Impacts of Forestry Best Management Practices on Logging Costs and Productivity in the Northeastern USA

Article *in* Journal of Forestry -Washington- · February 2017

DOI: 10.5849/jof.2016-031

Matthew C. Kelly
Michigan Technological University

RESEARCH ARTICLE

J. For. ●(●):000–000
http://dx.doi.org/10.5849/jof.2016-031

harvesting & utilization

Impacts of Forestry Best Management Practices on Logging Costs and Productivity in the Northeastern USA

Matthew C. Kelly, René H. Germain, and Steven Bick

Best management practices (BMPs) effectively mitigate erosion and sedimentation during and immediately after harvest operations. The responsibility for implementing BMPs typically falls on loggers, with implications for higher harvesting costs and, possibly, reduced logging productivity. Two methods were used to assess the impacts of BMPs on logging operations in the northeastern United States. First, a case study was conducted using shift-level production and activity data and machine rate calculations to assess the impacts of BMP implementation for eight harvest operations, ranging from single-operator hand-felling systems to fully mechanized whole-tree and cut-to-length systems. Second, a survey was conducted in which loggers were asked to estimate the number of days required to complete a hypothetical timber harvest with and without a set of prescribed BMPs and to indicate their minimum acceptable contract rates for each. The combined results revealed a range of costs from $0/ac to $62/ac and decreases in productivity between 0 and 20%.

Keywords: BMPs, water quality, timber harvesting, work study analysis, logger survey, watershed forestry

Forest operations can accelerate soil erosion and sediment delivery, with the potential to impair water quality. The Federal Water Pollution Control Act of 1972 and later the Clean Water Act Amendments of 1977 and 1987 identify forestry as a contributor of nonpoint source pollution (Cubbage 2004). In response, states have developed best management practice (BMP) guidelines for protecting water quality during and immediately after harvesting. These guidelines typically include a variety of BMP categories, including forest roads, skid trails, log landings, streamside management zones, stream crossings, wetlands protection, timber harvesting, site preparation, and reforestation. The degree of regulation varies among states, ranging from nonregulatory approaches with or without enforcement to regulatory approaches that mandate use of BMPs. Nationally, monitoring efforts have shown that BMPs are properly implemented 91% of the time (National Association of State Foresters 2015), which is up slightly from the 89% rate estimated by Ice et al. (2010).

Properly implemented BMPs have been proven effective for protecting water quality (Loehle et al. 2014, Barrett et al. 2016, Cristan et al. 2016). The benefits of BMPs are realized in healthy ecosystems (Vowell 2001) and clean drinking water supplies. BMPs also help prevent forest roads and skid trails from washing out, thereby ensuring their use for future operations. Typically, BMPs are implemented by loggers who incur costs directly or pass them on to landowners or sawmills by way of reduced stumpage prices or increased contract rates. Consumers of wood products may also bear the cost of BMPs in the form of higher prices for goods (Sun 2006). In this way, BMPs can place economic strain on the forest products industry and local communities (Shaffer et al. 1998).

To relieve economic pressure, BMP cost-share programs provide financial assistance to offset implementation costs. Examples of such programs include the Environmental Quality Incentive Program administered by the Natural Resources Conservation Service in partnership with state agencies, the Vermont Portable Skidder Bridge Initiative, and the BMP Program administered by the New York City Watershed Agricultural Council Forestry Program. The latter pays loggers for implementing BMPs on forest roads and skid trails within the Catskill and Delaware

Received August 17, 2016; accepted February 16, 2017.

Affiliations: *Matthew C. Kelly (mackelly@mtu.edu), School of Forest Resources and Environmental Science, Michigan Technological University, Houghton, NY. René H. Germain (rhgermai@esf.edu), State University of New York College of Environmental Science and Forestry. Steven Bick (steve@northeastforests.com), Northeast Forests LLC.*

Acknowledgments: *This project was supported by the Northeastern States Research Cooperative through funding made available by the USDA Forest Service, as well as by the Watershed Agricultural Council Forestry Program. We thank Gary Sabourin of the Vermont Department of Forests, Parks and Recreation for his contributions to designing the survey instrument. We also thank the logging professionals who participated in this study.*

Watersheds, which supply drinking water to New York City (VanBrakle et al. 2013.

Previous studies have estimated BMP costs using a variety of methods (Blinn et al. 2001, Cubbage 2004). Shaffer et al. (1998) used a mailed survey in which Virginia loggers were asked to provide average unit costs of 10 BMPs, taking into consideration costs of labor, equipment, supplies, and time. The authors estimated unit costs of water bars, broad-based dips, and temporary bridges to be $15, $25, and $737, respectively ($23, $39, and $1,145 in 2014 dollars). Unit costs were then scaled up to entire tracts, resulting in a range of costs per acre from $8.11 to $48.35 ($12.60 to $75.11 in 2014 dollars) depending on physiographic region and whether the harvest site was greater than 75 ac. Similarly, Lickwar et al. (1992) estimated costs of six BMPs on 22 harvest sites located throughout Florida, Alabama, and Georgia. Unit costs were determined largely from past research and from consultation with forest contractors, forest engineers, and researchers. The authors used topographic maps and harvest data from each study site to estimate total costs, resulting in BMP cost estimates of $2.34/thousand board feet (MBF) ($4.88 in 2014 dollars) and $12.45/ac ($25.95 in 2014 dollars). Shouse et al. (2001) observed dozers and skidders installing water bars on skid trails in Kentucky using time study methods. They detected a significant difference in mean cycle times per water bar between dozers (1.5 minutes) and skidders (3.5 minutes) and estimated costs per delay-free water bar of $2.00 for the dozer and $4.67 for the wheeled skidder ($2.67 and $6.24, respectively, in 2014 dollars).

The impacts of BMPs on logging productivity and their relationship to various harvest systems has been given little attention in the literature. The objective of this study was to estimate the impacts of BMPs on logging productivity and costs within the context of typical northeastern US harvest operations. Two distinct methods were used. First, a case study of eight logging operations was conducted using a work-study approach (Košir et al. 2015) to assess the impacts of BMP implementation on harvest costs and productivity. Second, a written survey was administered to loggers throughout the region to assess the effects of BMPs on logging productivity and to determine acceptable contract rates to account for a hypothetical set of BMP requirements. The results are expected to inform policy decisions regarding BMP cost-share programs as well as the larger forest products industry throughout the Northeast.

Methods

Work Study Approach

Shift-level production and activity data were collected from eight harvests located in New York (5), Massachusetts (1), Vermont (1), and Pennsylvania (1) between 2013 and 2014 (Figure 1). The eight contractors who participated in this study were recommended by consulting and procurement foresters. To ensure that crews were familiar with BMPs, efforts were made to identify crews with one or more members who had completed a logger certification training program, such as New York's Trained Logger Certification program and the New Hampshire Professional Loggers program, which require training in BMPs. Each participating contractor was asked to identify an upcoming job that was expected to last approximately 30–40 days. The purpose of this constraint was to limit the effort required of loggers and to ensure that data for entire harvest operations were collected within a reasonable period. Silvicultural treatment and forest type information was obtained directly from the timber sale prospectus or from supervising foresters and confirmed visually during site visits. Note that the harvests selected may not be representative of the larger population of logging operations in the region, given a small sample of eight and the potential bias toward crews with reputations for adequately and efficiently addressing BMP concerns. Moreover, given variations in terrain, silvicultural treatment, equipment mix, and weather, the eight harvests are considered a collection of case studies rather than a representative sample.

Throughout the entire duration of each harvest, crew members recorded daily start, end, and break times, as well as general site conditions. They also recorded production of their assigned machines and all delays greater than 10 minutes. Each delay was identified as one of five delay types: maintenance, mechanical, personal, BMP, and other (e.g., meeting with foresters and personal phone calls). Delay factors (Spinelli and Visser 2008) were calculated by dividing the number of hours spent on each delay type by the total productive machine hours (PMHs) required to complete the harvest. Reporting delay factors is generally preferred over reporting delays as percentages of the total scheduled machine hours (i.e., the sum of total PMHs and total delays) because the latter method produces results that are highly dependent on the amount of time spent on all delay types (Spinelli and Visser 2008).

Machine rates were calculated following Miyata (1980), Food and Agriculture Organization of the United Nations (FAO) (1992), and Brinker et al. (2002). Equipment information (e.g., purchase price, year, model, and hours) gathered during contractor interviews was used to determine ownership costs (e.g., depreciation, interest, and taxes) and operating costs (e.g., repair and maintenance, labor, and fuel) (Table 1). Two contractors were unwilling to share financial information. Thus, machine rates for these two harvests were estimated based on published rates (e.g., Thompson 2001; Brinker et al. 2002; Germain et al. 2016) and calculated rates for similar machines ob-

Management and Policy Implications

To protect water resources while maintaining an economically viable logging sector, logging contract rates and stumpage prices must reflect the costs of implementing BMPs, which can be highly variable. Fair compensation for BMPs is particularly important in states that have voluntary or quasi-regulatory policies regarding the use of BMPs. Encouraging effective implementation of BMPs by reducing the burden on loggers is in the best interest of landowners, loggers, and the general public. Cost-share programs can be an important mechanism for easing these burdens. However, subsidizing BMP implementation may distort the market for logging services by artificially reducing contract rates or increasing stumpage prices. From an operations management perspective, logging contractors and crew supervisors should pursue strategies that minimize the impacts of BMPs on logging productivity, such as assigning operators of nonconstrained machines to implement BMPs at various times throughout the harvest or subcontracting close-out operations. Overall, the results of this study provide a benchmark for loggers and practicing foresters throughout the Northeast with regards to BMP costs and impacts on productivity.

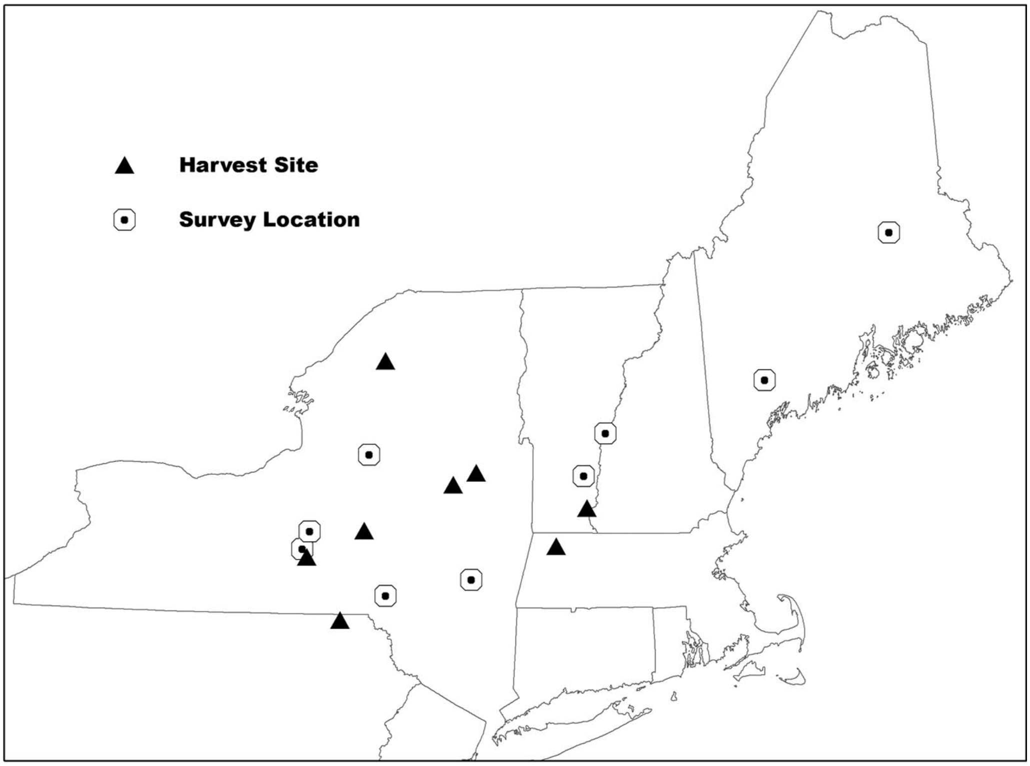

Figure 1. Sites of eight observed harvests and locations where paper surveys were administered in person at various logger events (e.g., training workshops and equipment exposition).

Table 1. Machine rate calculation inputs and assumptions.

Cost type	Variable	Source/description
Ownership	Purchase price (*P*)	Price gathered from interview
	Salvage (*S*)	Percent of purchase price (Brinker et al. 2002)
	Depreciation (*D*)	Straight line: $D = (P - S)/N$
	Years of useful life (*N*)	Machines with normal utilization rates, based on Brinker et al. (2002). Machines with very low utilization based on FAO (1992): (hours of useful life − hours at time of purchase)/(annual scheduled hours · utilization rate)
	Interest cost	0.05 × average annual investment (AAI), where $AAI = [(P - S) \cdot (N + 1)]/[2N] + S$ (Miyata 1980, Brinker et al. 2002)
	Insurance	% of purchase price per Brinker et al. (2002)
	Utilization	per data (PMHs/SHs)
Operating	Repairs and maintenance	% of depreciation, varies by machine type (Brinker et al. 2002)
	Fuel	Gallons per hour (from data, interview, or Brinker et al. 2002) × $3.50/gal (approximate price of off-road diesel in summer of 2013)
	Oil/lubricants	36.8% of annual depreciation (Brinker et al. 2002)
	Labor wage	Owner-operator = $30/SH, all else = $20/SH
	Labor benefits	20% of wage

SH, scheduled hours

served in this study. Machine utilization rates were calculated by dividing PMHs by the number of hours required to complete the harvest (i.e., the harvest duration). Machine utilizations were used to convert machine rates in terms of $/PMH (Miyata 1980). A $20/hour wage was used for all workers other than owner-operators. This wage is slightly higher than the median wage earned by logging workers throughout the United States in 2015 ($17.41/hour) (US Bureau of Labor Statistics 2015). A $30/hour wage was assumed for owner-operators with an additional 20% applied to all labor costs for benefits (i.e., workers compensation insurance).

BMP implementation costs were calculated by multiplying the machine rate ($/PMH) by the hours spent on BMPs for a given machine. Additional overhead costs ($120/day) were added if it was determined that BMP implementation extended the number of days required to complete the harvest. BMPs that occurred during harvest activities were determined to have extended the harvest only if implementation delayed the flow of logs from stump to landing (e.g., implementation affected a bottleneck machine) or if BMPs were implemented either before or after harvesting operations. It is important to note that the BMP costs reported here represent implementation costs only. Materials and supplies costs were not included in the analysis. Furthermore, the $120/day in overhead costs (Germain et al. 2016) was assumed for all crews to simplify the analysis. In actuality, this rate may not reflect the true overhead costs for all crews.

Logger Survey

Although the work-study method just described yielded detailed data from actual operations, the interpretation of those results was limited to the individual harvests because of the small sample size ($n = 8$) and high variation among harvests. Therefore, it was necessary to develop an alternative method for assessing BMP costs across a larger sample of contractors. To this end, loggers from Maine, New Hampshire, New York, and Vermont were surveyed in person at various training and exposition events held between fall of 2013 and spring of 2015 (Figure 1). At each event, loggers were invited to anonymously complete a two-part questionnaire (a copy of the questionnaire is found in Supplemental File S1[S]).

The first part of the questionnaire included questions regarding respondents' years in logging, their position within the company (i.e., business owner, crew supervisor, or crew member), their typical crew size, and the percentage of annual volume their company produced from purchased stumpage versus contract work. Loggers were then prompted to identify the equipment that comprised their typical harvest system (e.g., cable skidder, grapple skidder, or forwarder). The second part of the questionnaire prompted loggers to consider two hypothetical timber sales, which were identical with the exception of the required level of BMP implementation. Harvest A was absent BMPs, whereas Harvest B required the following BMP installations:

- 20-ft temporary bridge used for three stream crossings
- 50 water bars
- 150 linear feet of corduroy (i.e., poles or cull logs laid over wet areas [Cullen 2001]) in three sections of skid trails
- Seeding and mulching of six stream approaches and reshaping six stream banks

The two timber sales were identical in acres (100), species mix (northern hardwoods), silvicultural treatment (crown thinning), estimated volume removals (150 MBF of sawtimber, 400 cords of low-grade material), average skid distance (1,500 ft), and average tree diameter (18 in.).

Geospatial maps of both timber sales were created (Figure 2) using ArcGIS 10.2 with a skid trail layout designed to comprise 10% of the total harvest area, following recommendations by Germain and Munsell (2005). Thus, assuming an average trail width of 16 ft (Shouse et al. 2001), 27,000 linear ft was determined to approximate 10% of the harvest area. The requirement of 50 water bars for Harvest B was informed by New York's BMP guidelines, which recommend a 250-ft spacing between water bars on 2% slopes. Here, an average spacing of 500 ft was assumed, resulting in 54 water bars (27,000 ft/500 ft), which was then rounded down to 50 to simplify the survey instrument.

Loggers were asked to answer two questions related to each timber sale: How many days would it take you and your typical crew to complete this harvest? and What is the minimum contract rate you would be willing to accept for this job? Loggers were prompted to provide rates for both sawtimber ($/MBF) and low-grade material in terms of $/cord or $/ton. Differences between days required to complete each harvest indicated expected changes in productivity, whereas differences between minimum acceptable contract rates for each harvest represented the level of compensation that would be required for the prescribed BMPs.

Based on responses to the previous two questions, expected daily revenue was calculated for each timber sale using the following equation:

$$\text{daily revenue} = \frac{\text{total revenue(\$)}}{\#\text{ of days}} \tag{1}$$

$$\text{total revenue} = \frac{\$}{\text{MBF}} \cdot 150\text{ MBF} \cdot + \begin{cases} \dfrac{\$}{\text{TON}} \cdot 1200\text{ tons if} > \dfrac{\$}{\text{cord}} \cdot 400 \\ \dfrac{\$}{COR} \cdot 400\text{ cords, otherwise} \end{cases}$$

Total revenue was calculated by multiplying minimum acceptable contract rates for both product types (sawtimber and low-grade) by their associated sale volumes. Because some respondents included minimum contract rates for low-grade material in both $/ton and $/cord, the rate that produced the greatest dollar value was used in the calculation. For example, if a logger provided minimum contract rates of $20/ton and $50/cord, the revenue generated from low-grade material was assumed to be $24,000 based on the contract rate in tons ($20/ton × 1,200 tons), which was higher than that of the rate in cords ($50/cord × 400 cords = $20,000). Absolute and relative differences (% change) in daily revenues between the two harvests were calculated.

Survey responses were grouped by mechanized and nonmechanized systems, which were determined by the inclusion of a feller buncher or harvester in the respondent's typical equipment mix. Nonparametric Mann-Whitney-Wilcoxon (MWW) tests (Neuhäuser 2014) were conducted using SPSS 23 to test for differences between groups. In general, the null hypothesis for a MWW test is that two samples have equal distribution locations and are therefore from the same population. This test was used because of the nonnormal distribution of key variables, including differences in days to completion and minimum contract rates, which were generally skewed toward larger values (Sprent and Smeeton 2007).

Results

Work Study Results

Data from the eight harvests represented 249 work days and 3,991 worker-hours. Operations varied in crew size, equipment mix, harvest costs, and productivity (Table 2). Six crews felled by hand, whereas two were fully mechanized, using either a feller buncher (Harvest 6) or harvester (Harvest 7). The six hand-felling crews all worked in northern hardwood forests with varying components of eastern hemlock (*Tsuga canadensis*) and eastern white pine (*Pinus strobus*). The Harvest 6 crew operated in an upland oak forest, and the Harvest 7 cut-to-length system operated in a red pine (*Pinus resinosa*) plantation. All eight harvests were prescribed even-aged treatments; five received a regeneration method treatment (i.e., shelterwood, patch cut, or clearcut), and the other three received intermediate thinning treatments. Harvest costs ranged from $\$1.44/\text{ft}^3$ (Harvest 5) to $\$0.40/\text{ft}^3$ (Harvest 7) and were inversely related to productivity, which ranged from $51\ \text{ft}^3/\text{hour}$ (Harvest 1) to $668\ \text{ft}^3/\text{hour}$ (Harvest 7).

Time spent implementing BMPs varied from 0 to 37 hours among the eight harvests, and delay factors ranged from 0 to 14.3%

[S] Supplementary data are available with this article at http://dx.doi.org/10.5849/JOF-2016-031R1.

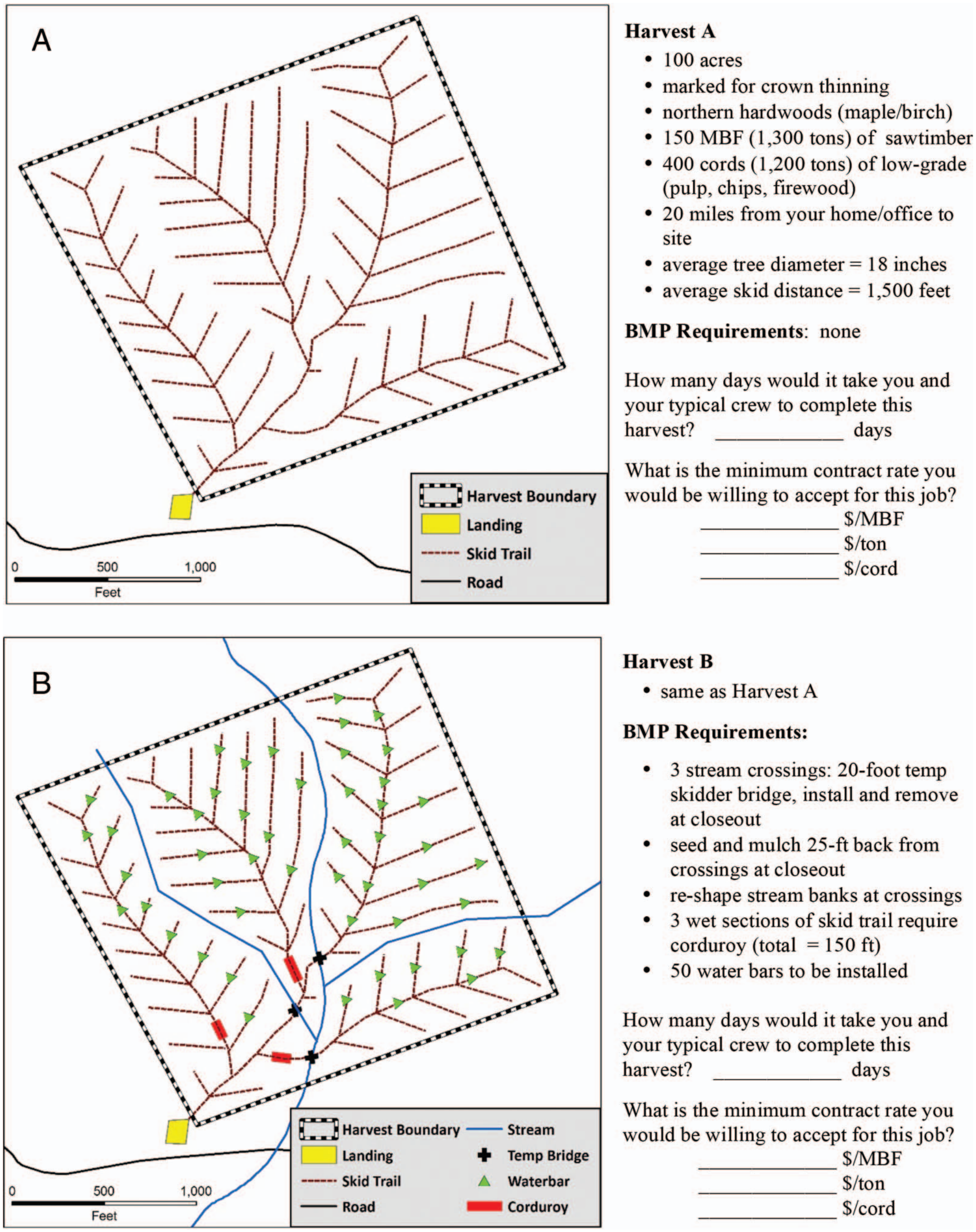

Figure 2. Two hypothetical timber sales used in a logger survey to elicit the impacts of BMPs. Both harvests are identical except that Harvest A (top) has no BMP requirements, whereas Harvest B (bottom) has substantial BMP requirements.

(Table 3). The 14.3% delay factor for Harvest 1 was the highest among the observed operations and the only one greater than 4%. Harvest 1 was cut by a single logger using a conventional cable skidding system who encountered a substantial amount of BMPs, including multiple stream crossings, several sections of skid trails that required corduroying, and installation of temporary water bars at various points throughout the harvest due to rain events.

The Harvest 6 crew spent 37 hours on BMPs, which was the most among the eight harvests in absolute terms. However, a delay factor of only 3.8% was calculated because of the large number of PMHs required to complete that harvest (963). The BMPs implemented during Harvest 6 included regrading forest roads and landings, spreading gravel, and installing broad-based dips. The slasher/loader operator completed nearly all of the BMP work for this job, because the slasher/loader was nearly twice as productive as the grapple skidder. As a result, much of the BMP work concurred with felling and skidding activities and had no impact on harvest productivity (i.e., BMPs did not extend the harvest). In contrast, Harvests 1, 2, and 3 were cut by three different contractors who single-handedly carried out all elements of their respective operations. Because of the nature of single-logger operations (Kelly and Germain 2016), these harvests were extended by exactly the number of hours spent on BMPs, resulting in reduced productivity. System productivity was not impacted by BMPs for Harvests 4, 6, and 8, whereas the crew for Harvest 7, which operated on relatively flat land with no stream crossings during a period of dry weather, reported no BMPs. Overall, decreases in productivity resulting from BMPs ranged from 0 to 9.4% (Table 3).

Table 2. Characteristics, costs, and productivities for eight harvest operations.

Variable	Harvest 1	2	3	4	5	6	7	8
Equipment mix	Chainsaw Cable skid Dozer	Chainsaw Grapple skid Slash/load	Chainsaw Grapple skid Slash/load	Chainsaw Cable skid Slash/load Dozer	Chainsaws Forwarder	Feller buncher Grapple skid Slash/load Triaxle truck Dozer	Harvester Forwarder	Chainsaws Grapple skid Cable skid Slash/load
Crew size	1	1	1	2	1–5	3	2	3–5
Forest type	Northern hardwoods	Northern hardwoods/ hemlock	Northern hardwoods	Northern hardwoods/ hemlock	Northern hardwoods/ white pine	Upland oak	Red pine plantation	Northern hardwoods/ hemlock/ white pine
Treatment	Thinning/ TSI	Shelterwood	Thinning	Thinning	Patch cut/ thinning	Shelterwood	Clearcut/thinning	Shelterwood
Harvest area (ac)	23	70	90	41	30	56	22	100
Average skid distance (ft)	625	1,678	1,374	1,262	1,672	356	800	2,668
Landings used	3	1	2	2	1	3	1	1
Average tree diameter (in.)	12.5	14.9	17.4	13.9	19.8	16.0	12.0	17.0
No. of stems cut	294	1,726	1,324	1,070	1,257	2,505	n/a	2,013
Total volume (ft^3)	7,603	43,934	43,220	13,334	26,730	76,512	52,360	56,525
ft^3/ac	331	627	480	325	891	1,366	2,380	566
ft^3/hr	51	184	116	115	70	183	668	245
Total cost ($)	10,440	24,577	26,958	12,220	38,362	90,985	21,191	43,585
Daily cost ($/day)	475	1,024	509	764	852	1,716	1,766	1,503
Unit cost ($/$ft^3$)	1.37	0.56	0.62	0.92	1.44	1.19	0.40	0.77

* No data.

Table 3. Hours spent on BMP implementation and their impact on productivity.

Variable	Harvest 1	2	3	4	5	6	7	8
Total PMH	97	227	340	189	665	963	119	245
Total BMP hours	13.9	8.7	2.0	3.3	9.7	37.0	0	4.0
Delay factor (%)	14.3	3.8	0.6	1.8	1.5	3.8	0	0.5
BMP hours/ac	0.60	0.12	0.02	0.08	0.32	0.66	0	0.04
% BMP hours spent pre- or postharvest	15	23	100	0	0	0	0	0
% reduction in productivity caused by BMPs	9.4	3.6	0.5	0	1.2	0	0	0
Reported BMPs	5+ WB, BBDs, rubber mat bridges, corduroy, smooth and regrade	WBs, slash mats, smooth and regrade, stream crossing	Smooth and regrade skid trails & landings	11 WBs, 4 temporary WBs, 2 BBDs, 3,000 ft skid trail smooth and regrade	Slash mats, panel mats, temporary bridge	Spread stone, regrade road and landings, WBs, BBDs	None	20+ WBs
Machine(s) used to implement BMP	Dozer	Grapple skidder	Grapple skidder	Dozer	Forwarder	Dozer		Grapple skidder
Average steepness (out of 3)	1.1	2.0	1.6	1.0	1.1	1.1	1.0	2.1
Average wetness (out of 3)	2.1	1.9	1.8	1.4	1.6	1.3	1.1	1.3

WB, water bar; BBD, broad-based dip. Steepness: 1 = gentle (0–9%), 2 = moderate (10–20%), 3 = steep (>20%). Wetness: 1 = dry, 2 = moderately wet, 3 = very wet.

BMP costs ranged from 0 to 10.7% of total delay-free harvesting costs among the case study harvests. On a per acre basis, costs of implementing BMPs ranged from $0 to $43. The magnitude of BMP costs was a function of the amount of time spent implementing BMPs and the cost of the equipment used and whether additional overhead costs accumulated as a result of the harvest being extended. The combination of these factors was unique for each harvest. For example, the total costs of BMPs was greater for Harvest 2 ($887.87) than for Harvest 1 ($826.51) despite Harvest 1 requiring 5.2 more hours of BMP implementation (Table 4). This was largely due to differences in equipment costs. The grapple skidder used to implement the majority of BMPs for Harvest 2 was more expensive to own and operate ($107/PMH) than the dozer used to implement a large portion of BMPs for Harvest 1 ($67/PMH). Moreover, dozers have been shown to be significantly faster at installing water bars than skidders (Shouse et al. 2001). Thus, the efficiency of the machine used to implement BMPs will influence the degree to which BMPs impact operations.

Survey Results

A total of 123 surveys were administered during 11 logger training and exposition events held throughout New York, Vermont, New Hampshire, and Maine. Ten questionnaires were discarded as grossly incomplete, leaving 113 for analysis. Despite the relative completeness of the remaining

Table 4. BMP costs calculated for eight harvest operations.

Cost	Harvest 1	2	3	4	5	6	7	8
Total BMP cost ($)	827	888	146	243	824	2,424	0	257
% of delay-free cost	10.7	4.2	0.5	2.2	2.4	2.9	0	0.6
$/ft^3	0.110	0.020	0.003	0.018	0.031	0.031	0	0.005
$/ac	36	13	2	6	27	43	0	3

Table 5. Descriptive statistics of survey respondents.

Variable	%	Median	Minimum	Maximum
Years in logging (n = 112)		25	1	47
Typical crew size (n = 109)		2	1	10
% of annual volume from contract work (n = 103)*		50	0	100
Role in company = owner or crew supervisor (n = 111)	92			
Typical equipment mix (n = 111)				
Fully mechanized system	53			
Cut-to-length system (subset of fully mechanized)	17			
Conventional hand-felling system	67			
Dozer included	63			
Chipper included	24			

* Versus purchased stumpage.

Table 6. Expected days to complete and minimum contract rates for a timber sale with and without BMP requirements.

Variable	Median	Range	n
Harvest A (no BMPs)			
Days to complete	32.5	5 to 178	106
Minimum sawtimber rate ($/MBF)	160	100 to 250	93
Minimum low-grade rate ($/ton)	22	5 to 50	72
Minimum low-grade rate ($/cord)	55	5 to 110	51
Daily revenue ($/day)	1,409	44 to 9,300	100
Harvest B (with BMPs)			
Days to complete	46.5	6 to 225	99
Minimum sawtimber rate ($/MBF)	186	120 to 350	92
Minimum low-grade rate ($/ton)	27	5 to 50	70
Minimum low-grade rate ($/cord)	65	5 to 113	51
Daily revenue ($/day)	1,260	32 to 8,525	94
Difference between A and B			
Days to complete	6.0	0 to 70	97
Minimum sawtimber rate ($/MBF)	20	0 to 75	86
Minimum low-grade rate ($/ton)	3	0 to 20	70
Minimum low-grade rate ($/cord)	6.5	0 to 85	50
Daily revenue ($/day)	−100	−1,864 to 429	93
Daily revenue change (%)	−8.3	−56.6 to 31.3	94

questionnaires, some were missing answers to one or more questions. Therefore, the number of responses used to calculate descriptive statistics (n) is indicated for each variable (Table 5). The average respondent had 25 years of experience in logging and worked in a higher-level position (i.e., owner or crew supervisor) within their company. Crew sizes ranged from 1 to 10, with a median of 2. Annual volume production was split between contract work (50%) and purchased stumpage. Just over one-half of respondents used fully mechanized systems (53%), whereas the remainder used conventional hand-felling systems. Overall, 63% of respondents included a dozer as part of their typical equipment mix, and 24% included a chipper.

Harvest A, which required no BMPs, required a median of 32.5 days to complete compared with 46.5 days to complete Harvest B (Table 6). Differences in the number of days required between the paired harvests were calculated for individual responses. On average, 6 additional days were required to complete the BMPs for Harvest B, which represented a 20% increase over the number of days to required complete Harvest A. Differences in minimum contract rates between the two harvests indicated that loggers required compensation values of $20/MBF for sawtimber and $3/ton or $7/cord for low-grade material. Multiplying these rates by the total volume harvested resulted in an estimated $6,200 of total additional compensation required, or $62/ac. Median daily revenue was greater for Harvest A ($1,409/day) than for Harvest B ($1,260/day). Although the higher minimum contract rates for Harvest B produced greater total revenues, when spread across the number of days required to complete the harvest, daily revenues fell by 8.3%. In fact, nearly 70% of survey respondents provided answers that resulted in a loss of daily revenue associated with Harvest B (Figure 2).

Nonparametric MWW tests revealed significant differences between loggers who ran fully mechanized systems and those who used conventional systems for a number of variables (Table 7). Mechanized loggers had more years of experience (28.0) than conventional loggers (20.5) and used larger crew sizes (3) than conventional loggers (2). Moreover, mechanized loggers expected to complete both Harvests A and B in half the time required of conventional loggers, which should not be surprising given the high rates of production achieved by mechanized systems (Sarles and Luppold, 1986, LeDoux 2011, Abbas et al. 2014). However, mechanized loggers were willing to accept lower minimum contract rates for the sawtimber component for both harvests: $150/MBF for Harvest A and $180/MBF for Harvest B, compared with $170/MBF and $195/MBF, respectively, for conventional loggers. This suggests that mechanized loggers probably enjoy lower production costs, which allows them to operate at lower contract rates. The number of additional days required of mechanized loggers to complete Harvest B (5) was significantly less than the additional days required of conventional loggers (10) ($P = 0.023$).

Discussion

This study set out to examine how BMP implementation affects logging operations at a systems level. From a cost perspective, the range of implementation costs observed from the eight case studies ($0–$43/ac) is similar to BMP cost estimates reported by Lickwar et al. (1992) ($26/ac) and by Shaffer et al. (1998) ($12–$75/ac). A more recent study in Virginia estimated the costs for implementing water bars at 50-ft intervals at

Table 7. Survey results grouped by mechanized and conventional harvest system types.

Variable	Mechanized		Conventional		P value
	n	Median	n	Median	
Years in logging	60	28	52	20.5	0.014*
Typical crew size	57	3	52	2	0.000*
% annual volume from contract work	56	35	47	50	0.965
Harvest A (no BMPs)					
Days to complete	60	25	46	50	0.000*
Minimum sawtimber rate ($/MBF)	56	150	37	170	0.116
Minimum low-grade rate ($/ton)	50	24	22	20	0.274
Minimum low-grade rate ($/cord)	30	55.5	24	55	0.766
Daily revenue ($/day)	58	2,020	42	753	0.000*
Harvest B (with BMPs)					
Days to complete	56	30	43	60	0.000*
Minimum sawtimber rate ($/MBF)	54	180	38	195	0.034*
Minimum low-grade rate ($/ton)	47	28	23	22	0.503
Minimum low-grade rate ($/cord)	30	65	21	70	0.833
Daily revenue ($/day)	55	1,800	39	798	0.000*
Differences between A and B					
Days to complete	56	5	41	10	0.023
Minimum sawtimber rate ($/MBF)	52	20	34	25	0.134
Minimum low-grade rate ($/ton)	47	3	23	3	0.955
Minimum low-grade rate ($/cord)	30	7	20	6.5	0.696
Daily revenue ($/day)	54	−142.6	39	−41.6	0.031*
% daily revenue	54	−8.5	49	−5.6	0.562

* Values significant at the $\alpha = 0.05$ level.

$64/ac (Sawyers et al. 2012), which compares to the $62/ac BMP cost estimate derived from the survey in the current study, which used a 500-ft spacing but included three stream crossings and multiple areas requiring soil stabilization.

Harvest Systems

In general, BMP costs for a given harvest are determined by the specific BMP requirements of the site, which are affected by terrain and/or contractual obligations. However, this study showed that the impacts of BMPs were also affected by harvest system characteristics, including machine and labor costs, crew size, degree of system balance, and overall system productivity. Harvest systems that employed multiple loggers were able to absorb the impacts of BMPs more readily than the three single-operator harvests. This occurred for two reasons. First, the sequential flow of harvested trees from stump to landing allowed upstream operators (i.e., fallers and skidders) to implement BMPs on completion of their respective duties, whereas downstream operators continued to skid, process, or load logs. For example, after the last tree was skidded for Harvest 4, the skidder operator spent 2 hours installing water bars while the slasher/loader operator processed the remaining stems. With both activities occurring simultaneously, BMP implementation did not extend the operation and, therefore, had no effect on system productivity. Second, differences in production rates among machines (Harrill and Han 2012) provided opportunities for operators to implement BMPs during operations without impacting system productivity. For example, the slasher/loader for Harvest 6 required 274 PMHs to complete the harvest compared with 324 PMHs and 301 PMHs for the feller buncher and grapple skidder, respectively. Therefore, the slasher/loader operator was available to implement BMPs at various points during harvest operations. Because of its higher production rate, the slasher/loader was able to catch up to the less productive grapple skidder, thereby avoiding impacts to system productivity. In contrast, where machine production rates are similar, BMP implementation will interrupt the flow of harvested material, leading to additional time required to complete operations.

The survey results further support the finding that the harvest system affects the degree to which BMPs impact costs and productivity. In contrast to the eight observed harvests, site and BMP requirements were held constant, whereas harvest systems varied in terms of crew size and equipment mix. The finding that mechanized systems required fewer additional days to complete Harvest B suggests that certain machines and/or harvest systems are better equipped to implement the specified BMPs. For example, stabilizing poorly drained skid trails using felled poles (i.e., corduroy) or logging slash is probably more easily accomplished with machines that can easily grip and move heavy loads (i.e., harvester, feller buncher, and grapple skidder) than with machines that have no such capability (i.e., chainsaw and cable skidder).

Change in Daily Revenue

A majority of survey respondents provided answers that generated lower daily revenues for Harvest B, which included BMPs, than for Harvest A. (Figure 3). Several possible rationales for this outcome are offered. First, the sample of respondents may have simply overestimated the number of days required to complete the harvest with BMPs as a result of hypothetical bias (Nape et al. 2003). However, assuming that estimates for the number of days required for each harvest were reasonably accurate, respondents may have failed to elevate their minimum contract rates for Harvest B sufficiently to compensate for the additional days. Failing to require sufficient contract rates could be a reflection of inadequate planning and cost analysis skills (Benjamin et al. 2014). Alternatively, failing to raise contract rates sufficiently may reflect a realist mentality, whereby loggers do not expect mills or landowners to agree to rates elevated beyond a certain level. If so, the BMP costs associated with Harvest B would be shared between mills or landowners (who are paying higher rates) and loggers (who are not being paid enough to be fully compensated). Finally, the reduction in daily revenues may accurately reflect a reduction in daily costs associated with the additional days required to complete the harvest. Contractors commonly leave a single operator behind to implement any remaining BMPs as part of the close-out operation while the rest of the crew moves to the next job. Thus, daily costs for a close-out operation are less than those associated with running an entire harvest system. Similarly, some contractors are known to subcontract with dozer owner-operators to close out jobs, a practice that could allow harvesting crews to maximize production.

Conclusion

BMPs provide important social and ecological benefits by protecting water resources from sedimentation, a form of nonpoint source pollution. Loggers are typically charged with the task of implementing BMPs and often incur implementation costs

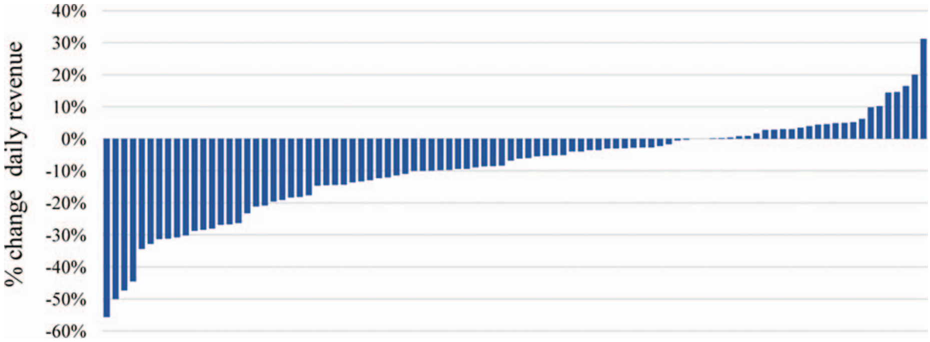

Figure 3. Distribution of percent change in daily revenue between Harvests A and B (BMPs) based on estimated additional days and minimum acceptable contract rates. Note that all 94 usable responses are presented along the *x*-axis.

directly. This study used multiple methods to assess the impacts of BMPs on logging costs and productivity for a variety of harvest systems. Overall, costs of BMPs ranged from $0/ac to $43/ac among the eight observed harvests with a median of $62/ac for the intensive BMPs included in the survey. Combined, the results from the case studies and survey provide insights into the variability of BMP requirements and the impacts that BMPs have on various harvest systems. Importantly, configuration of loggers and equipment, as well as operations management strategies, can mitigate or accentuate the impacts of BMPs. For instance, crew members working in nonbottleneck functions should be assigned to implement BMPs to maintain production flow and mitigate impacts to system productivity. In contrast, systems that struggle to free labor from the production process are more prone to the negative impacts of BMPs with regards to system productivity. Subcontracting with dozer owner-operators to conduct pre- or postharvest operations offers a viable strategy for some systems. However, the data from the eight harvests showed that BMPs are implemented throughout active harvesting and not only during pre- or postharvest operations. Therefore, subcontracting closeout operations will not entirely remove the burden of BMPs from logging crews. In general, harvest crews should handle BMP implementation up to the point where it lowers system productivity and then look for viable opportunities to subcontract. Ideally, mill contract rates and stumpage prices negotiated with landowners will reflect the true impacts of BMPs, which are highly variable. Ultimately, BMPs should not be so onerous as to impede logging profitability. Where BMP requirements are significant, both mills and landowners must be willing to share in the financial burden.

Literature Cited

Abbas, D., R. Handler, B. Hartsough, D. Dykstra, P. Lautala, and L. Hembroff. 2014. A survey analysis of forest harvesting and transportation operations in Michigan. *Croatian J. For. Eng.* 35(2):179–192. Available online at http://www.crojfe.com/r/i/crojfe_35-2_14/abbas.pdf.

Barrett, S.M., W.M. Aust., M. C. Bolding, W.A. Lakel III, and J.F. Munsell. 2016. Estimated erosion, groundcover, and best management practices audit details for postharvest evaluations of biomass and conventional clearcut harvests. *J. For.* 114(1):9–16. doi: 10.5849/jof.14-104.

Benjamin, J.G., S. Bick, W. Farrand, and R.H. Germain. 2014. Characteristics of successful and innovative logging contractors in the Northeast US. In *Proc. of the 37th Council on Forest Engineering annual meeting, Moline, IL*, Council on Forest Engineering, Morgantown, WV. 9 p.

Blinn, C.R., A.M. Alden, and P.V. Ellefson. 2001. Timber harvester perceptions of costs and benefits from applying water quality BMPs in North-Central USA. *J. For. Eng.* 12(1):39–51. doi:10.1080/08435243.2001.10702761.

Brinker, R.W., J. Kinard, B. Rummer, and B.L. Lanford. 2002. *Machine rates for selected forest harvesting machines*. Circ. 296, Alabama Agriculture Experiment Station, Auburn, AL. 32 p.

Cristan, R., W.M. Aust, M.C. Bolding, S.M. Barrett, J.F. Munsell, and E. Schilling. 2016. Effectiveness of forestry best management practices in the United States: Literature review. *For. Ecol. Manage.* 360:133–151. doi: 10.1016/j.foreco.2015.10.025.

Cubbage, F.W. 2004. Costs of forestry best management practices in the south: A review. *Water Air Soil Pollut. Focus* 4(1):131–142. doi: 10.1023/B:WAFO.0000012822.20500.ae.

Cullen, J.B. 2001. *Best management practices for erosion control on timber harvesting operations in New Hampshire*. State of New Hampshire Department of Resources and Economic Development, Division of Forests and Lands, Goffstown, NH. 67 p.

Food and Agricultural Organization of the United Nations. 1992. Calculation of machine rates. In *Cost control in forest harvesting and road construction*, Food and Agricultural Organization of the United Nations, Rome, Italy. 15 p.

Germain, R., S. Bick, M.C. Kelly, J. Benjamin, and W. Farrand. 2016. Case study of three high-performing contract loggers with distinct harvest systems: Are they thriving, striving or just surviving? *For. Prod. J.* 66(1/2):97–105.

Germain, R.H., and J.F. Munsell. 2005. How much land is needed for the Harvest Access system on nonindustrial private forestlands dominated by northern hardwoods? *North. J. Appl. For.* 22(4):243–247. http://www.ingentaconnect.com/contentone/saf/njaf/2005/00000022/00000004/art00004.

Harrill, H., and H.S. Han. 2012. Productivity and cost of integrated harvesting of wood chips and sawlogs in stand conversion operations. *Int. J. For. Res.* 2012:893079. doi:10.1155/2012/893079.

Ice, G.G., E. Schilling, and J. Vowell. 2010. Trends for forestry best management practices implementation. *J. For.* 108(6):267–273. http://www.ingentaconnect.com/contentone/saf/jof/2010/00000108/00000006/art00005.

Kelly, M.C., and R.H. Germain. 2016. Is it efficient to single-handedly run a multi-machine harvesting operation? A case study from the Northeast United States. *Int. J. For. Eng.* 27(3):140–150. doi:10.1080/14942119.2016.1214496.

Kosir, B., N. Magagnotti, and R. Spinelli. 2015. The role of work studies in forest engineering: Status and perspectives. *Int. J. For. Eng.* 26(3):160–170. doi:10.1080/14942119.2015.1111043.

Loehle, C., T.B. Wigley, Jr., A. Lucier, Jr., E. Schilling, R.J. Danehy, and G. Ice. 2014. Toward improved water quality in forestry: Opportunities and challenges in a changing regulatory environment. *J. For.* 112(1):41–47. doi:10.5849/jof.12-111.

LeDoux, C.B. 2011. *Harvesting systems for the northern forest hardwoods*. USDA Forest Service, Gen. Tech. Rep. NRS-91, Northern Research Station, Newtown Square, PA. 65 p. https://www.treesearch.fs.fed.us/pubs/39931.

Lickwar, P., C. Hickman, and F.W. Cubbage. 1992. Costs of protecting water quality during harvesting on private forestlands in the southeast. *South. J. Appl. For.* 16(1):13–20. http://www.ingentaconnect.com/contentone/saf/sjaf/1992/00000016/00000001/art00005.

Miyata, E. S. 1980. *Determining fixed and operating costs of logging equipment*. USDA Forest Service, Gen. Tech. Rep. NC-55, North Central Forest Experiment Station, St. Paul. MN. 16 p. https://www.treesearch.fs.fed.us/pubs/10120.

Nape, S., P. Frykblom, G.W. Harrison, and J.C. Lesley. 2003. Hypothetical bias and willingness to accept. *Econ. Lett.* 78(3):423–430. doi: 10.1016/S0165–1765(02)00250-1.

Neuhauser, M. 2014. Wilcoxon-Mann-Whitney Test. P. 1656–1658 in *International encyclopedia of statistical science*, Lovric, M. (ed.). Springer, Berlin, Germany.

National Association of State Foresters. 2015. *Protecting water quality through state forestry best management practices.* Available online at www.stateforesters.org; last accessed Jan. 31, 2017.

Sarles, R.L., and W. G. Luppold. 1986. *Technoeconomic analysis of conventional logging systems operating from stump to landing*. USDA Forest Service, Res. Pap. NE-577, Northeastern Forest Experiment Station, Broomall, PA. 23 p. https://www.treesearch.fs.fed.us/pubs/21719.

Sawyers, B.C., M.C. Bolding, W.M. Aust, and W.A. Lakel III. 2012. Effectiveness and implementation costs of overland skid trail closure techniques in the Virginia Piedmont. *J. Soil Water Conserv.* 67(4):300–310. doi:10.2489/jswc.67.4.300.

Shaffer, R.M., H.L. Hanley., E.G. Worrell, and W.M. Aust. 1998. Forestry BMP implementation costs for Virginia. *For. Prod. J.* 48(9):27–29.

Shouse, S., J. Stringer, M. Smidt, M. Pelkki, J. Ringe, and R. Kolka. 2001. Machine and labor times required to implement Kentucky's skid trail erosion control and revegetation BMPs. In *Proc. of the Council on Forest Engineering conference, 2001 July 15–18, Snowshoe, WV*. Council on Forest Engineering, Morgantown, WV. 6 p.

Spinelli, R., and R. Visser. 2008. Analyzing and estimating delays in harvester operations. *Int. J. For. Eng.* 19(1):36–41. doi:10.1080/14942119.2008.10702558.

Sprent, P., and N.C. Smeeton. 2007. *Applied nonparametric statistical methods*, 4th ed. Chapman & Hall/CRC, Boca Raton, FL. 530 p.

Sun, C. 2006. Welfare effects of forestry best management practices in the United States. *Can. J. For. Res.* 36(7):1674–1683. doi:10.1139/x06-052.

Thompson, J.D. 2001. Calculating utilization rates for rubber tired grapple skidders in the southern United States. In *Proc. of the Council on Forest Engineering conference, 2001 July 15–18, Snowshoe, WV.* Council on Forest Engineering, Morgantown, WV. 4 p.

US Bureau of Labor Statistics. 2015. *Occupational employment and wages, May 2015. 45-4029 logging workers, all other*. Available online at www.bls.gov/oes/current/oes454029.htm; last accessed Feb. 2, 2017.

VanBrakle, J., R.H. Germain, J. Munsell, and S. Stehman. 2013. Do forest management plans increase BMP implementation on family forests? A formative evaluation in the NYC watershed. *J. For.* 111(2):108–114. doi:10.5849/jof.12-034.

Vowell, J.L. 2001. Using stream bioassessment to monitor best management practices effectiveness. *For. Ecol. Manage.* 143(1–3):237–244. doi:10.1016/S0378-1127(00)00521-1.