The formative evaluation of a forestry Best Management Practices program in a municipal watershed

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ABSTRACT

Best Management Practices for water quality (BMPs) have been proven effective in reducing sedimentation from timber harvesting operations. Although most states in the country have BMP guidelines, many are non-regulatory, creating challenges for forest managers to ensure implementation. In surface watershed systems, BMP cost-sharing extension programs (BMP programs) are designed to encourage the implementation of BMPs. To assess the efficacy of a BMP program we examined the rates of BMP implementation on 45 properties harvested between 2013 and 2015: 22 harvests enrolled in a BMP program and 23 harvests not enrolled. We also compared our results to two previous studies completed in 2002 and 2011. Our results indicate BMP implementation was significantly better on properties participating in the BMP program. Also, BMP implementation scores improved for almost all categories evaluated when compared to the two previous studies. One BMP category with low implementation scores (even in 2018), was water diversion devices such as water bars. We suspect the BMP program is not sufficient to incentivize implementation given the time commitment for BMP implementation. Another factor at play here is that implementation may have been perceived as adequate to manage surface flow, but not optimal according to specifications dictated by the BMP field guide.

Key words: Best Management Practices, water quality, logging, forest management

RÉSUMÉ

Les pratiques exemplaires relatives à la gestion de la qualité de l'eau se sont avérées être efficaces pour réduire la sédimentation lors des opérations de récolte de bois. Même si la plupart des juridictions à l'échelle du pays ont rédigé des lignes directrices pour ces pratiques, plusieurs ne sont pas réglementaires, ce qui crée un défi pour les aménagistes forestiers chargés des appliquer. Dans le cas des eaux superficielles des bassins hydrographiques, les programmes d'atténuation des coûts liés aux pratiques exemplaires sont conçus pour en encourager l'utilisation. Dans le but d'évaluer l'efficacité d'un programme d'atténuation, nous avons étudié les taux d'implantation des pratiques exemplaires sur 45 sites exploités entre 2013 et 2015 : 22 sites inscrits sous un programme d'atténuation et 23 sites non-inscrits. Nous avons également comparé nos résultats avec deux études antérieures complétées en 2002 et en 2011. Nos résultats indiquent que l'implantation des pratiques exemplaires a été significativement meilleure sur les sites participant au programme d'atténuation. De même, les taux d'implantation ont augmenté pour presque toutes les catégories évaluées par comparaison avec les deux études antérieures. Une catégorie d'implantation des pratiques exemplaires ayant un faible taux d'implantation, (même en 2018), a été les dispositifs de déviation de l'eau comme les barres de dérivation. Nous suspectons que le programme d'atténuation ne constitue pas un incitatif suffisant pour ce type d'implantation étant donné le temps alloué pour sa réalisation. Un autre facteur qui entre en jeu est que l'implantation peut avoir été perçue comme étant adéquate pour gérer les eaux de surface, mais sans être la solution optimale selon les spécifications dictées par le guide technique des pratiques exemplaires.

Mots clés : pratiques exemplaires, qualité de l'eau, exploitation forestière, aménagement forestier

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Introduction

Forestry Best Management Practices (BMPs) for water quality are strategies to minimize the movement of soil and protect water quality, while still allowing other forest management objectives (e.g., timber production, recreation) to be met (Wenger 1984). Common BMPs include planning the access system, establishing riparian management zones, and using strategic techniques such as geotextile fabric, gravel, temporary skidder bridges, pipe culverts, corduroys, water bars, broad-based dips, rolling dips, rubber belt deflectors, open-top culverts, and diversion ditches. Water diversion devices are especially important, as they regulate the flow of surface water on exposed soil created by harvest access systems, which have been found to contribute as much as 90% of the sediment generated from logging operations (Patric 1976; Swift 1984). There are also operational BMPs such as reducing use of the access system during wet weather conditions or completely shutting down the operation until the site dries out or freezes. BMPs for each harvesting operation will vary based on the harvest system, site characteristics and landowner objectives. It is the role of the forester and logger to incorporate these factors into a BMP plan for a given woodlot.

Several decades of research have confirmed that BMPs are effective in reducing non-point source pollution and maintaining water quality (Black and Clark 1959; Lynch *et al.* 1985; Lynch and Corbet 1990; Martin and Hornbeck 1994; Kochenderfer *et al.* 1997; Arthur *et al.* 1998; Briggs *et al.* 1998; Schuler and Briggs 2000; Edwards and Stuart 2002; Ice 2004; Stednick 2008; Wang and Goff 2008; Anderson and Lockaby 2011; Cristan *et al.* 2016; Soman *et al.* 2019). Although BMPs have been proven effective, they are currently voluntary in many states across the US, creating BMP implementation challenges for forest and watershed managers (Cristan *et al.* 2016). Further compounding the problem are the costs of implementing BMPs which are often borne by logging contractors. The costs will vary with the characteristics of the site and harvesting operation, and may even be negligible when there is little surface water, topography and the weather cooperates, but studies have shown a definitive impact on productivity, costs and profit margins (Aust *et al.* 2003; Kelly *et al.* 2017; Regula *et al.* 2018; Germain *et al.* 2019; Soman *et al.* 2019).

The investment in logging productive capacity can be substantial, ranging into the hundreds of thousands of dollars for

small operations and well over a million dollars for larger mechanized operations (Baker *et al.* 2014; Conrad 2014). Because logging is capital intensive, maintaining the flow of wood products is critical to profitability. Implementing BMPs can disrupt that flow by re-directing from a productive function (e.g., felling, skidding, bucking, loading) to an activity that is not explicitly contributing to wood flow (Blinn *et al.*

1986; Egan and Taggart 2004; Allred *et al.* 2011; Leon and Benjamin 2012).

In a review of BMP cost studies from the southeast US, Cabbage (2004) reported a range of costs between roughly \$2 and \$6 per thousand board feet (MBF) and \$30 to \$101 per hectare. Shaffer *et al.* (1998) asked Virginia loggers to provide average unit costs of ten BMPs, taking into consideration costs of labor, equipment, supplies and time. The researchers estimated unit costs of water bars, broad-based dips, and temporary bridges to be \$15, \$25, and \$737, respectively. Unit costs were then scaled up to entire tracts, resulting in a range of costs of roughly \$20 to \$119 per hectare depending on physiographic region and whether the harvest site was greater than 30 acres. 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 reported that implementing BMPs at the recommended level would cost an estimated \$2.34/MBF and \$31 per hectare. Shouse *et al.* (2001) applied a modified time/motion method by collecting video data of dozers and skidders installing water bars on skid trails in Kentucky. Assuming a machine rate of \$80 per hour, the authors estimated dozer and skidder costs of \$2 and \$4.67 per delay-free water bar. In a study based in the Northeast, Kelly *et al.* (2017) examined the impacts of BMPs on costs and productivity and reported median BMP implementation costs at \$153 per hectare. Generally, up to a 9% decrease in productivity could be attributed to BMP implementation and BMP costs accounted for up to 11% of the total harvest costs. In a study examining mechanized harvesting in mixed wood forests in Maine, Soman *et al.* (2019) reported the cost of implementing BMPs per cubic meter of wood produced ranged from \$1.00 in clearcuts to \$3.70 in partial harvests. Productive machine hours associated to the skidders for BMPs ranged from \$10 in clearcuts to \$50 in partial harvests.

Sun (2006) recognized that previous research focused on estimating BMP costs failed to answer the question of who bears these costs, referring to Lickwar *et al.* (1992) and Shaffer *et al.* (1998) as evidence. The study used an equilibrium displacement model to project welfare loss to landowners, loggers, mills, and consumers associated with BMP implementation. Results indicated that absolute welfare loss was

greatest for consumers, while relative welfare loss was greatest for loggers. Primary mills suffered little welfare loss associated with BMP implementation. The impact on loggers was attributed to inelasticity associated with harvesting services and the non-liquid nature of their assets. Consequently, given loggers' high fixed investments and the oligopolistic nature of the market for harvest services, loggers lack leverage to demand higher contract rates or simply refuse jobs with large BMP requirements. It is important to note that the impact of these costs is particularly acute for smaller logging operations which lack the equipment infrastructure to implement BMPs while simultaneously maintaining productive functions such as felling, skidding and loading.

To relieve economic pressure, some government agencies and non-government organizations offer BMP cost-sharing extension programs (BMP programs) that provide financial assistance to offset implementation costs as well as technical assistance. These programs can be important in states that do not mandate use of BMPs or in sensitive watersheds. Examples of BMP programs include the Environmental Quality Incentive Program (EQIP) administered by the Natural Resources Conservation Service in partnership with state agencies, and the BMP Program administered by the Watershed Agricultural Council (WAC) in the New York City Watershed.

WAC has embraced a strategy that seeks to balance water

quality and a thriving rural economy in the Watershed located in the Catskill region of New York State (NYS) (Fig. 1). Explicitly, their mission is to promote economic viability, protect water quality, and preserve working landscapes in the Catskill region through local leadership and sustainable partnerships within the community. The NYC water supply system is the largest unfiltered surface water system in the US, providing over 4.9 billion liters of water daily to the greater metropolitan area as well as several upstate communities (Galusha 2002). Its primary water supply systems, the Catskill/Delaware Watersheds, are 78% forested, of which 75% is in family forest ownership (Hall *et al.* 2011). It is important to note that BMPs are not regulated in NYS; consequently, implementation is voluntary and often inconsistent. Within the Watershed, the stakes are clearly higher to promote water quality, thus WAC uses innovative approaches to encourage loggers, foresters and landowners to adopt and implement BMPs.

WAC has developed a BMP-specific cost-sharing program (unique to the country) to help offset the financial burden of implementation on loggers within the Watershed. The BMP Program provides financial and technical assistance to loggers in the Watershed to properly implement BMPs such as water bars and geotextile fabrics as well as protect streams by loaning temporary skidder bridges at no charge. WAC

Fig. 1 New York State and the New York City Watershed (outlined). This shows the West of the Hudson River watersheds (Catskill/Delaware) and the East of Hudson watershed (Croton)

foresters work with loggers prior to the harvesting operation to determine a BMP plan for the site which dictates the amount of funding designated to that particular job. Following the completion of the harvest, a WAC forester inspects the site to confirm if the agreed upon BMPs have been installed. Final payment is based on the degree to which the plan was followed coupled with the quality of BMP implementation (WAC 2019). Unfortunately, best intentions at the commencement of a job do not necessarily guarantee optimum results concerning the plan and BMP implementation once the logging is done – hence the reason for monitoring the BMP Program.

The primary goal of this study was to assess the efficacy of the WAC Forestry BMP program. This goal was supported by the following objectives: 1) Compare BMP implementation on recently harvested woodlots that participated in the WAC BMP Program with recent harvests that did not participate in the BMP program; 2) Assess implementation rates of individual BMP practices (i.e., water bars and stream crossings) and highlight those practices with poor as well as good implementation based on the NYS Best Management Practices for Water Quality Field Guide (NYS BMP Field Guide); and, 3) Evaluate the temporal efficacy of the WAC BMP Program by comparing 2018 implementation rates with two previous studies conducted in 2002 (Munsell *et al.* 2006) and 2011 (VanBrakle *et al.* 2013). This formative evaluation of BMP implementation rates will shed light on the efficacy of the WAC BMP Program. The temporal component will provide insights on the effectiveness of the program since its inception, and strategies to improve moving forward.

Methods

The study was conducted from June through August of 2018. Timber harvests conducted between 2013 and 2015 within the Watershed were considered for the project and multiple aspects of the harvests were assessed. It is important to note that this study was designed to assess BMP implementation on completed harvests with the understanding that BMPs are effective in controlling nonpoint source pollution from surface run-off. There was no attempt to document erosion or sedimentation. Also, no link was made between BMP implementation scores and the logger or harvest system associated with the assessed logging operation.

Study location

The NYC Watershed is situated in the Catskill region of NYS (Fig. 1). As part of the Allegheny Plateau, the Catskill region sits on bedrock comprised largely of sandstone, shale, and conglomerate, deposited during the Devonian Age (Miller 1914). The high peaks of the Catskill Mountains range from 900 – 1,280 m in elevation and taper westward from the Esopus and Schoharie River basins toward the Delaware River Valley and Finger Lakes. The mountainous landscape is largely covered in stony, sandy loams due to the veneer of glacial till that coats the area and is predominantly forested (O'melia *et al.* 2000).

Sampling

The sampled population consisted of property owners who conducted timber harvests between 2013 and 2015 within the boundary of the Watershed. The Feature Analyst function in

ArcMap (ESRI 2018) was used to identify tax parcels that showed changes in land cover between two sets of aerial imagery (2013 and 2015). The software was trained to find visual changes in standing tree density to accurately identify tax parcels where a timber harvest was likely to have occurred (VanBrakle 2018). Five hundred and forty-one properties were identified as having land-use change occur between 2013 and 2015 that was related to some kind of harvesting or disturbance. Tax parcel information from the NYS GIS Clearinghouse allowed us to contact current or past landowners. An initial mailing was sent out to the identified landowners to confirm if a harvest had occurred and to ask permission to visit their property.

Of the 541 harvests, 84 properties participated in the WAC BMP Program and 27 of those “WAC” landowners agreed to allow us on their property to examine their woodlots. Of the remaining 457 harvests who had not participated in the WAC BMP Program, 45 “NonWAC” landowners gave us permission to examine their woodlots. In total, we were granted permission to visit 72 properties: 27 “WAC” and 45 “NonWAC”. No owner had more than one eligible property in the sample. The sites were selected based on a “first come, first serve” basis. As we received responses, we contacted those landowners to schedule a visit date. Over the course of the 2018 field season, 23 (of 27) of the WAC properties and 22 (of 45) of the NonWAC properties were visited and evaluated (Fig. 2).

Because we needed landowner permission to examine harvest areas, the sample was self-selected by participants, allowing the potential for nonresponse bias. All studies requiring landowner permission, (including Schuler and Briggs 2000; Munsell *et al.* 2006; VanBrakle *et al.* 2013; Maker *et al.* 2014) suffer from this potential bias, and there is no reason to believe it would be higher in this study area than elsewhere. Although absolute levels of BMP implementation should be interpreted cautiously, comparisons between studies of this type or between groups of properties within this study are legitimate. Nonetheless, we did conduct statistical tests for bias using late respondents as a proxy for non-respondents (after Lindner *et al.* 2001). We were unable to find evidence of bias. Unpaired, unequal variance *t*-tests showed no significant differences in BMP scores between early and late respondents, suggesting that BMP implementation is used similarly on sampled and unsampled harvests.

Field protocol

In order to successfully navigate and keep track of our progress, a smart phone application (AVENZA Systems Inc.) was used in the field. This “app” allows the user to download PDF maps and uses GPS coordinates to track the user as they navigate the mapped area. Some of the features include tracking progress, dropping pins at areas of interest, and measuring distances traveled. For each property, two maps were created in ArcGIS (ESRI 2018): one showing the land cover, parcel boundaries, and skid trails, and one showing the topography of the area with parcel boundaries and skid trails. It is important to note that no forest roads were considered in the study due to an anticipated low sample size. In this area of the state, small parcel sizes (LaPierre and Germain 2005; Germain *et al.* 2016) generally negate the need to build forest roads to access timber. The typical harvest has one log landing near a county highway resulting in an access system that

Fig. 2 NYC Watershed with depiction of WAC and NonWAC properties visited during the 2018 field season

consists exclusively of skid trails. Past studies in the region included forest road assessments, but the limited occurrence of forest roads did not allow for statistical analysis.

While in the field, differently colored pins were dropped on the AVENZA maps to indicate the beginnings and ends of skid trails, the locations of water bars and stream crossings, and other points of interest. Labels were added to each dropped pin to be used later when looking at skid trail length, spacing of water bars, and the quality of stream crossings. Photographs were added to the pins as additional reference material. This information was also recorded on datasheets throughout the field visit.

The assessment protocol was modeled after Munsell *et al.* (2006) and VanBrakle *et al.* (2013). Because this study was designed to compare with the 2002 and 2011 studies, we used the same measurements to ensure we had comparable datasets. The NYS BMP Field Guide was used to measure if BMPs were installed according to specifications. Evaluative scores were given to each component of the access system addressed in the datasheets. The BMPs were scored on a scale of 0-3, with 0 being the lowest and 3 the highest. A score of "0" indicates that the site did not, in any way, meet the specifications of the BMP Field Guide. For example, if the question was "is all harvest residue placed away from drainage areas?" and there is harvest debris located directly in a drainage area, the site would receive a score of "0", indicating

no attempt at implementing the BMP. A score of "1" indicates that there was an attempt to meet BMP Field Guide specifications, but that there were serious flaws in the execution. For example, if the question was "are there water diversion devices leading into and out of the landing?" and there is a water bar leading into the landing, but it is too shallow, it would get a score of "1", indicating an attempt, albeit poor, at following BMP guidelines. A score of "2" means the BMP implementation was good, but not optimal. For example, if the question was "is the landing vegetated and left in a stable condition?" and there is vegetation and it appears mostly stable, but there is some evidence of erosion or runoff, then it would be scored "2", indicating a good attempt at stabilizing the site, but there is room for improvement. A score of "3" means that BMPs are textbook in their implementation. It is important to note that BMPs were scored based on the effort taken by the logger to implement them. For instance, if a water bar was breached and worn down due to suspected landowner post-harvest activities with all-terrain vehicles, the score would reflect the initial attempt. Also, a determination of "Not Applicable" (NA) was used when appropriate. For example, one evaluation question was "is the landing located at least 200 feet from bodies of water?" If there was no water in sight, the evaluation would be NA rather than 3 because there was no conscious effort to avoid water. Otherwise, a score of 3 would incorrectly inflate the overall landing score.

Access system census

Field visits started at the landing. The landing was graded based on 10 evaluations that examined everything from distance to waterbodies to being cleared of unnatural debris. Thereafter, we began our skid trail survey. We performed a census of the access system (see Fig. 3 for sample property), breaking up the skid trails into segments. A segment was started at the beginning of the access system and a new segment began whenever there was an intersection of skid trails, a significant slope change, or there was a marked difference in the area we walked into. For example, if there was a 30-meter length of skid trail that was relatively uniform in ground cover, canopy cover, and condition, but that started to increase in slope suddenly, we ended the segment before the slope change, assessed the trail, and started a new segment. The segments were graded on a litany of measurements, including length of the trail, slope of the segment, drainage structures, and filter strips. Stream crossings were evaluated based on the condition of the skid trail approaching and leaving the stream, the stability of the stream banks and bottom, and whether a temporary skidder bridge was used or a culvert was installed.

Analysis

Scores for INDIVIDUAL categories (landings, skid trail segments, and stream crossings) were calculated using the following formula:

$$[1] \quad S_{category} = \sum a_i / m$$

Where $S_{category}$ represents the overall score of a category per property, a_i the score for the applicable evaluation (i), and m is the total number of applicable evaluations. Scores for landings, when more than one was present on a property, were weighted by the area of each landing using the following formula:

$$[2] \quad S_L = S_{L1} \left(\frac{A_{L1}}{A_L} \right) + S_{L2} \left(\frac{A_{L2}}{A_L} \right)$$

Where S_L represents the overall score for the landings, S_{Li} the score for landing (i) based on Equation [1], A_{Li} is the area of landing (i), and A_L is the total area of all landings on a property. No more than two landings were ever found on a property.

Scores for skid trails were also weighted in a similar fashion to landings, substituting Length for Area. Weighted skid trail segments were calculated using the following formula:

$$[3] \quad S_{ST} = S_{ST1} \left(\frac{L_{ST1}}{L_{ST}} \right) + S_{ST2} \left(\frac{L_{ST2}}{L_{ST}} \right) + \dots S_{STi} \left(\frac{L_{STi}}{L_{ST}} \right)$$

Where S_{ST} represents the overall weighted score for the skid trail segments, S_{STi} the score for skid trail segment (i) based on Equation [1], L_{STi} is the length of the skid trail segment (i), and L_{ST} is the total length of all skid trail segments (in feet) on a property.

Fig. 3 Example of the skid trail network (yellow lines) on a NonWAC Property (purple lines) from the 2018 field season

Scores for water diversion devices (WDD) were calculated using individual WDD techniques associated with landings, skid trails and stream crossings. The final WDD score was determined using the following formula:

$$[4] \quad S_{WDD} = (WDD_{Landing} + WDD_{Skid Trail} + WDD_{Stream Crossing})/3$$

In all cases, scores of “NA” were not included in the calculation of the average. For example, if a property had no stream crossings, the total would be divided by 2 rather than 3.

Statistical analyses

The differences of the 2018 BMP mean scores between WAC and NonWAC properties were tested using a two-sample t-test for each of the four BMP categories (i.e., Landings, Skid Trails, Steam Crossings, and WDD), respectively. The statistical significance level was set at $\alpha = 0.05$.

To compare our 2018 study with the previous 2002 and 2011 studies (Munsell *et al.* 2006; VanBrakle *et al.* 2013), five treatment groups of data were organized as follows: WAC 2018, NonWAC 2018, WAC 2011, NonWAC 2011, and 2002. Analysis of Variance (ANOVA) was conducted to test the differences of the BMP mean scores among the five groups (Steel and Torrie 1980). Multiple pairwise comparisons between the five groups were then conducted using the Waller-Duncan Bayesian k-ratio t-test at the significance level of $\alpha = 0.10$. This multiple range test was chosen because it is designed to compare the Type I and Type II error rates based on Bayesian principles, unlike the commonly used Tukey’s test which is based on the principle of controlling Type I error (Steel and Torrie 1980; Carmer and Walker 1985). A paired two sampled T-test was used to compare overall mean scores between WAC and NonWac properties in the categories of skid trails, water diversion devices, landings, and stream crossings.

Since our field protocol provided a census of the access system, we calculated the percentage of the harvest area impacted by the access system. The sum of the skid trail lengths was calculated and multiplied by a 3.3-meter width (based on Germain and Munsell 2005) to determine the area dedicated to skid trails. The area of the landing(s) was included to determine the percent harvest area dedicated to the access system. As noted earlier, forest roads were not included in the assess-

ment. A paired two sampled for means T-test was used to compare harvest area between WAC and NonWAC harvests.

All statistical analyses were conducted using Statistical Analysis System software (SAS)[®] 9.4 (SAS Institute, Inc. 2013).

Results

A total of 45 properties were considered for the statistical analyses of data collected during the 2018 field season, i.e., 22 WAC vs. 23 NonWAC properties. The average harvest area for the WAC properties was 29 ha. while NonWAC properties averaged 17 ha. Across the 45 harvests, we assessed 47 landings, over 1400 skid trail segments totaling more than 120 km, more than 100 skid trail stream crossings and numerous associated water diversion devices. We did not encounter any forest roads across the 45 properties.

Our results indicated that there was no significant difference in landing scores (p-value = 0.946) between the WAC and NonWAC properties, but the WAC harvests had significantly higher BMP scores than the NonWAC properties for skid trails (p-value = 0.013), stream crossings (p-value = 0.002), and water diversion devices (p-value < 0.001) (Table 1).

Due to sample size limitations, the common BMPs compared across all three studies were landings, skid trails, and water diversion devices. Although landing scores did not improve from 2002 to 2011, holding in the 2.0 range, there was a significant improvement in 2018 on both WAC and NonWAC harvests. Skid trail scores improved from 2002 (1.56) to 2011 (2.0 range) and that performance continued through 2018 with scores in the 2.7 range. The mean scores for water diversion devices have come a long way since 2002 (0.28). There was almost no attempt at implementation in 2002, followed by an indication that WAC harvest sites were showing some improvement in 2011 (0.87) while the NonWAC sites (0.49) were not significantly different from the 2002 average. In 2018, we see mean scores approaching an acceptable level within the WAC group (1.40), but still plenty of room for improvement in the NonWac group (0.72) (Table 2).

The ratio of area disturbed by the access system to the area harvested was significantly different ($p > 0.001$) between the two groups with the WAC properties at 4.9% and the non-WAC properties at 7.4%. The average percentage of area disturbed by the access system across all properties in the 2018 sample was 5.7%. In 2002, the percentage of area disturbed by

Table 1. Comparison of 2018 BMP scores between properties involved in the Watershed Agricultural Council BMP program (WAC) and those not involved (NonWAC)

BMP Category	Group	Sample Size	Mean	Std. Dev	Std. Error	p-value
Landings	WAC	23	2.63	0.45	0.09	0.946
	NonWAC	24	2.62	0.36	0.08	
Skid Trails	WAC	23	2.80	0.10	0.02	0.013
	NonWAC	22	2.58	0.37	0.08	
Stream Crossings	WAC	61	2.16	0.89	0.11	0.002
	NonWAC	51	1.56	1.1	0.15	
Water Diversion Devices	WAC	23	1.40	0.51	0.11	0.000
	NonWAC 218	22	0.72	0.63	0.13	

Table 2. A summary of BMP mean scores in three studies. Scores range from 0 (no attempt at implementation) to 3 (implemented correctly). Means that do not share the same superscript letter are significantly different by the Waller-Duncan Bayesian k-ratio t-test at the significance level of $\alpha = 0.10$.

BMP Category	Group	Sample Size	Mean	Median	Std Dev	Minimum	Maximum
Landings	WAC 2018	23	2.63 ^a	2.80	0.45	1.67	3.00
	Non 2018	24	2.62 ^a	2.70	0.36	1.88	3.00
	WAC 2011	44	2.13 ^b	2.11	0.51	0.90	3.00
	Non 2011	39	1.99 ^b	2.00	0.49	0.80	2.69
	2002	31	1.89 ^b	1.90	0.50	0.86	2.88
Skid Trails	WAC 2018	23	2.80 ^a	2.78	0.10	2.63	3.00
	Non 2018	22	2.58 ^b	2.69	0.37	1.21	2.94
	WAC 2011	47	2.09 ^c	2.06	0.31	1.61	2.61
	Non 2011	42	1.84 ^d	1.83	0.33	1.05	2.44
	2002	31	1.56 ^e	1.52	0.47	0.90	2.94
Water Diversion Devices	WAC 2018	23	1.40 ^a	1.38	0.51	0.60	2.25
	Non 2018	22	0.72 ^{bc}	0.71	0.63	0.00	1.91
	WAC 2011	47	0.87 ^b	0.78	0.80	0.00	2.72
	Non 2011	42	0.49 ^{cd}	0.23	0.67	0.00	2.76
	2002	31	0.28 ^d	0.19	0.51	0.00	2.90

the access system was 6.3%, but included a few properties with forest roads. Nonetheless, the percentages are quite similar.

Discussion

This formative evaluation of BMP implementation in the NYC Watershed suggests that the WAC BMP Program is effective. VanBrakle *et al.* (2013) recommended a need for “evaluation” for this particular cost-sharing program due to the lack of difference in BMP implementation scores between 2002 and 2011. The underwhelming progress reported by the initial comparative study hinted at a lack of programmatic growth and possible stagnation in diffusing awareness and implementation of BMPs on harvests within the Watershed. In response, the WAC Forestry Program instituted changes, focusing exclusively on BMPs and de-emphasizing broader forest management goals and objectives linked to suggested stand-based silvicultural prescriptions designed to promote sustained yield management. With a renewed and exclusive focus on BMPs, the program has reaped on-the-ground progress as well as changes in overall behavior with respect to BMP implementation. Participants of the program are clearly out-performing their counterparts who are not taking advantage of the BMP program. BMP implementation scores were significantly higher for skid trails, stream crossings, and water diversion devices on WAC properties than on NonWAC properties. The landings did not significantly differ between the two property types. The temporal component of the study strongly indicates that implementation of BMPs has improved over the past decade and a half as the 2018 BMP scores showed significant improvement when compared to the previous two studies in 2002 and 2011 (Munsell *et al.* 2006, VanBrakle *et al.* 2013) (Table 2).

WAC’s outreach and extension efforts to loggers, foresters, and landowners, combined with the cost-sharing initiative, are resulting in higher BMP implementation rates for program participants across the Watershed. We believe this positive result stems from the well-recognized influence

of extension organizations such as WAC on individuals through personal contact, support, and partnerships (see for example West *et al.* 1988, Magill *et al.* 2004). The personal contact, guidance and monitoring by WAC foresters is critical to the success of the BMP program. The cost-sharing aspect of this program compensates logging contractors for spending the extra time and materials implementing BMPs. Additionally, compliance with the WAC BMP Program requires the involvement of a forester to assess the BMP plan, provide technical assistance during the operation, and conduct an evaluation once the job is complete. The difference in the ratio of harvest access system area to total harvest area between WAC and NonWAC properties suggests that harvest planning with a forester can minimize the area disturbed by the access system. Planning is the first, and most likely the most important aspect of BMPs. Planning of the access system is particularly important when faced with unpredictable extreme weather events; it is during these major events (i.e., torrential rain storms) that the majority of sediment losses occur (Kochenderfer *et al.* 1997).

In studies in Vermont and New York, both Maker *et al.* (2014) and VanBrakle *et al.* (2013) noted the influence of forest tax law program requirements monitored closely by foresters in promoting the highest level of sustainable forest management (including BMP implementation). Similarly, Wang and Goff (2008) reported that forester involvement in a harvest resulted in higher rates of BMP implementation and effectiveness. The combination of a strict management plan and direct forester contact appears to yield the best results on the ground. In their review of the USDA Forest Service Forest Stewardship Program, Butler *et al.* (2014) reported that direct one-on-one contact with a forester was more effective than a federally subsidized management plan without concrete requirements.

Although the overall progress in BMP implementation is encouraging, there is certainly room for improvement concerning water diversion devices designed to remove surface

flow from skid trails. VanBrakle *et al.* (2013) posited that this may be due to the lack of visibility of the skid trails. Unlike landings, which are often roadside and in public view, remote sections of skid trails are not easily visible to the landowner and public, and therefore may not receive due attention by loggers. The equipment spread on a particular job may also play a role in the quality and rate of implementation. For instance, a harvest system which includes a bulldozer is better equipped to construct deeper and better water bars than one limited to using the blade of a skidder. Related to the harvest system is the experience level of the loggers. An experienced logger with BMP training will be better able to install appropriate and proper BMPs than one with little or no experience and training. Another reason for poor-quality implementation, (or none at all), may be connected to the time of year the harvest was completed. If the ground was snow covered or frozen at the end of the harvest, the logger would have to make the extra effort to return to the site to install BMPs such as water bars. Perhaps that return visit to the site when soil conditions are amenable is not happening on a consistent basis. Also, it is important to remember that landowners often want to use their property for recreation following a harvest, meaning the harvest access system becomes the recreation access system. Water bars and other water diversion devices may not be conducive to landowner objectives.

Although any BMP program would prefer better implementation of water diversion devices, it is important to note that under the assessment protocol of these three studies, future implementation scores will likely plateau at about “2”. Why? To maintain consistency across the three studies, we used specifications referenced in the NYS BMP Field Guide which may go above and beyond what is effective and necessary for a given situation. For instance, on a skid trail with a 20% slope, the spacing for water bars should be roughly 14 meters, according to the spacing table (Haussman 1960) included in most BMP field guides across the country. Most experienced foresters and loggers would agree that the table, as a guide, is a bit aggressive and that surface flow protection is achievable with a wider spacing, depending on specific macro- and micro-site conditions. Whatever the on-site conditions, experienced foresters and loggers can implement the suitable number of water bars and achieve good results with respect to water quality. So yes, there is room for improvement concerning the implementation of water diversion devices, but that average score of “1.4” for water diversion devices on harvests with a BMP program is actually reasonable, and likely serving the needs of the landowner and water quality objectives of the Watershed. Again, we believe a mean water diversion device of “2” across all harvests in the Watershed would be a realistic goal in the coming decade.

Meeting water quality goals and landowner objectives while simultaneously maintaining the economic viability of loggers is critical for long-term success. Kelly *et al.* (2017) and Regula *et al.* (2019) determined that the impacts of implementing BMPs on costs and productivity were found to be situationally dependent. For contractors with larger crew sizes operating a wide array of equipment, it was possible to maintain some productive capacity while installing BMPs. However, the one and two-person logging operations, which are common in the study area, do not have the versatility of larger crews, thus BMP implementation becomes a bottle-

neck in the production process. Time spent implementing BMPs represent a loss of productive time not cutting, bucking, skidding or loading, ultimately impacting their profit margin. For this reason, it is important for cost-sharing programs like the WAC BMP Program to focus on smaller operations that do not have the economies of scale to absorb the extra time and costs of implementing BMPs so they can remain economically viable (Kelly and Germain 2016).

Conclusions

Much progress has been made in the past few decades with respect to the awareness and implementation of BMPs. The current culture surrounding BMP implementation is that it has become a normal expectation on all logging jobs. However, in non-regulatory states with forest ownership dominated by a patchwork of highly parcelized family forests (such as New York State), there is a higher likelihood of inconsistencies regarding BMP implementation, requiring more oversight and vigilance from resource managers. The personal contact and cooperation between the logger and forester fostered by the Watershed Agricultural Council (WAC) BMP program is a key component of its success, but that alone is not enough. The added costs associated with implementing BMPs are borne by the loggers, impacting their economic viability. Cost-sharing BMP programs, such as the WAC program, can serve as an important catalyst for BMP implementation, particularly in regions dedicated to water supply.

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