (SPA) removed. The percentage of biomass tons removed was also much lower than the percentage of saw log tons removed (Fig. 2). These results indicate that more small stems were removed in the thinning treatment, resulting in lower harvesting productivity. The shelterwood treatment, on the other hand, had high percentages of both BA removed and SPA removed, indicating a heavier removal across all stem diameters. The product removal percentages were close to being equally split between biomass and saw logs. Average productivity by treatment decreased as the percent of biomass removed increased. The shelterwood treatments had the highest productivity (3.98 tons/PMH) and the least percent of biomass removed (54 percent). The thinning treatments had the lowest productivity (2.60 tons/PMH) and the highest percentage of biomass removed (78 percent).

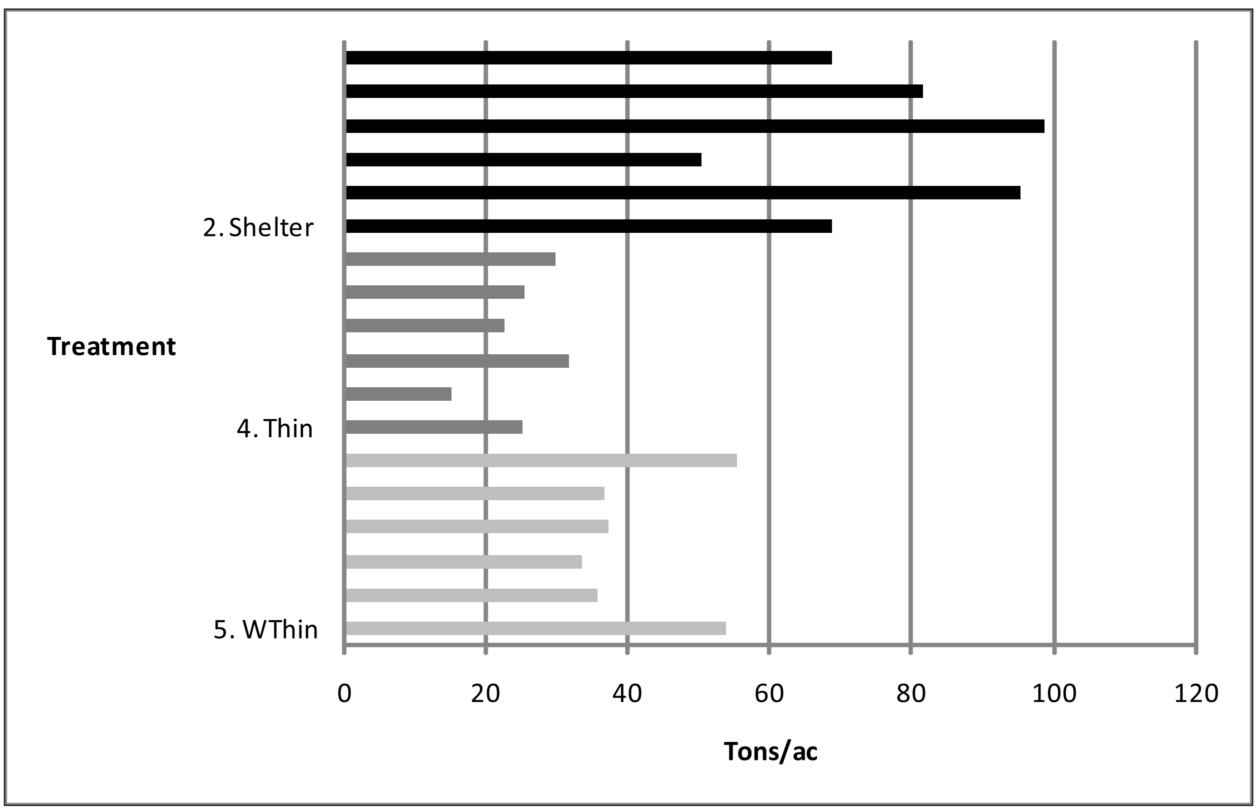

Figure 2.—Tons/ac removed from harvest units by treatment.

A gross system utilization rate of 30 percent was calculated for all units. This number was calculated using the number of weeks to harvest each unit, the productive machine hours for each unit, and the assumption that a typical working year is 2000 hours. Therefore, the overall average utilization rate calculated is lower than the actual system utilization because it does not factor in days lost to weather delays and days not scheduled to work, but it still reflects a low utilization rate. An additional factor affecting system utilization rates was availability of labor. Both harvesting contractors, at times, utilized one operator to run both the feller buncher and loader, which drastically reduced the utilization of the two machines and the system. Contractor 2 operated in this manner for every unit harvested, as reflected in a lower average production rate of 3.14 tons/PMH compared to 3.77 tons/PMH for contractor 1.

Sarles and Whitenack (1984) reported system productivity of 11 to 13 tons per productive hour for a three-man chainsaw crew using a truck-mounted crane in a West Virginia hardwood stand. Long and others (2002) reported tracked feller buncher productivity of 20 to 108 tons/PMH also in West Virginia hardwood stands. Average d.b.h. was 16.1 inches and overall system productivity was not reported. Sarles and Whitenack's (1984) study shows that even a manual felling/cable yarding system is capable of producing four times the tonnage of the harvesting productivity of the current study and Long and others' study shows that a feller buncher alone is capable of producing 5 to 30 times that of the current study.

Cost per ton was also estimated for each unit. The shelterwood with reserves and woodland thinning units averaged $53/ton, while the thinning to B-line units averaged $80/ton. This additional $27/ton reflects the low average harvest volume (25 tons/ac) compared to 77 tons/ac and 42 tons/ac for the shelterwood and woodland thinning treatments, respectively.

Site disturbance was sampled on all harvested units. The disturbance categories are combined into five main disturbance types in Table 6 to highlight differences among treatments. The category "Soil exposed" combines the three disturbance classes "Litter removed & topsoil exposed," "Litter removed & mineral soil exposed," and "Litter & soil mixed" from Table 2. The "Slash" disturbance class was included to illustrate the amount of biomass left in the units and combines the disturbance classes "Slash" and "Non-soil." "Non-soil" accounted for a very small percentage of data points, of which the majority was downed logs. Eighteen percent of the shelterwood with reserves units were classified as "Slash," while 9 percent and 11 percent of the thinning to B-line and woodland thinning units, respectively, were classified as "Slash." "Slash" was defined as any piled limbs and tops located at the survey point. Figure 3 averages the classes in Table 6 by treatment. "Soil Exposed" ranged from 24 percent on the thinning to B-line units to 32 percent on the shelterwood with reserves units. "Litter in Place" and "Undisturbed" combined, accounted for 49, 59, and 67 percent in shelterwood with reserves, woodland thinning, and thinning to B-line, respectively. Thinning to B-line units had the highest percent area in "Undisturbed" and "Litter in Place," which reflects the least average volume of timber removed (25 tons/ac).

The disturbance classes for location are summarized as "Stand Area" and "Skid Trails." "Skid Trails" consists of all non-"Stand Area" classes, including primary skid trails, secondary skid trails, landings, and internal roads. Shelterwood unit 35 has one of the highest percentages in skid trails (27 percent), probably a reflection of the contractor's efforts to become familiar with the prescription requirements and a high turnover in personnel. Woodland thinning Unit 4 has the highest percent of area in trails (28 percent). This unit had unusual topography that may have contributed to the disturbance value. It was a long, narrow unit aligned along

Table 6.—Summary of site disturbance sampling.

UNIT	TREATMENT[a]	DISTURBANCE TYPE (PERCENT OF TOTAL AREA) Undisturbed	Litter in place	Slash	Soil exposed	Soil on top	LOCATION TYPE Stand area	Skid trails
2	2. Shelter	18	29	15	36	2	95	5
12	2. Shelter	12	31	18	36	2	91	9
29	2. Shelter	19	33	12	36	1	91	9
35	2. Shelter	17	24	25	34	0	73	27
16	2. Shelter	12	47	16	24	0	89	11
32	2. Shelter	10	38	23	28	2	87	13
18	4. Thin	35	24	10	30	0	89	11
21	4. Thin	35	28	4	31	1	85	15
25	4. Thin	15	47	10	27	1	89	11
33	4. Thin	32	36	12	20	1	81	19
11	4. Thin	41	34	9	16	0	86	14
17	4. Thin	31	40	10	18	1	86	14
4	5. WThin	30	23	7	36	3	72	28
19	5. WThin	19	39	17	25	0	80	20
22	5. WThin	31	25	7	37	0	81	19
23	5. WThin	24	32	15	28	0	92	8
15	5. WThin	19	48	11	21	1	90	10
20	5. WThin	24	39	9	25	2	86	14

[a]Treatments, see Table 1.

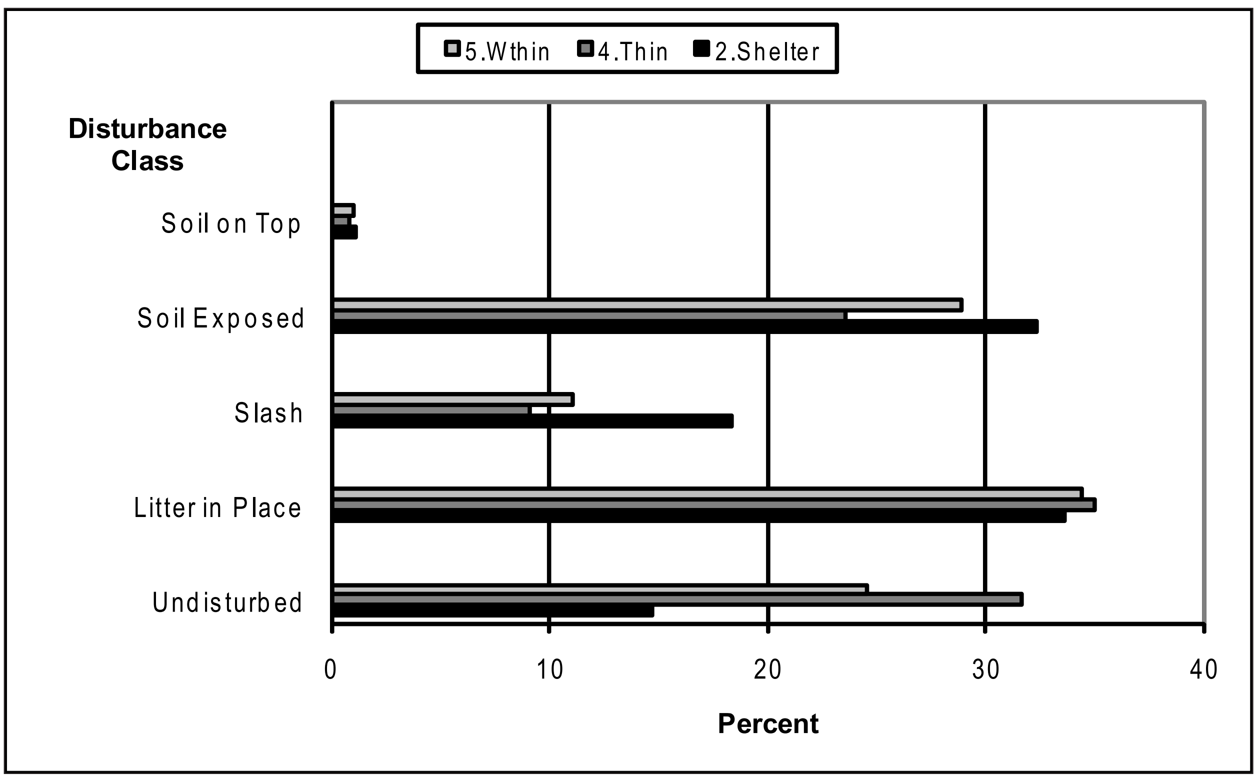

Figure 3.—Percentage of area in various disturbance classes.

a short ridge and consisted of steep slopes on both sides and along one end. The contractor was forced to winch timber from some sections of the unit. Figure 4 illustrates that, on average, all three treatments had average percent in trails between 12 percent and 16 percent.

Mitchell and Trimble (1959) reported on a manual felling and tracked dozer/cable skidding (with a wheeled arch) operation in West Virginia with percent area in skid trails ranging from 2.5 percent to 7 percent. Mitchell and Trimble (1959) also noted that a horse logging operation in West Virginia averaged 12 percent area in skid trails. Hatchell and others (1970) reported an average area of 33.8 percent occupied by primary and secondary skid trails and landings on pine harvesting operations in the Atlantic coastal plain using wheeled and tracked skidders and manual felling. Kochenderfer (1977) measured 10.3 percent of harvested area in skid trails from a manual felling wheeled cable skidding operation. These studies do not match the type of machines used in the current study on the Daniel Boone National Forest but show that a grapple skidder, tracked feller buncher system is within normal ranges for site disturbance.

CONCLUSIONS

The longevity of this study (May 2007-August 2009), the addition of a second harvesting contractor (and subsequent retraction of the first contractor), changing personnel and machines within crews, and adverse weather conditions all complicated the analysis of this study. The resulting productivity of the harvesting systems was very low. The data nevertheless indicate one potential treatment effect on harvesting productivity. The volume of small-diameter (biomass) stems removed from the thinning to B-line treatment resulted in lower productivity than measured on the other two treatments. The larger range of stem diameters and

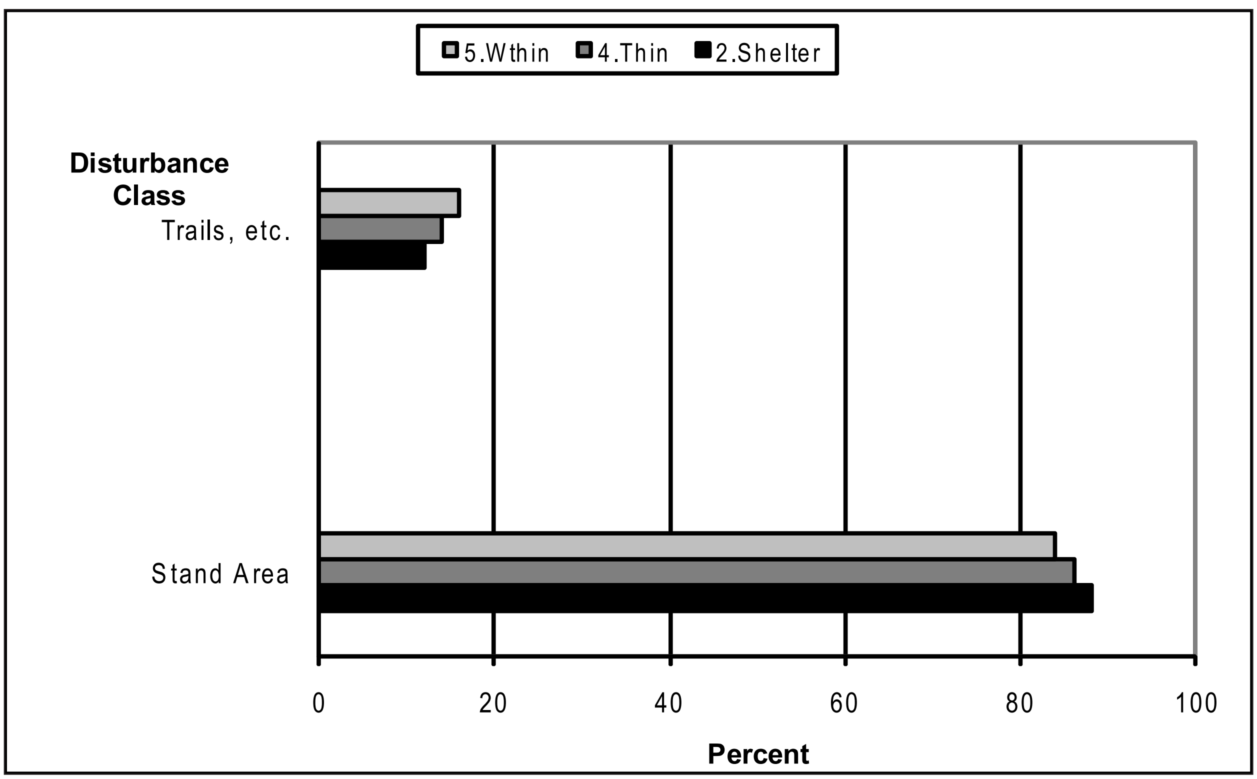

Figure 4.—Percentage of harvested area in general stand area and skid trails, landings, and roads.

number of stems removed from the shelterwood with reserves treatment led to the highest productivity of all three treatments. It is reasonable to assume that a more fully utilized and stable feller buncher, grapple skidder harvesting system could greatly out-produce the systems monitored in this study.

Soil disturbance resulting from mechanized ground-based harvesting appeared to be related to the volume removed. More removal was associated with higher levels of soil disturbance and more coverage of logging residues. The amount of stand area impacted by skid trails was relatively low, averaging between 12 percent and 16 percent of total area. This range is in line with those measured by other studies.

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