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Implementation of Forestry Best Management Practices on Biomass and Conventional Harvesting Operations in Virginia

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Abstract: Logging residues are often utilized as a Best Management Practice (BMP) for stabilizing bare soil on forest harvesting operations. As utilization of woody biomass increases, concern has developed regarding availability of residues for implementing BMPs. The Virginia Department of Forestry (VDOF) inspects all logging operations in Virginia and randomly selects a portion of harvests for more intensive audits. The VDOF BMP audit process intensively evaluates implementation of BMPs in seven categories (84 specific BMPs) on 240 sites per year. This research analyzed three years of audit data (2010–2012) to quantify differences in BMP implementation between biomass and conventional harvesting operations. Among 720 audited tracts, 97 were biomass harvests, with 88 occurring in the Piedmont region. Only the streamside management zone (SMZ) category had significant implementation percentage differences between biomass (83.1%) and conventional harvests (91.4%) (p = 0.0007) in the Piedmont. Specific areas where biomass harvesting operations had lower implementation were generally not related to a lack of residues available for implementing BMPs, but rather were from a lack of appropriate SMZs, overharvesting within SMZs, or inadequate construction of roads, skid trails, and stream crossings. Existing BMP recommendations already address these areas and better implementation would have negated these issues.

Keywords: biomass harvest; water quality; logging residues; streamside management zones (SMZs)

1. Introduction

In Virginia, as in many other areas, there are multiple new biomass energy facilities in production (e.g., [1,2]. Much of the feedstock for these energy facilities is anticipated to come from logging residues [3]. Therefore, utilization of woody biomass from logging residues, including limbs, tops, and otherwise non-merchantable trees or portions of trees, has increased to meet this new demand. As more intensive biomass harvesting occurs, there have been concerns related to the potential impacts of biomass harvesting [4–7]. Increased use of logging residues is a potential concern because inadequate amounts of logging residues may remain for soil protection and implementation of Best Management Practices (BMPs) for water quality.

Existing forestry BMPs for water quality are generally considered adequate for protecting water quality on biomass harvesting operations [5]. However, there has been little research on the implementation of BMPs for protecting water quality specifically on biomass harvesting operations. A number of states have enacted biomass harvesting guidelines (e.g., Minnesota, Maine, Pennsylvania, and Missouri) and suggested BMPs for biomass harvesting. Biomass harvesting guidelines often

reinforce conventional harvesting water quality BMPs and make precautionary recommendations such as avoidance of harvesting more biomass from streamside management zones (SMZs) or buffers than would be removed with conventional harvests. Harvesting guidelines often address non-water quality-related issues such as wildlife habitat or nutrient removals (e.g., [8]).

Forest harvesting operations have the potential to negatively impact water quality [9–12]. Following the Federal Water Pollution Control Act of 1972 and subsequent amendments, states throughout the U.S. have adopted voluntary or mandatory BMP guidelines for protecting water quality during timber harvests [11,12]. Individual states have been charged with monitoring BMP implementation rates for forest harvesting operations [13]. Research regarding the use of forestry BMPs has supported their use for protecting water quality [11,14–17].

The Virginia Department of Forestry (VDOF) has not developed specific BMPs for biomass harvesting; however, the current BMP manual [18] does include a succinct paragraph on biomass harvesting with five suggested practices. The suggested practices include retention of ground cover to protect soil from erosion, retention of the forest floor including leaf litter, rapid regeneration of the stand, retention of residues as needed to protect water quality, and a suggestion for harvesting after leaf fall to retain nutrients where possible [18].

BMPs for protecting water quality often involve soil protective measures such as utilizing logging residues as a ground cover (e.g., [18–20]). BMP implementation could be negatively affected if removal of logging residues caused increases in bare soil, or if inadequate quantities of residues remained for BMP implementation to protect bare soil on decks, skid trails, or stream crossings.

The Piedmont region of Virginia has active markets for biomass or wood fuel produced from logging residues, and many logging operations have responded to these markets by adding a chipper to utilize logging residues for energy [21]. The VDOF has an active BMP monitoring program to evaluate statewide implementation of BMPs [22]. Beginning in 2010, the VDOF also began collecting data on biomass harvesting during harvest inspections. The VDOF harvest audits provided an opportunity to evaluate implementation of BMPs for water quality on operational biomass harvesting sites and compare biomass harvests to conventional harvests. The overall objective of this study was to evaluate and compare implementation of BMPs for water quality on current operational biomass harvests and conventional roundwood harvests. The following specific research questions were addressed:

1. Do biomass harvest sites have lower BMP implementation rates than conventionally harvested sites?
2. Do any specific BMPs have significantly different implementation rates on biomass *versus* conventional harvests?
3. Do any of the differences in BMP implementation result from a lack of residues remaining on-site?
4. Do BMP implementation rates on biomass harvest sites indicate the need for additional specific water quality BMP recommendations for biomass harvests?

2. Materials and Methods

The VDOF water quality program requires all logging businesses to notify the VDOF within three days of starting a harvest. The notification includes the logging business contact information, landowner information, location, and estimated size of harvest. After harvest notification is received, VDOF personnel inspect and monitor the harvest to ensure compliance with the Virginia Silvicultural Water Quality Law (§10.1–1181.2 through 10.1–1181.7) [18]. After harvest completion, VDOF personnel conduct a final tract inspection. Annually, these water quality inspections are completed on over 5000 timber harvests throughout Virginia [23]. As part of its statewide BMP implementation monitoring, the VDOF randomly selects a portion of these completed tracts for a more intensive BMP audit. Statewide, 240 tracts per year (approximately 5%) are intensively audited for BMP implementation. Sixty tracts per quarter are selected from the list of of all tracts that received a final inspection two quarters prior to selection. This criteria results in selection of tracts where harvesting was completed approximately six months prior to the audit and enables assessment of BMP integrity

over time [22]. Selected tracts are evaluated based on BMP implementation related to specific BMPs from the VDOF BMP Technical Manual [18]. The VDOF BMP auditing and reporting methods are based on methods outlined by the Southern Group of State Foresters [24]. The complete audit includes 10 categories and 117 questions. For this study we excluded the site preparation BMP categories related to chemical application, mechanical site preparation, and use of prescribed fires. This study evaluated only the logging-related BMPs, which included seven categories with 84 questions consisting of (number of questions): Roads (19); Decks (9); Stream or Wetland Crossings (19); Streamside Management Zones (SMZs) (13); Wetlands (8); Harvest Planning (3); and Skidding (13).

Data collected during VDOF BMP inspections also include information on the location and site characteristics and whether or not biomass harvesting occurred. Tracts were classified as biomass harvests by the inspector if chipping or other indications of biomass harvesting were observed (e.g., chips left on the landing after the harvest was completed). Tracts were evaluated by trained VDOF auditors and each of the 84 BMP implementation questions received an answer of "Yes," "No," or "Not Applicable" for the tract. Audits were completed by VDOF water quality personnel who attend regular training to maintain consistency in audit scoring across the state [22]. Audit scores are reported as the percentage of applicable BMPs receiving a "Yes" on the audit. This percentage represents the proportion of applicable audit questions that were appropriately implemented by the operator [22]. While not all BMP categories are specifically related to impacts from biomass harvesting, all logging-related categories were included in the evaluations in order to compare differences between biomass and conventional operations.

VDOF BMP audit data from three years (2010–2012) were compiled and reconfigured into a single dataset with 720 tract audits and analyzed using JMP version 10 [25]. Each tract received an average implementation score for each of the BMP categories based on methods outlined by Lakel and Poirot [22]. The score for each category was calculated as the percentage of applicable questions in that category that received a "Yes" from the auditor. An overall BMP implementation score was also calculated for each tract based on the total number of "Yes" answers divided by the total number of questions applicable to the tract. Tracts were classified into physiographic provinces based upon US Forest Service classification of physiographic regions by county [26]. Northern and Southern Piedmont regions were combined into a single Piedmont region, and Northern and Southern Mountain regions were combined into a single Mountain region.

BMP implementation scores for conventional *versus* biomass harvests were compared for each of the seven BMP categories and for the overall tract score using the non-parametric Wilcoxon rank sums test [27]. Each of the 84 individual questions was evaluated to determine differences in implementation of specific BMPs. Each applicable audit question resulted in categorical responses of "Yes or No" and "Biomass or Conventional." These two categorical variables resulted in a 2×2 contingency table and were tested using a chi-square test [27]. Tests were conducted at the $\alpha = 0.05$ level using JMP [25].

3. Results

Biomass harvests were conducted on 97 of the 720 BMP audits performed over three years (Table 1). Within the 97 biomass harvests, three were in the Mountain region, six were in the Coastal Plain, and the remaining 88 were in the Piedmont region. Biomass harvests were primarily in the Piedmont region due to the proximity to markets for biomass or wood fuel produced from logging residues and an existing logging workforce where integrated biomass harvesting operations are more common.

There were few biomass harvests observed in the Mountain and Coastal Plain regions; therefore, comparisons of BMP implementation on biomass and conventional harvests were limited to the Piedmont region. Comparisons of BMP implementation percentages by category (Table 2) indicated that the only category where biomass harvests had significantly lower BMP implementation scores was the SMZ category ($p = 0.0007$).

Table 1. Distribution of biomass and conventional harvest tracts across physiographic regions.

Physiographic Region	Biomass (n)	Conventional (n)	Total (n)	Biomass Harvests (%)
Mountains	3	107	110	2.7
Piedmont	88	284	372	23.7
Coastal Plain	6	232	238	2.5
	97	623	720	13.5

Table 2. Best Management Practice (BMP) audit scores by category for biomass (n = 88) *versus* conventional (n = 284) harvests over a three-year period (2010–2012) in the Piedmont of Virginia.

BMP Category	Biomass (n)	Percent "Yes"	SE	Conventional (n)	Percent "Yes"	SE	p-Value
Roads	84	77.61	2.43	259	81.05	1.24	0.2901
Decks	88	92.66	1.36	284	91.64	0.83	0.7392
Crossings	39	90.21	3.03	123	90.36	1.60	0.7626
SMZs	73	83.05	2.67	224	91.35	1.13	0.0007
Wetlands	2	100.0	0	0	—	—	—
Planning	87	86.78	2.39	283	82.80	1.44	0.1775
Skidding	88	83.72	2.00	280	85.69	1.14	0.2443
Overall BMP Score	88	83.89	1.43	284	86.62	0.70	0.1402

3.1. Potential Deficiencies If Adequate Residues Were Not Available for BMP Implementation

The VDOF audits examined multiple aspects of BMP implementation on forest harvesting sites and many of the questions would not be expected to differ based on whether logging residues and whole trees were harvested for biomass or were left on site with conventional operations. Seven of the 84 BMP audit questions [22] might be expected to differ between biomass and conventional operations (Table 3). These differences could be expected based on availability of logging residues to protect disturbed areas or because biomass harvesting operations might require additional space on the deck to accommodate additional equipment. Only one of the seven questions indicated significant differences. The roads BMP question that asked, "Are riprap and/or brush dams used where needed to slow water and trap sediment?" indicated lower BMP implementation on biomass versus conventional harvests (p = 0.0143).

Table 3. BMP audit questions that might be expected to differ between conventional and biomass harvests based on availability of logging residues or size of deck needed to accommodate additional equipment.

BMP Question	Biomass (n)	Percent "Yes"	Conventional (n)	Percent "Yes"	p-Value
SMZ Q10: Was exposed soil in the SMZ revegetated or covered with organic materials?	20	85.00	50	92.00	0.3778
Skidding Q7: Were brush mats used to stablize trails and prevent erosion where needed?	70	74.29	223	69.51	0.4437
Crossings Q17: Are stream banks and approaches reclaimed with sufficient vegetation, rock, or slash?	37	89.19	112	86.61	0.6831
Decks Q2: Are appropriate soil protection measures in place to prevent erosion on the deck?	84	78.57	267	79.03	0.9290
Decks Q5: Are sediment trapping structures present if needed to prevent pollution?	35	97.14	106	91.51	0.2603
Decks Q6: Are all decks limited in size?	88	96.59	284	98.59	0.2275
Roads Q17: Are riprap and/or brush dams used where needed to slow water and trap sediment?	20	40.00	61	70.49	0.0143

3.2. Analysis of All BMP Implementation Audit Questions

All logging-related BMP audit questions were analyzed to determine specific differences in implementation rates between biomass and conventional harvesting operations in the Piedmont. This analysis indicated that of the 84 logging-related BMP questions, 11 had significant differences between biomass and conventional harvests (Table 4). These differences related primarily to SMZs as well as road and skid trail layout. There were five SMZ-related questions that indicated lower BMP implementation scores for biomass harvests because the SMZ width was insufficient, inadequate proportions of trees remained in the SMZ, the SMZ was partially clear cut, or sediment entered the stream due to inadequate SMZs.

Table 4. The Virginia Department of Forestry (VDOF) BMP audit questions with significant differences at the $\alpha < 0.05$ level between biomass and conventional harvests.

BMP Question	Biomass (n)	Percent "Yes"	Conventional (n)	Percent "Yes"	*p*-Value
SMZ Q1: Are all SMZs a minimum of 50 feet wide on each side of the stream bank?	72	55.56	224	78.13	0.0002
SMZ Q4: Does at least 50% of the original basal area exist in the SMZ?	73	65.75	219	81.74	0.0045
SMZ Q5: Is SMZ width relatively consistent along the entire length?	72	76.39	222	88.74	0.0093
SMZ Q6: Did the logger avoid partial or patch clear cutting in the SMZ?	73	73.97	222	86.49	0.0127
SMZ Q13: Did the logger avoid silvicultural sediment in the stream that might endanger public health, beneficial uses, or aquatic life as stated in the "silvicultural water quality law?"	73	95.89	224	99.55	0.0184
Roads Q11: Is construction of dips, bars, turnouts, and traps adequate to maintain function?	44	45.45	129	65.89	0.0165
Roads Q17: Are riprap and/or brush dams used where needed to slow water and trap sediment?	20	40.00	61	70.49	0.0143
Roads Q18: Are roads built outside of SMZs where possible?	69	95.65	178	99.44	0.0344
Skidding Q4: Are all skid trails free from channelized flow that is likely to cause sedimentation?	86	88.37	273	95.97	0.0088
Crossings Q9: Are culvert pipes installed properly in the channel to avoid undercutting and channel erosion?	6	66.67	32	93.75	0.0473
Crossings Q13: Do all ford crossings have a 50-foot approach of clean gravel?	3	0.00	10	70.00	0.0329

Two roads-related questions also had significantly lower implementation scores for biomass harvests. One of the roads category questions was also related to SMZs and road construction in SMZ areas. The other related to road construction and structures for turning water off of roads or installation of sediment trapping structures where needed. There was also significantly lower implementation where skid trails had channelized flow that was likely to cause sedimentation.

The stream crossings category was the final one in which significantly lower implementation occurred on biomass harvests. Stream crossings included both skidder and haul road crossings; thus, they could be considered as part of the skidding or road network. However, stream crossings are evaluated separately from roads and skid trails because of their greater propensity to contribute sediment based on their direct connectivity to streams. Significantly lower implementation scores for biomass harvesting operations were noted for two crossing questions. One of the crossing questions was related to proper installation of culverts, and the other related to appropriate use of gravel to stabilize ford approaches.

4. Discussion

Due to well-established markets for woody biomass in the Piedmont region of Virginia, nearly 20% of logging businesses have added a chipper to their operations for utilizing whole trees and logging residues for biomass energy [21]. For biomass harvesting operations, increased utilization of logging residues is a potential concern because inadequate amounts of logging residues may remain for soil protection and BMP implementation. Utilizing logging residues for biomass energy might be expected to result in lower BMP implementation for BMPs that incorporate logging residues for protection of disturbed soil areas. However, this analysis revealed few significant differences between conventional and biomass harvesting operations. Some important differences in BMP implementation were detected, and the differences were primarily related to leaving adequate SMZs, road and skid trail design and installation, and proper stream crossing design. Some of the more important findings of this research are that current BMP guidelines already exist that address the problems identified by the study and better usage and implementation of existing BMPs would have been sufficient to address the problems. A similar conclusion was reported by Shepard [5] following an extensive review of existing BMPs for the United States.

The analysis of all BMP audit questions indicates that the significant differences between biomass and conventional harvests that occurred were generally not related to the availability of logging residues for protecting bare soil and implementing water quality BMPs. Rather, the differences between biomass and conventional harvests were primarily related to adequacy of SMZs and design and installation of roads, skid trails, and stream crossings. The lower implementation rates for roads, skid trails, and stream crossings are a potential concern because these are major sources of erosion on logging operations, and stream crossings are a primary conduit for sediment to enter streams (e.g., [17,19,20,28,29]). Similarly, SMZs are important BMPs because they are the last major BMP that has the potential to trap sediment before it can enter streams [15,30].

Analysis of the BMP audit data can show where differences occur, but does not necessarily explain all of the reasons for differences in BMP implementation. Differences in BMP implementation rates on harvests performed by the group of loggers that harvested biomass compared to harvests performed by the group of loggers that did not harvest biomass could be caused by numerous factors. Market conditions, types of tracts that are chosen for biomass harvesting operations, goals of landowners who select biomass harvesting operations, level of involvement of professional foresters, and many other factors could influence BMP compliance. For example, a study of West Virginia harvest sites by Wang and Goff [31] found that BMP application and effectiveness was higher on industry-owned lands than on private lands and was higher when a professional forester was involved. In the Piedmont region of Virginia, loggers also report that many landowners often prefer or even require utilization of logging residues [32]. Some landowners prefer the "clean" look of a site where residues are chipped and may encourage loggers to harvest as much timber as possible from the site. Furthermore, some landowners who specifically request biomass harvests may plan to convert the site to other uses, which may also encourage loggers to harvest as much as possible, even in the SMZ area. These scenarios may result in inadequate SMZs for protection of water quality. While their study was not specifically related to biomass harvesting operations, Vanbrakle *et al.* [33] also found similar differences with lower implementation of BMPs on roads and skid trails and discussed the impacts of family forest owners and management plans on implementation of voluntary BMPs.

5. Conclusions

A lack of logging residues for protecting disturbed areas did not appear to reduce BMP implementation on biomass harvests. However, BMP implementation related to the SMZs category was significantly lower for biomass (83.05%) *versus* conventional harvests (91.35%) (p = 0.0007). Additional differences on specific BMP questions related primarily to inadequate installation of roads, skid trails, and associated stream crossings. Lower BMP implementation rates on biomass harvests were not necessarily caused by fundamental characteristics of biomass *versus* conventional harvests.

Instead, differences appeared to result from operational decisions made by harvesting contractors, foresters, or landowners. These decisions related to installation of roads, skid trails, and crossings, as well as whether or not to leave an SMZ or how much to harvest in an SMZ. These BMP problems were not related to the availability and adequacy of harvest residues. These harvesting decisions relate to adequate harvest planning and concern for implementation of BMPs to protect water quality and appear to be addressed by current BMP recommendations. With appropriate attention to harvest planning and implementation, existing water quality BMPs are appropriate for biomass harvest sites.

Logging business owners and foresters involved in harvest planning for biomass harvests should be aware that there could be a greater likelihood for overharvesting in SMZs. SMZs should be clearly identified prior to harvest, and acceptable harvesting levels within the SMZ should be clearly specified. Additionally, during harvest planning, roads and skid trails should be appropriately located, installed, and then closed after harvest completion. Logging operations should also consider logging residue management as a part of their overall harvest plan to ensure an adequate amount of residues are available for implementing BMPs. If biomass harvesting operations adequately protect SMZs and implement properly designed access roads and skid trails, then biomass harvest operations do not appear to be more of a water quality concern as compared to conventional operations in the Virginia Piedmont. Where differences in BMP implementation rates occurred, the differences were due to operational decisions rather than lack of residues for implementing BMPs. Existing BMP recommendations already address the water quality protection guidelines needed for such operations and better implementation of existing BMPs would have minimized problems. Overall, with existing harvesting systems and market conditions in this region, additional water quality BMPs appear unnecessary.

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