Operational characteristics, erosion potential, and implementation of forestry best management practices on biomass harvesting operations

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ABSTRACT

Utilization of woody biomass for energy is expected to increase rapidly and logging residues are a likely feedstock to meet increased demands. Potentials for increased biomass utilization have created concerns regarding possible impacts of using logging residues for energy. The overall goals of this project were to characterize biomass harvesting operations and to evaluate potential impacts on soil erosion and implementation of Best Management Practices (BMPs) for water quality on biomass harvesting sites. Results indicate that biomass harvesting was integrated into a wide range of logging businesses. Existing biomass harvesting businesses reported total production levels ranging from 6 to 250 loads per week. The majority (98%) of biomass harvesting operations utilized integrated harvesting techniques where roundwood and fuel chips were produced concurrently. Potential erosion rates and BMP implementation scores were evaluated on ten biomass and ten conventional harvest sites in the Piedmont of Virginia. This study of 20 sites found no significant differences in overall estimated erosion rates between biomass harvests (0.7 tons ac^{-1} yr^{-1}) and conventional harvests (0.8 tons ac^{-1} yr^{-1}) ($p=0.8282$). Additionally, there were no significant differences observed in overall BMP implementation scores for biomass (85.2%) and conventional (81.3%) harvests ($p=0.5930$). A separate, but related study evaluated BMP implementation over a three year period on 88 biomass and 284 conventional harvests in the Piedmont of Virginia. Within the seven logging related BMP categories, only the Streamside Management Zones (SMZs) category had significant differences between biomass (83.1%) and conventional harvests (91.4%) (p=0.0010). Implementation score differences were not caused by insufficient residues for stabilization of bare soil but were apparently the result of operational decisions which resulted in lower implementation of BMPs related to SMZs. Overall, these findings indicate that existing BMPs appear adequate to protect water quality on biomass harvesting operations in the Virginia Piedmont when appropriately implemented.

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PREFACE / ATTRIBUTION

Dr. Aust and Dr. Bolding assisted with the overall research framework for this dissertation and reviewed and offered revisions for all of the manuscripts. Dr. Munsell assisted with development of the logger survey instrument and assisted with review and revision of the logger survey manuscript. Dr. Lakel assisted with the research framework and review of the erosion estimate, and BMP implementation manuscripts. All committee members reviewed and approved the research methodology for this study.

1.0 INTRODUCTION

Currently there is considerable focus on woody biomass for energy and utilization of biomass is expected to increase substantially in the future (Janowiak and Webster 2010, US EIA 2012a). Interest is often focused on woody biomass to address concerns related to energy security, climate change, and carbon dioxide emissions from fossil fuels (Gan and Smith 2006). Biomass fuel can also be more cost effective when compared to fossil fuels. Biomass currently contributes to US energy needs with much of the production from the existing forest industry use of mill residues (Bain and Overend 2002, Zerbe and Skog 2007). For woody biomass to contribute a larger percentage of the US energy needs, large scale biomass utilization will be necessary and additional feedstock will be required from sources other than existing mill residues. Biomass from logging residues or previously non-merchantable small trees from ongoing forest harvesting operations is a potential source of additional material for energy production (Gan and Smith 2006; Galik et al. 2009).

Several methods have been investigated for harvesting woody biomass from logging residues, but the most cost effective method is generally associated with an integrated harvesting operation utilizing conventional harvesting equipment combined with a chipper for processing biomass at the landing (Miller et al. 1987, Stokes et al. 1989, Hudson 1995, Conrad 2011). Numerous studies have evaluated machinery and harvesting systems in order to establish productivity and costs of specific systems (Mitchell and Gallagher 2007, Westbrook et al. 2007, Baker et al. 2010, and Conrad 2011). However, few studies have attempted to characterize biomass harvesting operations regionally. In particular there is a lack of research regarding the owners' attitudes of firms harvesting biomass in a region with active markets (Munsell et al. 2011).

Although there are advantages to utilizing woody biomass for energy there are also concerns regarding the impacts that this harvesting can have on forests. Many concerns relate to the additional organic material removed from harvest sites because of the potential to degrade water quality, site productivity, and wildlife habitat (Janowiak and Webster 2010). Studies have evaluated the site productivity (Mann et al. 1988, Johnson and Todd 1998, Fox 2000) and wildlife habitat (Rifell et al. 2011) concerns related to biomass or whole tree harvesting, but fewer studies have evaluated possible water quality impacts (Shepard 2006).

While there has recently been an increased interest in biomass utilization the use of wood for energy is not a new concept. In 1850, fuelwood accounted for over 90 percent of all energy consumption in the U.S (Bain and Overend 2002). Even in the 21st century, MacCarty et al. (2008) found that 2 billion people use biomass for cooking on a daily basis. The most viable current technology for utilizing energy from biomass such as logging residues generally involves direct combustion to produce thermal energy for heating or electricity production (Zerbe 2006). Woody biomass is currently utilized at an industrial scale by a number of facilities for generating heat, steam, and electricity. The forest products industry has utilized woody biomass for decades as a source of process heat and power (Bain and Overend 2002, Zerbe and Skog 2007). Current expansion in biomass for energy makes it increasingly likely that woody biomass utilization will continue to develop in terms of total consumption, types of bioenergy products produced, and number of areas with markets for woody biomass. Additional uses and markets for woody biomass will require increased harvest of biomass for energy.

Large scale expansion of markets for biomass energy could cause management and operational changes to logging businesses that elect to harvest biomass as well as altering post harvest site characteristics. In order to better understand potential impacts from large scale biomass harvesting, research focused on existing biomass harvesting businesses and harvest sites are needed to suggest and potentially predict possible impacts due to market expansion. Therefore, research focused on harvesting operations within a region that currently has well developed biomass markets could illustrate how additional operations might adapt to biomass harvesting and predict future impacts if markets increase. Potential impacts could include those to the individual logging business as their harvesting operations produce new products and add machinery as well as potential water quality impacts related to increased removal of logging residues.

The Piedmont region of Virginia has had active biomass markets for approximately 20 years. Nearly 20 percent of logging businesses in the Virginia Piedmont have added whole tree chippers to conventional harvesting operations to utilize biomass for energy (Bolding et al. 2010). This region provides an opportunity to study biomass harvesting practices that have developed in response to active markets. Additionally, it offers an opportunity to study forest harvesting Best Management Practices (BMPs) for water quality on sites where logging residues were utilized for bioenergy production.

1.1 Literature Review

1.1.1 Utilizing Wood for Energy

Utilizing wood for energy is not a recent development. Wood has long been utilized as an energy source in the U.S. (Bain and Overend 2002). Woody biomass received considerable attention in the U.S. after the 1970's oil embargo resulted in increased use of wood for energy and an increase in related research. Between the 1973 oil crisis and 1985 the use of wood for energy in the U.S. increased by 76 percent (Aguilar et al. 2011). The forest industry, especially the pulp and paper industry, has historically been a large producer and consumer of biomass energy (Bain and Overend 2002, Zerbe and Skog 2007). Multiple biomass powered thermal and electrical facilities operate across the country for commercial, residential, municipal, and industrial purposes (Bergman and Zerbe 2004).

Rises in prices for petroleum and other fossil fuels and many other factors increase interest in and utilization of biomass for energy. Factors include concerns related to climate change and carbon dioxide emissions from fossil fuels, as well as concerns related to energy independence and national security. Such concerns have resulted in policy responses that impact markets for woody biomass (Abt et. al. 2010). In addition to environmental benefits and energy security, there are also other benefits from wood-based energy production. Gan and Smith (2007) found that biomass harvesting reduces carbon dioxide emissions, creates additional jobs, and potentially reduces site preparation costs following harvesting. Biomass harvesting also has been shown to increase silvicultural opportunities for thinning and intermediate treatments, as well as aiding in forest stand and site rehabilitation (Manley and Richardson 1995, Munsell and Germain 2007).

1.1.2 Sources and Uses of Woody Biomass for Energy

Woody biomass for energy has a variety of sources including logging residues, fuel treatments on forest lands, fuel wood harvesting (direct conversion of roundwood to fuel), forest industry residues, and urban wood residues. The combined sources of biomass in the U.S. could provide up to 368 million dry tons per year of sustainably recoverable forest biomass, including up to 41 million dry tons from logging and other residues (Perlack et al. 2005, Perlack and Stokes 2011).

Woody biomass can be utilized for thermal energy by direct combustion of wood pieces or can undergo additional processing through pyrolysis, gasification, or conversion to charcoal, pellets or briquettes prior to combustion. Biomass can also be used to produce transportation fuels including ethanol, methanol, gasoline, and diesel; however, costs involved with fuel conversion technologies are currently limiting production (Zerbe 2006). Biomass thermal energy is utilized for electricity production primarily in direct combustion boilers that use thermal energy to produce steam to power a turbine (Bain and Overend 2002).

1.1.3 Biomass Energy Utilization Methods and Feedstock Requirements

Different biomass utilization methods can require substantially different feedstock characteristics and forms of suitable biomass. This variability impacts cost, availability, and physical characteristics (Bain and Overend 2002). When considering sources and characteristics of biomass it is important to understand end use and feedstock requirements.

1.1.3.1 Woody Biomass for Thermal Energy and Electricity Production

Biomass thermal energy can be used for space heat in residences or commercial buildings, for process heat at manufacturing facilities, or for electricity generation, cogeneration, or co-firing at electricity generation facilities. Cogeneration is also referred to as combined heat and power (CHP) and involves generating electricity with steam and utilizing a portion of the steam for process heat (Zerbe 2006). Cofiring is the use of biomass as a supplemental source of energy at plants that are primarily fueled by coal. Cofiring of up to 10-15% biomass can reduce emissions of sulfur dioxide, nitrogen oxides and result in a net reduction of greenhouse gases (FPL 2004).

Biomass power facilities are generally designed for processing and handling multiple fuel sources and are designed for flexibility in feedstock requirements (Bain and Overend 2002). Biomass boilers can typically handle green or high moisture wood with larger pieces and less consistent size as well as material such as bark and leaves which often have higher ash content. These boilers commonly utilize mill residues, urban wood waste, as well as chips or grindings from whole tree harvesting and logging residues (Zerbe 2006).

Woody biomass is an important component of the United States' (US) renewable energy portfolio, serving as feedstock for over 22% of all production in 2011 (US EIA 2012b). Demand for biomass in support of renewable energy production is predicted to increase (US EIA 2012a). As of April, 2013 there were 456 existing or announced wood-to-energy facilities in the US, representing an estimated consumption of 75 million green tons per year by 2023 (Forisk Consulting 2013). Recent announcements for planned biomass power generation in Virginia seem to reflect the EIA projection of increased demand. Recent announcements include a plan by Dominion Virginia Power to convert three coal fired plants to utilize 100% biomass with production rated at 50 MW each (Dominion 2011); and to co-fire a new 585 MW plant with up to 20% biomass (Dominion 2013). Additionally, Northern Virginia Electric Cooperative (NOVEC) is constructing a new 50 MW wood fired power plant in South Boston, VA (NOVEC 2011). Within the forest products industry MWV is adding a new 75 MW biomass boiler to support mill energy needs (MWV 2011). When completed, these new projects will represent over 300 MW of additional electricity production from biomass in Virginia (Figure 1.1).

Utilizing thermal energy from woody biomass for electricity and process heat is a viable operation with proven technology and capable of using almost any form of biomass feedstock. In the near term, biomass utilization for electricity and thermal energy is the most likely large scale consumer of woody biomass from logging residues. In general, this is assumed to be the end use for woody biomass produced from harvesting operations described in this document.

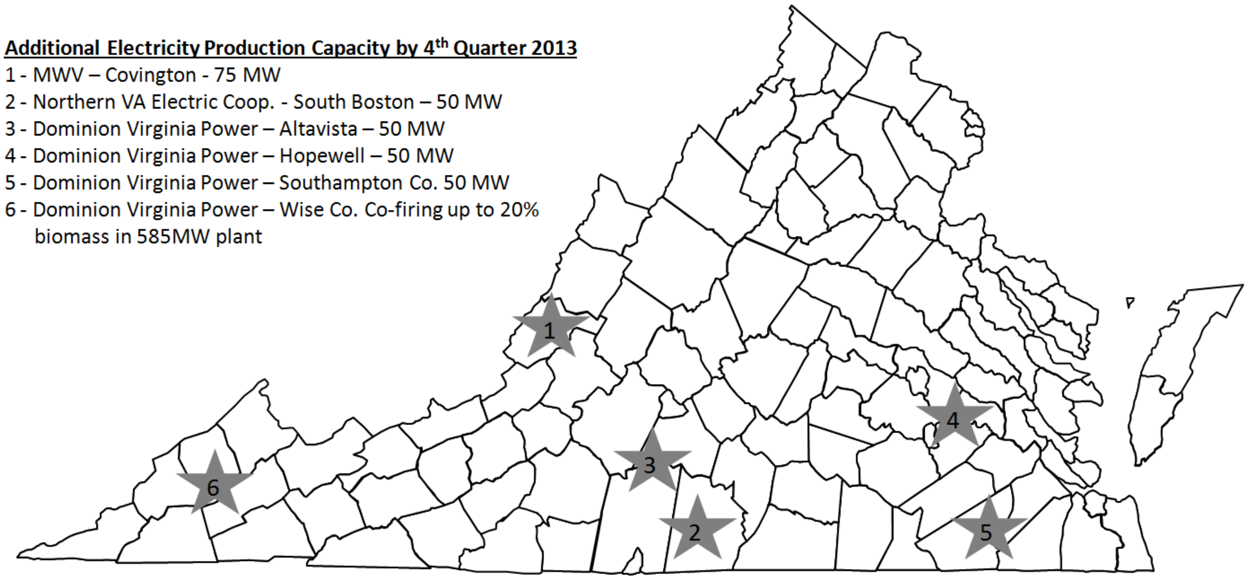

Figure 1.1. Additional wood fired electricity production capacity in Virginia projected to be operational by the end of 2013.

1.1.3.2 Woody Biomass for Pellet Production

The modern era for pellet production began in the 1970s following the energy crisis. Compared to green wood, wood pellets have lower moisture and an energy density that is more comparable to coal (Spelter and Toth 2009). Pellets are also easier to transport and handle through automatic feeding systems (Pellet Fuels Institute 2013). Since 2000, rising fossil fuel prices combined with European Union renewable fuel goals led to rapid growth in the North American pellet industry (Spelter and Toth 2009). Pellets can be produced from a wide range of woody biomass materials including sawdust, planer shavings and logging residues (Lehtikangas 2001) or roundwood (Spelter and Toth 2009). While logging residues or whole tree chips can be utilized for pellet production, the use of material with bark, leaves, and other contamination can cause inconsistent performance and is generally less desirable. With limited quantities of mill residues for pellet production and a rapidly expanding pellet industry, the majority of future feedstock for pellet production will potentially be composed of roundwood (Spelter and Toth 2009).

Most current and proposed large scale pellet production facilities primarily use roundwood as the raw material. While the expanding pellet industry has the potential to increase total wood consumption and affect wood markets (Conrad et al. 2010), harvesting roundwood for pellet production would be similar to conventional forest harvesting operations.

1.1.3.3 Woody Biomass for Liquid Transportation Fuels

Woody biomass can be converted into liquid transportation fuels such as ethanol, methanol, biodiesel, and other liquid motor fuels through processing that enables fermentation of sugars in cellulose or by upgrading and biorefining processes such as the Fischer-Tropsch process (Demirbas 2009). Biorefineries could use logging residues and other non-food cellulosic agricultural wastes and therefore avoid competition with food supplies (Demirbas 2009). However, this technology has been difficult to develop, thus it has not fully developed commercially. Therefore, the U.S. reduced its total renewable fuel production projections because of delays and technological challenges associated with cellulosic ethanol production plants (U.S. EIA 2012a). Research may advance technology so that this industry could consume large quantities of woody biomass including logging residues. However, current consumption of woody biomass by biorefineries is minimal.

1.1.4 Woody Biomass Harvesting

1.1.4.1 Woody Biomass Harvesting Terminology

Different definitions of biomass, especially in relation to public policies or incentive programs can substantially impact industries utilizing woody biomass. Therefore, opinions differ on biomass definitions (Aguilar and Garrett 2009). The U.S. Internal Revenue Service (IRS) defines biomass eligible for electricity production tax credits in an open loop biomass facility based on the following code section:

> *45(c)(3)(A), as amended by section 7(b)(1) of the Tax Technical Correction Act of 2007, defines the term "open-loop biomass" to mean—*
>
> *(a) any agricultural livestock (including bovine, swine, poultry, and sheep) manure and litter, including wood shavings, straw, rice hulls, and other bedding material for the disposition of manure (agricultural livestock waste nutrients); or*
>
> *(b) any solid, nonhazardous, cellulosic waste material or any lignin material which is derived from— (i) any of the following forest-related resources: mill and harvesting residues, precommercial thinnings, slash, and brush; (ii) solid wood waste materials, including waste pallets, crates, dunnage, manufacturing and construction wood wastes, and landscape or right-of-way tree trimmings; or (iii) agricultural sources, including orchard tree crops, vineyards, grain, legumes, sugar, and other crop by-products or residues* (IRS 2008).

A broader definition used by the Southern Forest Research Partnership, Inc. (SFRP) includes the following definitions for biomass, woody biomass, and bioenergy (Hubbard et al. 2007):

> Biomass — organic matter renewable over time (at its simplest form)
>
> Woody Biomass — accumulated mass, above and below ground, of the wood, bark and leaves of living and dead woody shrubs and trees
>
> Bioenergy — Renewable energy produced from organic matter through the conversion of complex carbohydrates. This energy may be used directly as fuel, processed into liquids or gasses, or be a residual of the processing or conversion mechanisms

Using a broad definition, any wood product could be considered woody biomass. However, in common vernacular, the term woody biomass generally refers to the lower value products such as mill residues, logging residues, or non-merchantable trees that are used for energy because they are generally not marketable as higher value products. The distinction between conventional roundwood products and non-merchantable trees and residues may be less clear in market situations where the value of wood fuel increases such that it is more economical to utilize pulpwood sized material as fuel. Also in the case of pellet production using pulpwood, the final product (pellets) is a biomass energy product yet the raw material is typically not referred to as biomass. Benjamin et al. (2010) suggested that the term energywood better represents the end use of the product similarly to the way that pulpwood and sawtimber classifications represent end uses. However, the term biomass harvesting is still typically used to describe harvests of residues for energy. For this manuscript, biomass harvesting can be considered synonymous with energywood harvesting as outlined by Benjamin et al. (2010) and the term biomass harvest will be used to describe harvesting logging residues or whole trees for energy.

1.1.4.2 Biomass Harvesting Methods

In the 1970's many forest products companies began to investigate use of logging residues as a source of fuel for manufacturing facilities. However as oil prices decreased by the late 1980's many firms abandoned biomass harvesting operations (Watson and Stokes 1989). Examples of early strategies involved specially designed prototype machines such as the swathe-felling mobile chipper which could harvest standing cull trees and logging residues (Koch and Savage 1980, Stuart et al. 1981). Watson and Stokes (1989) and Watson et al. (1986) noted that in addition to the specially designed prototype biomass harvesting machines there were three biomass harvesting methods that utilized conventional equipment:

1. A pre-harvest operation before conventional harvesting (two-pass), or
2. An integrated operation which removed roundwood and biomass in one pass, or
3. A post-harvest operation following conventional harvesting (two-pass).

A one-pass integrated system harvesting roundwood and biomass at the same time is often the most cost effective method (Miller et al. 1987, Watson and Stokes 1989, Hudson 1995). An integrated harvesting system enables utilization of roundwood and biomass with a single entry into the stand by a single harvesting crew. Two-pass systems enable operations to be more specialized for either roundwood or biomass. One-pass systems where biomass is harvested during the roundwood harvesting operation tend to be more common, especially in areas with strong markets for pulpwood (Greene et al. 2011).

1.1.4.3 Processing or Comminution of Biomass

Branches and other logging residue used for biomass are difficult to transport by truck and typically must be processed in-woods into a more easily transported form. Methods of processing biomass include chipping, chunking, crushing, baling, and grinding/shredding/hogging. Of these methods, modified conventional harvesting systems that utilize whole-tree chippers located at the landing are typically the lowest cost method of harvesting biomass (Stokes et al. 1989, Stokes 1992, Mitchell and Gallagher 2007, Saunders et al. 2012).

Jackson et al. (2007) reviewed biomass harvesting technology and reported that chippers are currently the most common equipment used for processing biomass. Chippers are most easily integrated into conventional harvesting systems, however grinders are also used on many operations. Grinders are better than chippers for utilizing biomass material contaminated by soil or rocks. When processing biomass with grinders, material is dropped or dumped into trailers instead of being blown into trailers when using chippers. As a result, the loads are often not packed as densely as with a chipper. Greene et al. (2011) noted that use of grinders can sometimes reduce payloads, especially when processing hardwoods. Shredders are more common on land clearing operations where material such as stumps have significant soil and rock contamination, but they are less common on forest harvesting operations. Bundling of residues and forming composite residue logs (CRL) is another method of processing biomass. CRLs can take advantage of transpirational drying and can be transported by conventional log trailers to a central site where a large stationary chipper could more efficiently chip the materials to end-use specifications. The main disadvantage of CRLs is their higher cost of production (Jackson et al. 2007). Slash bundlers are typically mounted on a forwarder so they can move across a harvest site to collect residues and require a forwarder to bring CRLs to the landing. However, residues accumulate at the landing for typical tree length southern logging operations. A study by Meadows et al. (2011) found that costs can be reduced and bundling systems can be adapted to southern logging systems by mounting the bundler on a trailer at the landing.

1.1.4.4 Integrated Harvesting Systems

Several studies of integrated biomass harvesting operations conclude that adding a chipper to southern pine harvesting operations can be feasible (Baker et al. 2010, Westbrook et al. 2007, Mitchell and Gallagher 2007). Integrated biomass harvesting productivity and costs were studied in Missouri hardwood stands by Saunders et al. (2012). Integrated harvesting operation in these stands produced an average of 35.7 tons of roundwood and 15.5 tons of biomass per acre with an average biomass cost $22.80 per ton (Saunders et al. 2012). Conrad et al. (2011) noted that harvesting biomass on conventional operations can potentially increase roundwood harvesting costs when smaller stems are harvested for energy because of decreased productivity for felling and skidding. Decreased productivity caused onboard truck roundwood production costs to rise from $8.48 to $9.96 per green ton. The additional time required to harvest small stems can make biomass harvesting uneconomical especially in high production specialty operations such as those observed by Conrad (2011).

1.1.5 Characteristics of Biomass Harvesting Operations

Previous surveys have characterized logging businesses within states (Bolding et al. 2010, Moldenhauer and Bolding 2009, Baker and Greene 2008, Milauskas and Wang 2006) and regions (Allred 2009, Egan et al. 2007). Although these data may provide percentages of loggers that are harvesting biomass (Bolding et al. 2010), biomass harvesting was not the primary focus of the surveys. Fewer studies have focused specifically on characteristics of biomass harvesting operations on statewide or regional levels. Greene et al. (2011) combined literature information, an online survey and field visits to evaluate regional approaches to biomass harvesting in the U.S. The authors reported that biomass markets were more developed in areas without strong pulpwood markets. They also noted that chippers were the dominant method for processing biomass in most regions and the amount of ash in material produced by grinders was a reason chippers were often preferred.

Spinelli and Hartsough (2001) completed a comprehensive observational survey of more than 100 chipping operations in Italy which showed a diversity of chippers and production levels. A study by Huyler (1989) of 25 logging businesses supplying fuel chips to electrical generation and co-generation facilities in northern New England revealed that most loggers operated an integrated operation harvesting roundwood and biomass. This study also indicated that fuel chips were produced with in-woods chippers and their harvesting operations consisted primarily of mechanized felling with grapple skidders. A study of Minnesota loggers by Dirkswager et al. (2011) utilized a phone survey to characterize operations and attitudes of Minnesota loggers that harvested forest residue. All loggers harvesting biomass used either a chipper or grinder and there was considerable variation in the methods used for biomass harvesting. However, they did not report specific details on equipment type, size, age and basic harvesting strategies for the operations surveyed. They identified logger attitudes regarding major obstacles to utilizing logging residues. Obstacles included inconsistent demand for biomass, high operating and transportation costs, and uncertainty for biomass supply (Dirkswager et al. 2011). Munsell et al. (2011) examined logging businesses operating in a region with biomass markets and noted the business owners' attitude towards biomass harvesting, perspectives regarding job security and satisfaction, and operational characteristics such as mechanization were positively related to their decision to harvest biomass.

1.1.6 Potential Concerns Related to Biomass Harvesting

Although benefits of biomass utilization may include energy security, greenhouse gas reductions, and potential economic advantages of lower fuel cost, there are still concerns related to biomass harvesting. Janowiak and Webster (2010) reviewed literature regarding increased bioenergy utilization and noted concerns related to nutrient and organic matter removal, additional soil compaction, as well as the potential to impact hydrology and water quality (Janowiak and Webster 2010). Hall (2002) also noted potential concerns related to soil and site productivity and noted the importance of protecting soil and water resources during harvesting operations. Water quality issues related to biomass harvesting were reviewed by Shepard (2006) with a focus on the existing system of BMPs. Shepard (2006) noted that if bioenergy systems utilized intensive short rotation crops with increased use of fertilizer then additional BMP consideration may be needed related to fertilizer use. In a review of biomass harvesting guidelines Abbas et al. (2011) also noted that concerns related to biomass harvesting frequently relate to soil productivity, water quality, and wildlife habitat.

1.1.7 BMP Guidelines and Biomass Harvesting

In the U.S., states have adopted forestry Best Management Practice (BMP) guidelines to protect water quality from non-point source (NPS) pollution (NCASI 2009). A literature review by Aust and Blinn (2004) indicated that BMPs are generally effective at protecting water quality. Additionally, they concluded that water quality problems on forest harvesting sites are often caused by improper design, construction, or closure of roads, skid trails, and stream crossings, or from areas with excessive amounts of exposed soil. Previous work by Martin and Hornbeck (1994) comparing undisturbed forested watersheds with intensive whole tree harvesting using BMPs resulted in only minor increases in sediment yield. Sediment yields on whole tree harvested sites decreased to pre-harvest levels within five years (Martin and Hornbeck 1994).

A number of studies have documented effectiveness of using BMPs when compared to harvests without BMPs. A study in the Coastal Plain of Virginia found that BMP implementation reduced sedimentation and nutrient loading (Wynn et al. 2000). Watershed studies of clearcut harvests in Kentucky also showed reductions in sediment and nutrients when BMPs were applied (Arthur et al. 1998). A study of harvests in New York found that appropriately installed BMPs reduced sediment movement (Schuler and Briggs 2000). Shepard (2006) concluded that existing BMPs should apply to bioenergy production from conventional forestry systems because BMPs were designed for conventional forestry. However, the author also noted that intensive production of short rotation woody crops with frequent fertilizations would be a different situation that could warrant additional BMPs related to fertilization.

A number of states (e.g., Maine, Michigan, Minnesota, Missouri, Pennsylvania, Wisconsin, and South Carolina) have adopted biomass harvesting guidelines, some of which focus on retaining downed woody material (DWM) and the impacts of DWM on site productivity and biodiversity (Ice et al. 2010). The Virginia Department of Forestry has not developed specific BMPs for biomass harvesting; however, the current BMP manual (VDOF 2011) does include a 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 (VDOF 2011).

Site productivity concerns related to biomass harvesting are primarily a concern of the forest landowner, but impacts to water quality can have a broader impact through impairment of public waters. Although state biomass harvesting guidelines may focus on slash and DWM retention, these issues are less important to water quality than the amount of disturbed or bare soil (Aust and Blinn 2004), thus implying that more efforts might be needed to minimize these conditions. Ice et al. (2010) suggested that biomass harvesting BMPs that specify a maximum percent of disturbed or bare soil, especially in riparian areas, could be a simpler BMP mechanism to minimize water quality problems.

1.1.8 Conclusions

The contribution of woody biomass to meeting our nation's energy needs could potentially increase. The most viable use of wood for energy is for direct combustion as a source of thermal energy to produce heat and steam for electricity and process heat. Much of the existing biomass energy is produced from mill residues but if consumption increases as anticipated, a larger percentage of the feedstock for additional facilities will likely come from underutilized sources such as logging residues.

Integrated roundwood and biomass harvesting operations using whole tree chippers to process biomass are cost effective and commonly used harvesting methods. Case studies of individual harvests have established productivity and costs for individual pieces of equipment and specific harvest situations. However, little information related to the characteristics of the current logging workforce involved in biomass harvesting operations and business owner's attitudes towards biomass harvesting exists for regional or state levels. Anticipated increases in the number of facilities consuming biomass as a fuel source has caused many loggers to consider the option of integrating biomass harvesting into existing operations. Such operations could benefit from information regarding the lessons learned and status of biomass harvesting to date.

There are many potential benefits to biomass utilization; however there are also concerns. Relatively little research has focused on soil erosion and associated water quality concerns or the adequacy of current BMPs to protect water quality on biomass harvesting operations. Comparative research to evaluate BMP implementation on biomass versus conventional harvesting operations could help clarify adequacy of current BMPs for harvests utilizing biomass. Additionally, research comparisons of post harvest site conditions could differentiate erosion potential between conventional versus biomass harvest sites.

1.2 Research Objectives

The overall objective is to assess potential impacts of integrating biomass harvesting into ongoing forest harvesting operations. Impacts include those to the logging business as well as biomass harvesting sites. This overarching objective was accomplished through research focused on impacts to logging businesses that integrate biomass harvesting into conventional operations, impacts related to erosion and post harvest site conditions, and impacts to BMP implementation on biomass versus conventionally harvested sites.

Studies were conducted in Virginia's Piedmont region. The region has active markets for wood fuel and conventional roundwood products and research focused on biomass harvesting operations could enhance understanding of possible impacts if biomass markets were to expand in other regions. Analyses could benefit logging businesses deciding whether or not to harvest biomass, decision makers involved in developing biomass harvesting guidelines, and help focus future research related to integrated biomass harvesting operations.

Specific objectives were to:

(1) Evaluate characteristics and operating strategies of logging businesses currently harvesting biomass in the Virginia Piedmont,

(2) Compare post-harvest erosion potential of conventional versus biomass harvest sites, and

(3) Evaluate Best Management Practices (BMP) implementation for biomass versus conventional harvest sites.

1.3 Methods

Study I: Characteristics of logging businesses that harvest biomass for energy production

The objectives of this study were to determine characteristics and operating strategies of logging businesses currently harvesting biomass and evaluate impacts on their operations. The study utilized a mail survey of logging business owners who are currently harvesting biomass. The survey was designed based on the Dillman (2000) method. The study population consisted of all suppliers of in-woods produced biomass (wood fuel) delivering to one or more of the three primary wood fuel consuming facilities in the Piedmont region.

Study II: Potential erosion, ground cover, and BMP audit details for post-harvest evaluations of biomass and conventional clearcut harvests

The objectives of this study were to evaluate post harvest site conditions and compare potential erosion rates for conventional versus biomass harvest sites in the Piedmont region. Potential erosion rates were estimated using the Universal Soil Loss Equation (USLE) as modified for forest land (USLE-Forest version) by Dissmeyer and Foster (1984). This methodology was recommended by Christopher and Visser (2007) for estimating soil erosion on forest land and has been used in similar studies estimating soil erosion in Virginia (e.g. Hood et al. 2002, Lakel et al. 2010, Aust et al. 2011, Worrell et al. 2011, Sawyers et al. 2012, Wear et al. 2013). This project evaluated erosion potential on 20 Piedmont clearcut harvest sites. This included ten conventionally harvested sites and ten integrated roundwood and biomass harvesting operations. Erosion estimates were obtained for each of the operational areas (roads, decks, skid trails, stream crossings, harvest area, SMZs, and fire lines) and were used to calculate an overall weighted erosion estimate for each tract.

Study III: Implementation of Forestry Best Management Practices (BMPs) on biomass and conventional harvesting operations

The objective of study III was to compare implementation of BMPs for water quality on biomass and conventionally harvested sites. On biomass harvesting sites, in addition to conventional roundwood products, logging residues such as limbs, tops, and non-merchantable trees and portions of trees are utilized for energy. The Virginia Department of Forestry (VDOF) has active water quality monitoring and enforcement programs (VDOF 2011). As part of its statewide BMP implementation monitoring, the VDOF randomly selects 60 recently harvested tracts per quarter for intensive BMP evaluation (Lakel and Poirot 2013). The selected tracts are evaluated based on BMP implementation in ten categories with a total of 117 questions related to specific BMPs from the VDOF BMP Technical Manual (VDOF 2011). In addition to BMP implementation, data collected by the VDOF includes information on whether or not biomass was harvested at the site. Overall BMP compliance and audit results were reported by Lakel and Poirot (2013). This project used this extensive dataset to compare BMP implementation on conventional harvest sites versus sites where biomass was also harvested.

1.4 References

Abbas, D., D. Current, M. Phillips, R. Rossman, H. Hoganson, and K.N. Brooks. 2011. Guidelines for harvesting forest biomass for energy: a synthesis of environmental considerations. Biomass and Bioenergy 35(11):4538-4546.

Abt, R.C., K.L. Abt, F.W. Cubbage, and J.D. Henderson. 2010. Effect of policy-based bioenergy demand on southern timber markets: a case study of North Carolina. Biomass and Bioenergy 34(12):1679-1686.

Aguilar, F.X., N. Song, and S. Shifley. 2011. Review of consumption trends and public policies promoting woody biomass as an energy feedstock in the U.S. Biomass and Bioenergy 35(8):3708-3718.

Aguilar, F.X., and H.E. Garrett. 2009. Perspectives of woody biomass for energy: survey of state foresters, state energy biomass contacts, and National Council of Forestry Association Executives. Journal of Forestry 107(6):297-306.

Allred, S.B. 2009. Logging firm succession and retention. Forest Products Journal 59(6):31-36.

Arthur, M.A, G.B. Coltharp, and D.L. Brown. 1998. Effects of best management practices on forest stream water quality in eastern Kentucky. Journal of American Water Resources Association 34(3):481–495.

Aust, W.M. and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, & Soil Pollution: Focus 4(1):5-36.

Aust, W. M., M.B. Carroll, M.C. Bolding, and C.A. Dolloff. 2011. Operational forest stream crossings effects on water quality in the Virginia Piedmont. Southern Journal of Applied Forestry 35(3):123-130.

Baker, S.A., and W. D. Greene. 2008. Changes in Georgia's Logging Workforce, 1987-2007. Southern Journal of Applied Forestry 32(2):60-68.

Baker, S.A., M.D. Westbrook Jr., and W.D. Greene. 2010. Evaluation of integrated harvesting systems in pine stands in the southern U.S. Biomass and Bioenergy 34(5):720-727.

Bain, R.L., and R.P. Overend. 2002. Biomass for heat and power. Forest Products Journal 52(2):12-19.

Benjamin, J.G., R.J. Lilieholm, and C.E. Coup. 2010. Forest biomass harvesting in the northeast: A special-needs operation? Northern Journal of Applied Forestry 27(2):45-49.

Bergman R., and J. Zerbe. 2004. Primer on wood biomass for energy. USDA Forest Service, State and Private Forestry Technology Marketing Unit, Forest Products Laboratory, Madison, WI. 10 p.

Bolding, M.C., S.M. Barrett, J.F. Munsell, and M.C. Groover. 2010. Characteristics of Virginia's logging businesses in a changing timber market. Forest Products Journal 60(1):86-93.

Christopher, E.A. and R. Visser. 2007. Methodology for evaluating post harvest erosion risk for the protection of water quality. New Zealand Journal of Forestry 52(2):20-25.

Conrad, J. L. IV, M.C. Bolding, W.M. Aust, and R.L. Smith. 2010. Wood-to-energy expansion, forest ownership changes, and mill closure: consequences for U.S. South's wood supply chain. Forest Policy and Economics 12(6):399-406.

Conrad, J.L. IV. 2011. Anticipated impact of a vibrant wood-to-energy market on the U.S. South's wood supply chain. Ph.D. Dissertation. Virginia Tech, Blacksburg, VA. 149 p.

Demirbas, M. Fatih. 2009. Biorefineries for biofuel upgrading: A critical review. Applied Energy 86(1):151-161.

Dillman, D.A. 2000. Mail and Internet Surveys: The Tailored Design Method. John Wiley and Sons, New York. 480 pp.

Dirkswager, A.L., M.A. Kilgore, D.R. Becker, C. Blinn, and A. Ek. 2011. Logging business practices and perspectives on harvesting forest residues for energy: a Minnesota case study. Northern Journal of Applied Forestry 28(1):41-46.

Dissmeyer, G.E. and G.R. Foster. 1984. A guide for predicting sheet and rill erosion on forestland. USDA For. Ser. Gen. Tech. Publ. R8-TP 6. 40 p.

Dominion Virginia Power. 2011. Dominion Virginia Power plans to convert three coal-fired stations to renewable biomass. Dominion press release. April 1, 2011. Available online at http://dom.mediaroom.com/index.php?s=43&item=976 ; last accessed on June 8, 2013.

Dominion Virginia Power. 2013. Virginia City Hybrid Energy Center. Available online at http://www.dom.com/about/stations/fossil/virginia-city-hybrid-energy-center.jsp; last accessed June 8, 2013.

Egan, A., D. Taggert, and I. Annis. 2007. Effect of population pressures on wood and procurement and logging opportunities in northern New England. Northern Journal of Applied Forestry 24(2):85-90.

Forest Products Laboratory (FPL) 2004. Wood biomass for energy. USDA Forest Service, Forest Products Laboratory, State and Private Forestry Technology Marketing Unit, Madison WI. 3 p.

Forisk Consulting. 2013. Forisk Bioenergy Research - Estimated wood use by announced facilities in the U.S. Available online at http://forisk.com/Forisk-Bioenergy-Research-v-42.html Last accessed April 19, 2013.

Fox, T. R. 2000. Sustained productivity in intensively managed forest plantations. Forest Ecology and Management 138(1):187-202.

Galik, Christopher S., R. Abt, and Y. Wu. 2009. Forest biomass supply in the southeastern United States – implications for industrial roundwood and bioenergy production. Journal of Forestry 107(2):69-77.

Gan, J., and C.T. Smith. 2006. Availability of logging residues and potential for electricity production and carbon displacement in the USA. Biomass and Bioenergy 30(12):1011-1020.

Gan, J., and C.T. Smith. 2007. Co-benefits of utilizing logging residues for bioenergy production: The case for east Texas, USA. Biomass and Bioenergy 31(9):623-630.

Greene, D., S. Baker, J. Cutshall, and A. Enrich. 2011. Regional approaches for harvesting forest biomass: a report on field studies to the Wood Supply Research Institute. Forest Operations Review. Forest Resources Association. Rockville, MD. 13(1):14-25.

Hall, J.P. 2002. Sustainable production of forest biomass for energy. The Forestry Chronicle 78(3):391-396.

Hood, S. M., S.M. Zedaker, W.M. Aust, and D.W. Smith. 2002. Universal Soil Loss Equation (USLE)-Predicted soil loss for harvesting regimes in Appalachian hardwoods. Northern Journal of Applied Forestry 19(2):53–58.

Hubbard, W.; L. Biles; C. Mayfield; S. Ashton (Eds.). 2007. Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook. Athens, GA: Southern Forest Research Partnership, Inc. 316 p.

Hudson, J.B. 1995. Integrated harvesting systems. Biomass and Bioenergy 9(1):141-151.

Huyler, N.K. 1989. Fuel supply structure of wood-fired power plants in the northeast: logger's perspective. USDA Forest Service. Research paper NE-624. Northeastern Forest Experiment Station. Broomall, PA. 19 p.

Ice, G., M. McBroom, and P. Schweitzer. 2010. A review of best management practices for forest watershed biomass harvests with an emphasis on recommendations for leaving residual wood onsite. Center for Bioenergy Sustainability, Oak Ridge National Laboratory, Oak Ridge TN. 5 p.

Internal Revenue Service. 2008. Internal Revenue Bulletin 2008-30. July 28, 2008. 96 p. Available online at http://www.irs.gov/pub/irs-irbs/irb08-30.pdf; last accessed June 8, 2013.

Jackson, B., R. Schroeder, and S. Ashton. 2007. Pre-processing and Drying Woody Biomass. In: Hubbard, W.; L. Biles; C. Mayfield; S. Ashton (Eds.). 2007. Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook. Athens, GA: Southern Forest Research Partnership, Inc. 316 p.

Janowiak, M.K. and C.R. Webster. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry 108(1):16-23.

Johnson, D.W. and D.E Todd Jr. 1998. Harvesting effects on long-term changes in nutrient pools of mixed oak forest. Soil Science Society of America Journal 62(6):1725-1735.

Koch, P., and T.E. Savage. 1980. Development of the swathe-felling mobile chipper. Journal of Forestry 78(1):17-21.

Lakel, W. A., W.M. Aust, M.C. Bolding, C.A. Dolloff, P. Keyser and R. Feldt. 2010. Sediment trapping by streamside management zones of various widths after forest harvest and site preparation. Forest Science 56(6):541-551.

Lakel, W. and M. Poirot. 2013. Silvicultural best management practices implementation monitoring for Virginia - 2012. Virginia Department of Forestry. Charlottesville, VA. 10 p.

Lehtikangas, P. 2001. Quality properties of pelletised sawdust, logging residues, and bark. Biomass and Bioenergy 20(5):351-360.

MacCarty, N., D. Ogle, D. Still, T. Bond, and C. Roden. 2008. A laboratory comparison of the global warming impact of five major types of biomass cooking stoves. Energy for Sustainable Development 12(2):56-65.

Manley, A. and J. Richardson. 1995. Silviculture and economic benefits of producing wood energy from conventional forestry systems and measures to mitigate negative impacts. Biomass and Bioenergy 9(1):89-105.

Mann, L.K., D.W. Johnson, D.C. West, D.W. Cole, J.W. Hornbeck, C.W. Martin, H. Riekerk, C.T. Smith, W.T. Swank, L.M. Tritton, and D.H. Van Lear. 1988. Effects of whole-tree and stem-only clearcutting on postharvest hydrologic losses, nutrient capital, and regrowth. Forest Science 34(2):412-428.

Martin, C.W. and J.W. Hornbeck. 1994. Logging in New England need not cause sedimentation of streams. Northern Journal of Applied Forestry 11(1):17-23.

Meadows, S., T. Gallagher, and D. Mitchell. 2011. A new slash bundling concept for use in a southern US logging system. Forest Products Journal 61(3):210-215.

MeadWestvaco, 2011. MWV to improve power infrastructure at Covington, VA mill. Press release from MeadWestvaco Corporation. June 27, 2011. Richmond Virginia. Available online at http://www.meadwestvaco.com/mwv/groups/content/@corp/@newsevts/documents/document/mwv031745.pdf ; last accessed June 8, 2013.

Milauskus, S., and J. Wang, 2006. West Virginia logger characteristics. Forest Products Journal 56(2):19-24.

Miller, D.E., T.J. Straka, B.J. Stokes, and W.F. Watson. 1987. Productivity and cost of conventional understory biomass harvesting. Forest Products Journal 37(5):39-43.

Mitchell, D., and T. Gallagher. 2007. Chipping whole trees for fuel chips: A production study. Southern Journal of Applied Forestry 31(4):176-180.

Moldenhauer, M.C. and M.C. Bolding. 2009. Parcelization of South Carolina's private forestland: Loggers' reactions to a growing threat. Forest Products Journal 59(6):37-43.

Munsell, J. F. and R.H. Germain. 2007. Woody biomass energy: an opportunity for silviculture on nonindustrial private forestlands in New York. Journal of Forestry 105(8):398-402.

Munsell, J.F., S.M. Barrett, and M.C. Bolding. 2011. An exploratory study of biomass harvesting among logging firms in Virginia and North Carolina. Forest Science 57(5):427-434.

National Council for Air and Stream Improvement, Inc. (NCASI). 2009. Compendium of Forestry Best Management Practices for Controlling Nonpoint Source Pollution in North America. Technical Bulletin No. 0966. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc. 208 p.

Northern Virginia Electric Cooperative. 2011. Biomass generation plant approved. NOVEC What's Current. September 2011. Available online at http://www.novec.com/books/WC9-11/WC9-11.pdf ; last accessed June 8, 2013.

Pellet Fuels Institute. 2013. What are Pellets? Available online at http://pelletheat.org/pellets/what-are-pellets/ ; Last accessed June 8, 2013.

Perlack, R.D., L.T. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. Oak Ridge National Lab., Oak Ridge, TN. 59 p.

Perlack, R. D. and B.J. Stokes. 2011. US billion-ton update: biomass supply for a bioenergy and bioproducts industry. Oak Ridge National Laboratory. Oak Ridge, TN. 227 p.

Riffell, S., J. P. Verschuyl, D. Miller, and T. B. Wigley. 2011. Biofuel harvests, coarse woody debris, and biodiversity – a meta-analysis. Forest Ecology and Management 261(4):878-887.

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. Journal of Soil and Water Conservation 67(4):300-310.

Saunders, A.M., F.X. Aguilar, J.P. Dwyer, and H.E. Stelzer. 2012. Cost structure of integrated harvesting for woody biomass and solid hardwood products in southeastern Missouri. Journal of Forestry 110(1):7-15.

Schuler, J. L., and R.D. Briggs. 2000. Assessing application and effectiveness of forestry best management practices in New York. Northern Journal of Applied Forestry 17(4):125-134.

Shepard, J.P. 2006. Water quality protection in bioenergy production: the US system of forestry best management practices. Biomass and Bioenergy 30(4):378-384.

Spelter, H., and D. Toth. 2009. North America's wood pellet sector. Research Paper FPL-RP-656. Madison WI: USDA Forest Service, Forest Products Laboratory. 21 p.

Spinelli, R. and B. Hartsough. 2001. A survey of Italian chipping operations. Biomass and Bioenergy 21(6):433-444.

Stokes, B.J. 1992. Harvesting small trees and forest residues. Biomass and Bioenergy 2(1):131-147.

Stokes, B.J., D.L. Sirois, and W.F. Watson. 1989. Recovery of forest residues in the southern United States. In: Stokes, B.J., ed. Proceedings of the International Energy Agency, Task VI, Activity 3 Symposium "Harvesting Small Trees and Forest Residues"; 1989 June 5-7; Auburn, AL: Auburn AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1989:32-43.

Stuart, W., C. Porter, T. Walbridge, and R. Oderwald. 1981. Economics of modifying harvesting systems to recover energy wood. Forest Products Journal 31(8):37-42.

U.S. Energy Information Administration (EIA). 2012a. Annual energy outlook 2012. DOE/EIA-0383(2012) June 2012. Available online at http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf Last accessed on 11/30/12.

U.S. Energy Information Administration (EIA). 2012b. November 2012 Monthly Energy Review. DOE/EIA-0035(2012/11). Available online at http://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf . Last accessed on 11/30/12.

Virginia Department of Forestry. 2011. Virginia's Forestry Best Management Practices for Water Quality Technical Manual. 5th Edition. Virginia Department of Forestry. Charlottesville, VA. 165 p.

Watson, W.F., and B.J. Stokes. 1989. Harvesting small stems—A southern USA perspective. In: Stokes, B.J., ed. Proceedings of the International Energy Agency, Task VI, Activity 3 Symposium "Harvesting Small Trees and Forest Residues"; 1989 June 5-7; Auburn, AL: Auburn AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1989:131-139.

Watson, W.F., B.J. Stokes, and I.W. Savelle. 1986. Comparison of two methods of harvesting biomass for energy. Forest Products Journal 36(4):63-68.

Wear, L.R., W.M. Aust, M.C. Bolding, B.D. Strahm, and C. A. Dolloff. 2013. Effectiveness of best management practices for sediment reduction at operational forest stream crossings. Forest Ecology and Management 289:551-561.

Westbrook, M.D. Jr., W.D. Greene, and R.L. Izlar. 2007. Utilizing forest biomass by adding a small chipper to a tree-length southern pine harvesting operation. Southern Journal of Applied Forestry 31(4):165-169.

Wynn, T. M., S. Mostaghimi, J. W. Frazee, P.W. McClellan, R. W. Shaffer, and W. M. Aust. 2000. Effects of forest harvesting best management practices on surface water quality in the Virginia coastal plain. Transactions ASAE 43(4):927-936.

Worrell, W.C., M.C. Bolding, and W.M. Aust. 2011. Potential soil erosion following skyline yarding versus tracked skidding on bladed trails in the Appalachian region of Virginia. Southern Journal of Applied Forestry 35(3):131-135.

Zerbe, John I. 2006. Thermal energy, electricity, and transportation fuels from wood. Forest Products Journal 56(1):6-14.

Zerbe J., and K. Skog, 2007. Sources and uses of wood for energy. USDA Forest Products Laboratory, Madison WI. 10p .

2.0 CHARACTERISTICS OF LOGGING BUSINESSES THAT HARVEST BIOMASS FOR ENERGY PRODUCTION

2.1 Abstract

Forest management that supports wood-based renewable energy production depends on the harvest and delivery of biomass by logging businesses. As biomass markets emerge, businesses will need to adapt to meet operational requirements. Owners of logging businesses that delivered biomass for energy production in Virginia were surveyed regarding operations and attitudes. Results show that businesses across a broad range of total production levels (6 to 250 loads/week) harvested biomass and roundwood using integrated harvesting operations with whole tree chippers. Firms had produced wood fuel an average of 6.8 years. Sixty-one percent of operations utilized a single loader at the landing for processing roundwood and biomass. Biomass accounted for an average of 28% of the firms' total production and was often produced with relatively large (median = 600 horsepower), older chippers (12.5 years). Findings also suggest that firms were more likely to begin harvesting biomass to satisfy landowners and diversify operations rather than in response to encouragement from consuming facilities. Most owners viewed biomass harvesting positively and plan to continue production in the future.

2.2 Introduction

Woody biomass is an important component of the United States' (US) renewable energy portfolio, serving as feedstock for production of over 22% of all renewable energy in 2011 and demand for biomass in support of renewable energy production is predicted to increase (US EIA 2012a, US EIA 2012b). As of September 2012, there were 452 existing or announced wood-to-energy facilities in the US, representing an estimated consumption of 75 million green tons per year by 2023 (Forisk Consulting 2013). Woody biomass from logging residues is viewed as a viable feedstock for meeting increased demand (Perlack and Stokes 2011). However, Galik et al. (2009) noted that if the quantity of biomass consumed for energy exceeds available residue supplies, pulpwood will likely be substituted for residues and the price for both products will increase.

Increased utilization of logging residues could be an important step toward supplying woody biomass for energy markets and minimizing use of roundwood for energy (Galik et al. 2009, Conrad et al. 2011). Operational studies have demonstrated that biomass production from logging residues is feasible on integrated harvesting systems in pine and hardwood forests (Westbrook et al. 2007, Baker et al. 2010, Saunders et al. 2012). However logging residues converted to "fuel chips" are typically the lowest value product derived from logging operations (Timber Mart South 2012).

Previous research indicates that biomass or fuel chip harvesting is feasible within existing markets (Conrad et al. 2010). Studies have documented productivity and analyzed delays on chipping operations (Spinelli and Hartsough 2001, Spinelli and Visser 2009). A recent case study of Minnesota biomass harvesting operations found considerable operational variability (Dirkswager et al. 2011). Yet there is little contemporary research empirically addressing the nature and characteristics of logging businesses that harvest biomass for renewable energy production.

Because transportation costs are high, biomass harvesting in close proximity to renewable energy production facilities is generally most feasible (Becker et al. 2009, Munsell and Fox 2010). Yet not all logging businesses in close proximity to wood-based renewable energy markets have made adaptations necessary to harvest biomass (Munsell et al. 2011). Landowner management preferences may also influence logging business decisions related to biomass harvesting (Becker et al. 2010, Brinckman and Munsell 2012, Markowski-Lindsay et al. 2012).

Our objective was to study the characteristics and operating strategies of logging businesses harvesting biomass in a region where multiple wood-based renewable energy markets exist. We measured the attitudes of logging business owners about harvesting biomass. The study also evaluated perceived impacts of biomass harvesting on operations. Reasons for operational adaptation among logging firms that harvest biomass has important implications for forest management where bioenergy markets are emerging. These insights could provide useful information for decision makers involved with establishing biomass supply in new markets. Landowners, loggers, and forestry professionals involved in forest management could benefit from a better understanding of biomass harvesting strategies and how they may develop over time when markets are established.

2.3 Methods

2.3.1 Study Area

There are multiple woody biomass markets in the Piedmont region of central and southern Virginia (Figure 1). Regional wood energy facilities consume biomass for purposes of direct combustion to generate electricity and process heat. The largest biomass consumer is a 79.5 Megawatt (MW) wood-fired power plant that began operation in 1994. At the time of construction, this facility was the world's largest stand-alone wood fired power plant, however it was originally operated primarily during peak demand periods and initially operated at less than 20% capacity (Wiltsee 2000). In 2004, the plant was sold and biomass consumption increased under new ownership. In addition to the power plant, two paper mills purchase biomass to generate process heat for manufacturing. Together these facilities have capacity to consume over one million green tons per year of woody biomass, with much of it originating from in-woods harvesting operations. In addition to biomass consumers, the region also has markets for conventional roundwood products for paper mills, oriented strand board (OSB) mills, as well as pine and hardwood sawmills.

This region offers unique opportunities to empirically study biomass harvesting operations because it has a relatively long history (15+ years) of biomass utilization. Therefore, this region has logging operations that have adapted over time due to demands for biomass. This region also has relatively widespread adoption of biomass harvesting among logging operations. A 2009 survey of Virginia logging businesses (Bolding et al. 2010) indicated nearly 20% of all existing logging operations in the Piedmont of Virginia produced wood fuel, compared to only 1% of logging businesses in the Mountains and approximately 10% in the Coastal Plain.

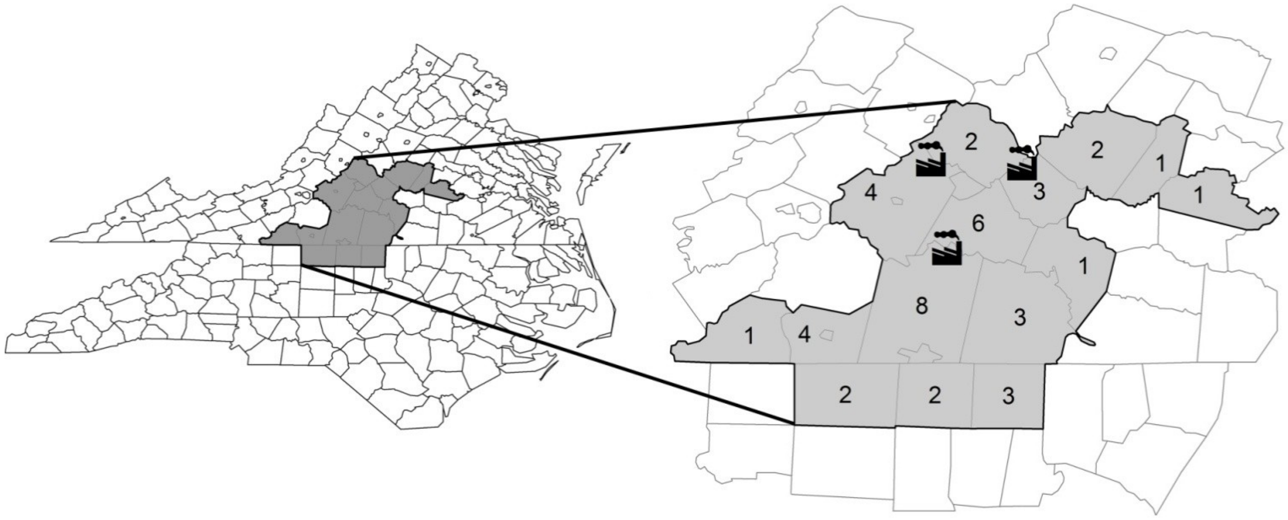

Figure 2.1. Biomass harvesting study area in Virginia and North Carolina, including biomass consuming mills, and number of survey responders reporting a particular county as the center of their harvesting operations.

2.3.2 Survey Methods

We surveyed logging businesses that harvested and delivered woody biomass to renewable energy facilities in the study area (Figure 1). This approach excluded suppliers of mill residues and urban wood waste, thereby focusing on businesses that produce wood for energy from harvesting operations. Mailing lists for biomass suppliers (94 businesses) were provided by the wood-fired power plant and one of two paper mill consumers.

A questionnaire was developed and administered based on the Dillman (2000) method. The survey included 45 questions designed to collect data on operational characteristics, business owner demographics, owner attitudes and reasons for deciding to harvest biomass, and the impact biomass harvesting has had on operations. Categorical and continuous measures were used to measure demographics and operational characteristics and 5-point Likert-type items were used to quantify owner attitudes. Three open ended questions were also included. A draft questionnaire was reviewed by multiple industry experts and subsequently revised. The term *wood fuel* was identified as most common among businesses in the region and used to describe any combination of chips, grindings, and other woody biomass utilized as a fuel source. The questionnaire included definitions for the terms *wood fuel*, *logging residues*, and *roundwood* to ensure clarity for survey participants. *Wood fuel* was defined as chipped or ground woody material intended for burning as a fuel source. *Logging residues* were defined as logging slash such as limbs, tops, and trees that are generally not merchantable as pulpwood or logs. *Roundwood* was defined as pulpwood, logs, or other products sold without being processed by chipping or grinding.

Ninety-four logging businesses were contacted during November and December 2010 first using a pre-notice letter followed by a separate mailing that included the questionnaire. A third mailing thanked those that responded and reminded others to complete and return the questionnaire. The final mailing consisted of a second questionnaire mailed to those that had yet to respond.

Survey data were analyzed using JMP statistical software (JMP 2010). Statistical analyses were performed at the $\alpha \leq 0.05$ level. Non-response bias was assessed by comparing early responders to late responders. Groves et al. (2002) report that late responders are more like non-responders. Wilcoxon signed-rank tests (Ott and Longnecker 2010) were used to analyze the ordinal 5 point Likert-type scale data and test the null hypothesis that the mean responses were neutral (i.e., equal to 3). Pairwise comparisons of Likert-type scale data were performed using the Wilcoxon method, a nonparametric method comparable to a t-test (Ott and Longnecker 2010). Continuous variable responses for *length of time producing wood fuel* and *wood fuel production level* were used to divide businesses into two groups which were evaluated using t-tests to compare average chipper ages of the two groups. Respondents who indicated wood fuel production was profitable were grouped together and compared to respondents who were neutral or in disagreement with profitability. Selected operational variables of the two groups were compared using t-tests. Responses to open ended questions were classified and grouped so that general response themes could be reported. Results from open ended questions are reported as the percent of all questionnaires that included at least one comment categorized into the response theme. Respondents could provide multiple responses to a single open ended question, and some did not respond. Therefore percent of responses reported do not total 100%.

2.4 Results and Discussion

2.4.1 Survey Response and Owner Demographics

Fifty of the 94 questionnaires mailed were returned. Forty-four of the fifty respondents indicated they were conventional logging operations that produced wood fuel. Six respondents did not complete the questionnaire or were not conventional logging businesses (e.g., land clearing operations, wood dealer, or sawmill), resulting in an adjusted response rate of 47%. The 44 responses used in this study were received from logging businesses with operations centered in 12 Virginia and 3 North Carolina counties (Figure 1).

The average age of respondents was 49.6 years with a median of 48 years. Twenty five percent indicated they had not completed high school, 14% had attended some college, 11% were college graduates and 50% indicated high school graduate as their level of formal education. Owners had operated their business an average of 23.1 years and produced wood fuel an average of 6.8 years with a median of 5.5 years. A non-response bias check indicated there were no significant demographic or operational differences between early and late respondents.

Respondents' age and education levels were similar to a larger statewide study of logging businesses (Bolding et al. 2010) and were distributed throughout the procurement regions for all three of the biomass consuming facilities.

2.4.2 Biomass Harvesting Strategies

Biomass harvesting can be directly integrated into roundwood harvesting operations or can occur separately from the roundwood operation. In a study of regional approaches to biomass harvesting across the US, Greene et al. (2011) found that integrated biomass harvesting operations tend to be more common where pulpwood markets are stronger and harvests result in less volume per acre of residue remaining after completion. They found chipping operations were more common with integrated systems where residues were chipped green and grinding operations often had higher ash contents that were not acceptable for some markets. For our study area, logging businesses typically integrate wood fuel production directly into conventional operations. Forty-three of 44 respondents indicated they normally produced wood fuel during a roundwood harvesting operation, with roundwood and wood fuel produced at the same time (Table 2.1). The single respondent indicating wood fuel production did not occur during roundwood harvesting operations produced both roundwood and wood fuel, but apparently these operations occurred separately. Results from all 44 operations are included in the analysis. Respondents indicated wood fuel production occurred almost entirely with whole tree chippers and only one respondent reported using a grinder. The majority (61%) utilize a single loader to handle roundwood and wood fuel on the landing, while 39% utilize multiple loaders with one dedicated to wood fuel.

Table 2.1. Operational and owner characteristics of respondents delivering biomass to facilities in the southern Piedmont of Virginia.

Operational and owner characteristics	Respondent average (n=44)
Wood fuel production was directly integrated into roundwood operation with roundwood and wood fuel produced at the same time	98%
Single loader was utilized for roundwood and wood fuel	61%
Owner's average age	49.6 years
Length of time operating a conventional logging operation	23.1 years
Length of time producing wood fuel	6.8 years

Owners were asked to report the sources of woody biomass material used within the previous year to produce wood fuel. Responses indicate that on average, 82% of the material used to produce wood fuel came from logging residues derived from their own roundwood operations. None of the respondents indicated that they chipped residues from other loggers' harvesting operations. An average of 1% of wood fuel came from land clearing activity. Over 16% was produced from standing timber bought primarily for chipping/grinding, which indicates firms considered biomass markets during timber procurement and tract acquisition. Most loggers (81%) were able to diversify their marketing to access multiple wood energy markets and reported selling wood fuel to more than one facility. These firms indicated they supplied wood fuel to two (46%), three (33%) or four (2%) facilities.

2.4.3 Harvesting Operation Characteristics

Respondents reported an average of 1.5 logging crews per business with a range between 1 and 5 crews. The average number of workers per crew was 3.5 and ranged from 1 to 6.

Businesses reported an average weekly production of 34 truck loads (1 truck load, or “load”= approximately 25 tons of wood or chips) of roundwood and 9.6 loads of wood fuel (Table 2.2). When asked to categorize average tract size harvested in the past year, the most commonly reported range was between 41 and 80 acres (48% of responses). Nine percent reported an average tract size between 10 and 20 acres, 32% between 21 and 40 acres and 11% over 80 acres. No respondent reported an average tract size less than 10 acres. Forty-seven percent of harvests were hardwood clearcuts, 28% were pine clearcuts, 11% were pine thinnings, 9% were hardwood select or partial cuts, and 5% other harvests types. Fuel chip harvesting was integrated into a wide variety of operations, ranging from small single crew operations to high-production multi-crew operations. The variety of stand types and harvest levels from hardwood clearcuts to pine thinning, indicate that biomass harvesting could be a viable operation in a variety of stands and silvicultural systems for other regions when biomass markets develop.

Table 2.2. Average weekly production of roundwood, wood fuel, and clean (pulp quality) chips for respondents delivering wood fuel to facilities in the Piedmont region of Virginia.

Loads/week (1 load = approx. 25 tons)	n[a]	Mean	Median	Minimum	Maximum	SD
Roundwood	43	34.4	20	4	220	40.5
Wood Fuel	43	9.6	9	1	32	6.2
Clean / Pulp Chips	6	14.7	15.5	8	20	4.8
Total Production[b]	43	43.7	30	6	250	43.3
Wood fuel calculated as a percentage of each respondent’s total production	43	28.0%	27.3%	3.9%	60%	-

[a] A total of 44 responses were received. One respondent did not report roundwood production and another respondent did not report wood fuel production level. Only 6 respondents indicated production of clean / pulp chips.

[b] Total production calculated based on each respondent’s reported production level of roundwood + wood fuel + clean chips.

2.4.4 Wood Fuel Production Characteristics

Average wood fuel production was 9.6 loads per week, representing an average of 28% of the firm’s total production (Table 2.2) and a roundwood to fuel chip ratio of approximately 2.5:1. Wood fuel production levels ranged from 4% to 60% of total production. Baker et al. (2010) reported similar fuel chip production ranges between 5% and 47% of total production in southern pine harvests. Saunders et al. (2012) found an average fuel chip production level of 30% of total production in Missouri hardwood harvests.

Seventy-seven percent of operations reported they accumulate wood fuel material and periodically start the chipper to process the material. The remainder (23%) chipped material as it was skidded to the landing. Most logging businesses (77%) consist of a single crew. Of businesses with multiple crews, 50% (5 businesses) indicated they rotated a chipper between crews. Logging businesses most commonly reported using three chip vans (32%) for transporting wood fuel. Only 2% reported using a single chip van, 14% utilized two, 23% utilized four, and 29% reported utilizing 5 or more. The most frequently reported (68%) ranges of haul distances for wood fuel were between 41 and 60 miles. Eleven percent of businesses reported an average haul distance between 20 and 40 miles, 18% reported an average distance between 61 and 80 miles, and 2% reported an average distance of over 80 miles. None of the businesses indicated an average haul distance of less than twenty miles. In other regions with emerging biomass markets, specific local market conditions will dictate feasible haul distances for wood fuel. However these results, which were collected across broad operational and market conditions within the region, indicate 40-60 miles was generally the upper limit for acceptable haul distances for transportation of wood fuel. Only 20% of operations reported average haul distances greater than 60 miles.

2.4.5 Chipper Characteristics and Investment in Wood Fuel Production

Average chipper age was 12.5 years and ranged from 1 to 40 years (Figure 2.2). Chipper horsepower ranged from 250 to 950. Mean and median horsepower were 581 and 600 respectively. The median investment in wood fuel production equipment including chippers, chip vans, extra loaders, or other necessary equipment was $200,000. One-third of all operations had less than $100,000 invested and only 5% invested over $500,000 (Figure 2.3). Investments ranged between $40,000 and $1.2 million. Most operations utilized a single loader for wood fuel and roundwood (61%), so additional investments in wood fuel production were often limited to the chipper and chip vans.

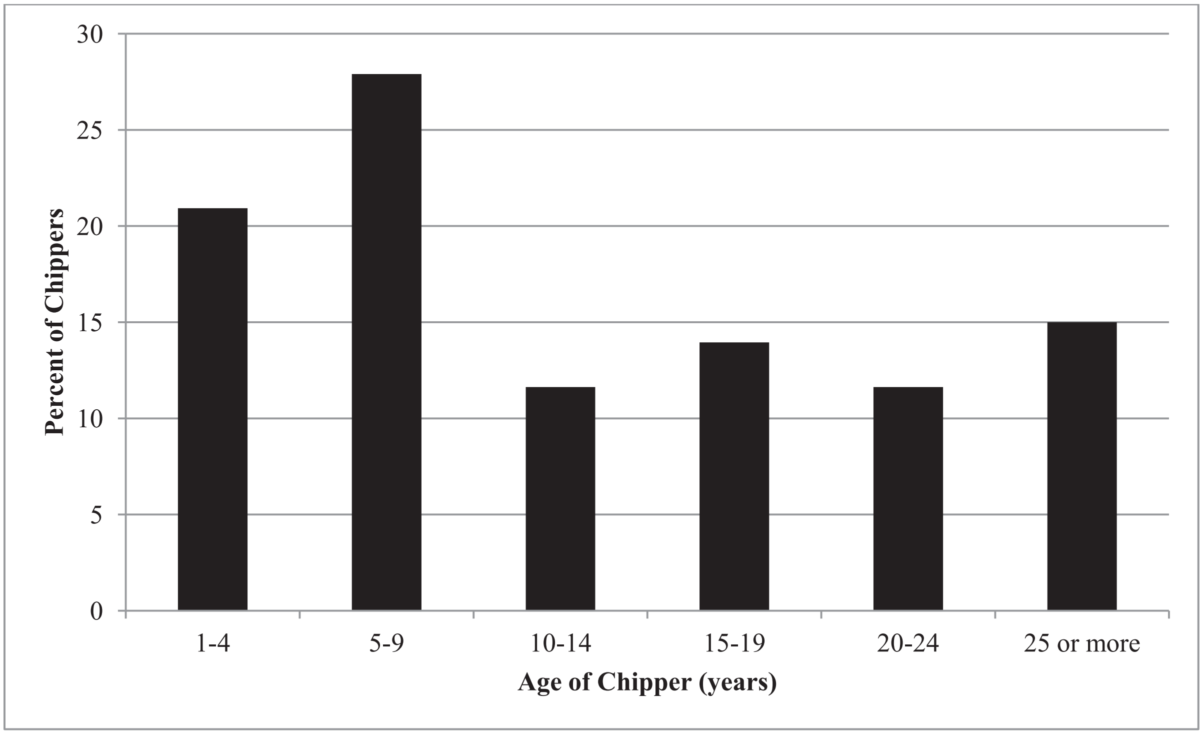

Figure 2.2. Age of chipper used for wood fuel production as reported by logging business owners.

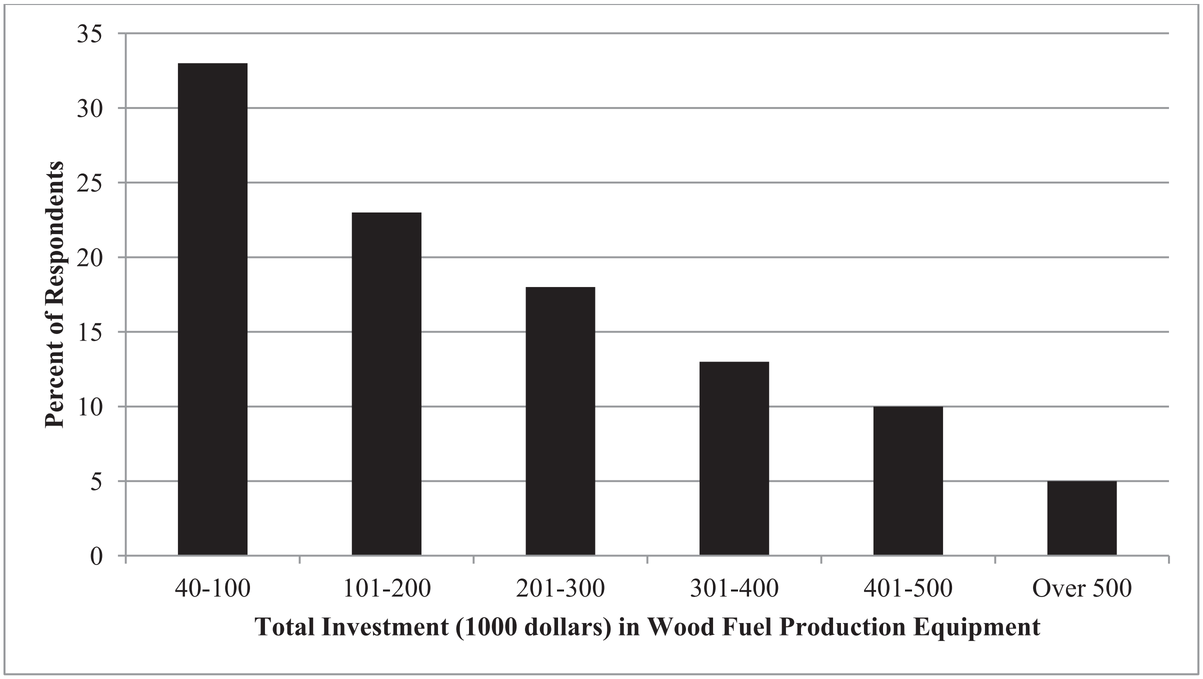

Figure 2.3. Total investment in equipment required for wood fuel production as reported by logging business owners.

Chipper ages were relatively old (12.5 years), which could be a concern that biomass harvesting is not profitable and businesses cannot afford to replace chippers as they age. Chipper ages were evaluated to determine if age was consistent across the owners' length of time producing fuel and wood fuel production level. Businesses were categorized into two wood fuel production levels. Smaller operations producing less than 10 loads of wood fuel per week had an average chipper age of 18.7 years, which was significantly older than for operations that produced over 10 loads of wood fuel per week and had an average chipper age of 7.7 years ($p = 0.0004$). Firms that produced wood fuel for 5 years or less had an average chipper age of 16 years and those that had produced wood fuel for over 5 years had an average chipper age of 10.5 years ($p = 0.0944$). Utilizing older chippers could be a strategy that allows smaller operations to integrate biomass harvesting into their operations with minimal investment. Similarly, starting out with an older chipper could be a strategy for firms that want to begin harvesting biomass but are unsure if it will ultimately be a good fit for their operation.

2.4.6 Impact of Fuel Chip Markets on Harvesting Operations

Respondents were asked to report the percentage of time during the past year that wood fuel prices were competitive enough to justify producing wood fuel from pulpwood. Categorical responses indicated that 14% believed market conditions in the past year never justified using pulpwood for wood fuel. Fifty percent reported 1-10% of the time, 24% reported 11-25%, and 12% reported greater than 25% of the time (Figure 2.4).

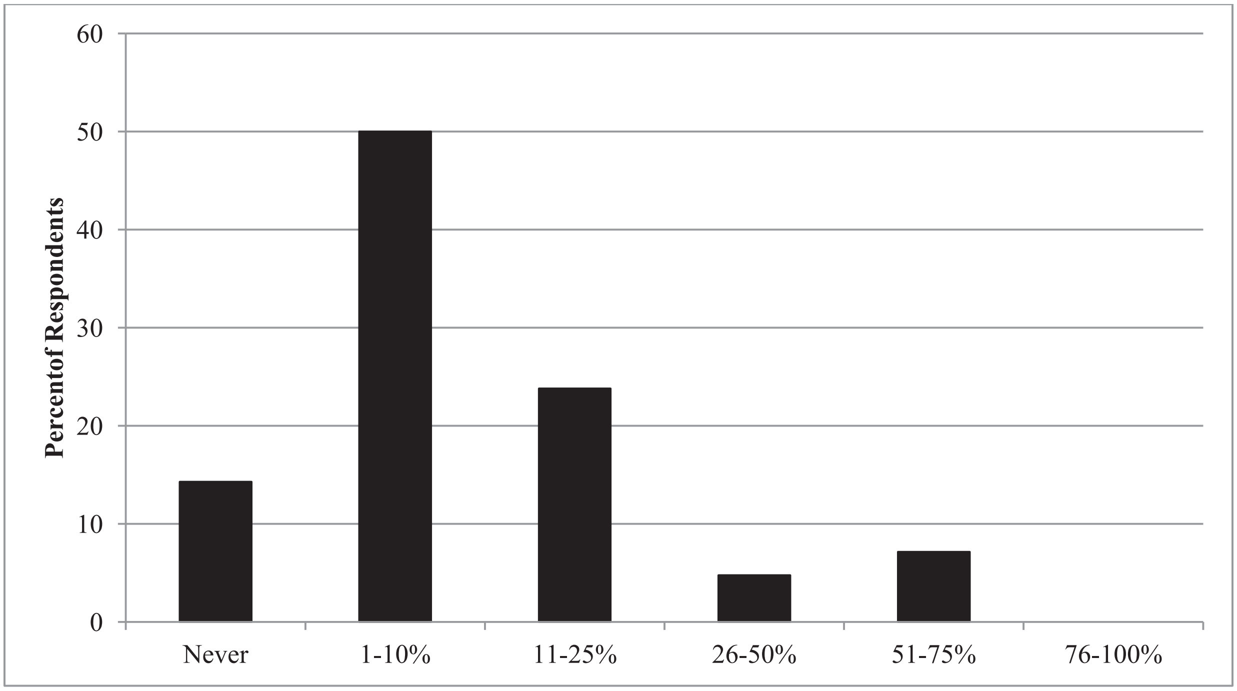

Figure 2.4. Percentage of time during 2010 when prices justified producing wood fuel from roundwood/pulpwood.

Although many respondents indicated there were periods when markets justified use of pulpwood for fuel, 24 of 44 firms also reported that additional wood fuel markets would enable them to increase total production from logging residues without using pulpwood. Only half of respondents produced fuel chips on all harvest sites in the past year. Respondents that had not produced wood fuel on all sites were provided an open ended question to describe the most common reason for not producing wood fuel. Common responses included lack of markets, quota restrictions, or lack of profit based on wood fuel prices relative to transportation costs.

Utilizing logging residues for fuel can provide additional income; however, loggers also consider their value and benefits for other management purposes such as their use on decks and skid trails for protection of water quality. Virginia does not have specific biomass harvesting guidelines, but does have a silvicultural water quality law and all timber harvests are inspected to ensure compliance (VDOF 2011). Sixty-four percent of respondents reported encountering situations where only a portion of available residues were chipped because it was ultimately more valuable to leave residues on site for use as a Best Management Practice (BMP) for protecting water quality. In these cases, residues would be utilized as a ground cover to protect bare soil areas from erosion. Additionally, 61% reported using chips to mulch a landing or skid trail to satisfy BMP guidelines.

2.4.7 Owner Attitudes and Operational Impacts

The questionnaire included 12 measures regarding the owner's decision to harvest wood fuel and the impacts of this decision on operations (Table 2.3). Participants were asked to respond to statements using a 5 point Likert-type scale where "strongly agree"=5, "neutral"=3, and "strongly disagree"=1. The lowest response mean (least agreement) occurred when asked if they began producing wood fuel because a mill representative encouraged them to do so (mean = 2.59). The two overall highest mean responses indicated they began producing wood fuel to satisfy landowners that wanted residues chipped (mean = 4.25) and so they could be competitive on timber sales that required residue chipping (mean = 4.23). Responses also indicated strong agreement that they began producing wood fuel to diversify their business (mean = 4.18) and to increase total profit (mean = 4.09). Regarding overall impacts, respondents also agreed that deciding to produce wood fuel was a good decision (mean = 4.11). In general, there was less agreement that they made a profit on wood fuel produced (mean = 3.52). However, this was significantly higher than neutral, and only 6 of 44 (14%) disagreed. Respondents had a mean response of 3.16 to the statement that they had never harvested wood fuel at a financial loss to satisfy a landowner. This was not significantly different from neutral and 16 of 44 (36%) disagreed or strongly disagreed that they had never harvested at a loss to satisfy a landowner.

Pairwise comparisons were performed to identify significant differences in response means. Respondents were significantly more likely to begin harvesting wood fuel to satisfy landowners rather than in response to encouragement from a mill ($p < 0.0001$). There were no significant differences between response means when queried if they began harvesting wood fuel to satisfy landowners as compared to being competitive on timber sales that required chipping ($p = 0.9563$), to diversify their business ($p = 0.7414$), or to increase total profit ($p = 0.2113$). The mean response for the statement that they make a profit on wood fuel was significantly lower than the mean response that they began producing wood fuel so that they could increase total profit ($p = 0.0005$).

Table 2.3. Logging business owner attitudes related to statements about their decision to begin producing wood fuel, and the impact it has on their operation. Mean responses are based on a value of 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree with a Wilcoxon signed-rank test of the null hypothesis that the mean response is neutral (=3).

Statement	Mean response	Wilcoxon signed-rank
I began producing wood fuel to satisfy landowners that wanted logging residues chipped.	4.25	398 (p<0.0001)
I began producing wood fuel so I could be competitive on timber sales that require logging residues to be chipped.	4.23	360 (p<0.0001)
I began producing wood fuel so I could diversify my business.	4.18	422.5 (p<0.0001)
Given the overall impacts to my operation, deciding to produce wood fuel was a good decision.	4.11	351.5 (p<0.0001)
I began producing wood fuel so I could increase my total profit.	4.09	375 (p<0.0001)
Producing wood fuel makes my overall business stronger.	4.09	375.5 (p<0.0001)
I began producing wood fuel so I could contribute to renewable energy production using a resource that would otherwise be wasted.	4	253.5 (p<0.0001)
I have to be able to produce wood fuel from logging residues for my business to remain competitive.	3.86	302.5 (p<0.0001)
Producing wood fuel makes running my business more challenging.	3.75	270 (p<0.0001)
On average, I make a profit from the wood fuel I produce.	3.52	184.5 (p<0.0001)
I have never harvested wood fuel at a financial loss in order to satisfy a landowner.	3.16	56 (p=0.3756)
I began producing wood fuel because a mill that I do business with encouraged me to do so.	2.59	-101.5 (p=0.0124)

Business owners were also asked if they expected to be producing wood fuel in 5 years. All but one owner indicated that they expect to continue. Those that planned to continue were asked if they expected their wood fuel production level to be more, less, or about the same 5 years from now. Fifty-three percent indicated they expected production to increase and none expected decreases.

2.4.8 Characteristics of Firms Indicating Profit from Wood Fuel

Owners indicated landowner preference and other competitive factors were important reasons for producing wood fuel. This can be an important marketing strategy, yet for the long term viability of integrated wood fuel production, making a profit on wood fuel is important. Twenty-five (57%) respondents agreed they profited from the wood fuel they produce. Two (5%) strongly agreed. Eleven (25%) were neutral and 6 (14%) disagreed. No respondent strongly disagreed. To compare operational differences, respondents that were neutral or disagreed (n=17) were grouped together and compared with respondents that agreed or strongly agreed (n=27) (Table 2.4). Firms that agreed they profited had an average investment of $188,500 in wood fuel production equipment, versus $377,143 for the neutral/disagree group (p=0.0161). While not significant at the $\alpha = 0.05$ level, firms that agreed they profited tended to have lower production at 25.08 loads per week of roundwood compared to 48.76 for the neutral/disagree group (p=0.0601).

Table 2.4. Response means for operational variables grouped based on agreement to the statement “On average I make profit on wood fuel I produce”. Responses for the group that agreed (strongly agree or agree) compared to the group that was neutral or disagreed using t-tests.

	Agree (n[a])	Neutral or Disagree (n[a])	p-value
Years producing wood fuel	6.78 (27)	6.82 (17)	0.9800
Total years logging	21.44 (25)	25.53 (17)	0.3161
Roundwood production level (loads/week)	25.08 (26)	48.76 (17)	0.0601
Wood fuel production level (loads / week)	9.15 (27)	10.25 (16)	0.5818
Average chipper age (years)	13.6 (25)	11.96 (14)	0.6379
Average chipper horsepower	480.63 (27)	530.77 (17)	0.5195
Total investment in wood fuel production equipment	$188,500 (26)	$377,143 (14)	0.0161

[a] 27 respondents were in the “agree” category and 17 were in the “neutral or disagree category”. Some respondents did not provide a response for all operational variables, so n for each variable may total less than the total group n.

2.4.9 Advantages and Barriers to Wood Fuel Production

The questionnaire included open ended questions pertaining to the most significant barriers to producing wood fuel profitably and asked respondents to identify the most substantial advantages of producing wood fuel. Regarding the advantages of wood fuel production, 50% of respondents indicated landowner satisfaction or improving post-harvest aesthetics were the biggest advantages. Twenty-three percent noted it helps in terms of procurement and acquiring additional tracts. Twenty percent provided responses indicating residue harvesting facilitated reforestation. Eighteen percent provided statements related to reducing waste and producing renewable energy from a mostly unused resource. Sixteen percent of responses related to profit and business diversification. Profitability barriers identified in the open ended questions were primarily related to prices and markets, not operational feasibility or logistical challenges. Seventy-five percent of respondents indicated delivered prices for wood fuel or costs associated with diesel fuel, equipment, or operating and maintenance costs were barriers. A need for additional markets was noted by 23% and production restrictions due to mill quotas were specifically cited as barriers by 9% of respondents. A need for more stable market pricing with less fluctuation was identified by 14% of respondents. Dirkswager et al. (2011) also noted concerns related to prices and markets for wood fuel among biomass harvesting operations in Minnesota.

2.5 Conclusions

With active markets for biomass and conventional forest products, a diversity of logging operations integrated biomass harvesting into ongoing operations to produce roundwood and biomass. Logging firms reported that many landowners prefer the characteristics of harvests where residues are chipped. Business owners were more likely to decide to produce biomass to satisfy landowner demand than because a mill had encouraged them to do so. Business owners generally believed that deciding to produce biomass was a good decision for their business. The addition of biomass markets in other regions could benefit existing logging businesses willing to produce biomass to meet new demands. This could be especially important in regions where logging businesses primarily harvest timber on non-industrial private landowner properties. Although overall biomass utilization will be dictated by quantities demanded by consuming mills, utilization of logging residues among existing businesses may become more widely adopted over time as landowners express a preference for utilizing harvest residues and logging firms enter biomass harvesting to satisfy the demand.

The studied region had a higher proportion of firms that recently adopted biomass harvesting (6.8 years producing fuel chips) compared to the total length of time biomass markets have existed (over 15 years). Perhaps, this is due to a combination of increased demand for biomass in recent years combined with perceptions among firms that biomass harvesting allowed them to remain competitive and satisfy landowners.

Production levels for wood fuel on integrated harvesting operations were typically less than 10 loads per week. Many operations accumulate wood fuel material at the landing and periodically produce fuel chips. The low utilization of chippers allows operations to use older chippers, especially among smaller operations that generate less residue. This strategy of utilizing older chippers allows firms to enter biomass markets to diversify operations, produce an additional product and satisfy landowners, yet invest less capital in equipment. Firms that agreed they profited on wood fuel also tended to be the firms that had a lower overall investment in wood fuel production equipment. While older chippers may not be as reliable, they are generally less expensive. Thus, if chipper breakdowns occur, roundwood production can continue and residues can either be accumulated until the chipper is repaired or residues can be left in the woods.

Integrated biomass harvesting appears to be advantageous for logging operations of varying size. However, even with additional markets, not all logging operations will want to integrate biomass harvesting into their operations. If biomass consumption increases substantially, it will be important to also utilize logging residues generated by firms that do not integrate residue harvesting into their operations. Additional research would be needed to investigate strategies and best practices for utilizing logging residues generated by conventional operations that do not utilize their own residues.

2.7 References

Baker, S.A., M.D. Westbrook, Jr., and W.D. Greene. 2010. Evaluation of integrated harvesting systems in pine stands in the southern U.S. Biomass and Bioenergy 34(5):720-727.

Becker, D.R., D. Larson, and E.C. Lowell. 2009. Financial considerations of policy options to enhance biomass utilization for reducing wildfire hazards. Forest Policy and Economics 11(8):628-635.

Becker, D.R., J.J. Klapperich, G.M. Domke, M.A. Kilgore, A.W. D'Amato, D.A. Current, and A.R. Ek. 2010. 2010 outlook for forest biomass availability in Minnesota: Physical, environmental, economic, and social availability. Staff paper series No. 211. Department of Forest Resources, College of Food, Agricultural and Natural Resource Sciences, University of Minnesota, St. Paul, MN. 96 p.

Bolding, M.C., S.M. Barrett, J.F. Munsell, and M.C. Groover. 2010. Characteristics of Virginia's logging businesses in a changing timber market. Forest Products Journal 60(1):86-93.

Brinckman, M.D. and J.F. Munsell. 2012. Disproportionality, social marketing, and biomass availability: A case study of Virginia and North Carolina family forests. Southern Journal of Applied Forestry 36(2):85-91.

Conrad, J.L., M.C. Bolding, W.M. Aust, and R.L. Smith. 2010. Wood-to-energy expansion, forest ownership changes, and mill closure: Consequences for U.S. South's wood supply chain. Forest Policy and Economics 12(6):399-406.

Conrad, J.L. IV, M.C. Bolding, R.L. Smith, and W.M. Aust. 2011. Wood-energy market impact on competition, procurement practices, and profitability of landowners and forest products industry in the U.S. South. Biomass and Bioenergy 35(1):280-287.

Dillman, D.A. 2000. Mail and Internet Surveys: The Tailored Design Method. John Wiley and Sons. New York. 480 p.

Dirkswager, A.L., M.A. Kilgore, D.R. Becker, C. Blinn, and A. Ek. 2011. Logging business practices and perspectives on harvesting forest residues for energy: a Minnesota case study. Northern Journal of Applied Forestry 28(1):41-46.

Forisk Consulting. 2013. Forisk Bioenergy Research - Estimated wood use by announced facilities in the U.S. Available online at http://forisk.com/Forisk-Bioenergy-Research-v-42.html Last accessed April 19, 2013.

Galik, C. S., R.C. Abt, and Y. Wu. 2009. Forest biomass supply in the Southeastern United States – implications for industrial roundwood and bioenergy production. Journal of Forestry 107(2):69-77.

Greene, D., S. Baker, J. Cutshall, and A. Enrich. 2011. Regional approaches for harvesting forest biomass: a report on field studies to the Wood Supply Research Institute. Forest Operations Review. Forest Resources Association. Rockville, MD. 13(1):14-25.

Groves, R.M., D.A. Dillman, J.L. Eltinge, and R.J.A. Little (Eds.). 2002. Survey nonresponse. John Wiley and Sons, New York. 500 p.

JMP Version 9.0. 2010. SAS Institute Inc., Cary, NC, 1989-2010.

Markowski-Lindsay, M., T. Stevens, D.B. Kittredge, B.J. Butler, P. Catanzaro, and D. Damery. 2012. Family forest owner preferences for biomass harvesting in Massachusetts. Forest Policy and Economics 14(1):127-135.

Munsell, J.F. and T.R. Fox. 2010. An analysis of the feasibility for increasing woody biomass production from pine plantations in the Southern United States. Biomass and Bioenergy 34(12):1631-1642.

Munsell, J.F., S.M. Barrett, and M.C. Bolding. 2011. An Exploratory study of biomass harvesting among logging firms in Virginia and North Carolina. Forest Science 57(5):427-434.

Ott, L., and M. Longnecker. 2010. An introduction to statistical methods and data analysis. Sixth Edition. Belmont, CA: Brooks/Cole Cengage Learning. 1273 p.

Perlack, R. D. and B.J. Stokes. 2011. US billion-ton update: biomass supply for a bioenergy and bioproducts industry. Oak Ridge National Laboratory. Oak Ridge, TN. 227 p.

Saunders, A.M., F.X. Aguilar, J.P. Dwyer, and H.E. Stelzer. 2012. Cost structure of integrated harvesting for woody biomass and solid hardwood products in southeastern Missouri. Journal of Forestry 110(1):7-15.

Spinelli, R. and B. Hartsough. 2001. A survey of Italian chipping operations. Biomass and Bioenergy 21(6):433-444.

Spinelli, R., and R.J.M. Visser. 2009. Analyzing and estimating delays in wood chipping operations. Biomass and Bioenergy 33(3):429–433.

Timber Mart-South. 2012. Norris Foundation, Univ. of Georgia, Athens, GA.

U.S. Energy Information Administration (EIA). 2012a. November 2012 Monthly Energy Review. DOE/EIA-0035(2012/11). Available online at http://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf Last accessed on 11/30/12.

U.S. Energy Information Administration (EIA). 2012b. Annual energy outlook 2012. DOE/EIA-0383(2012) June 2012. Available online at http://www.eia.gov/forecasts/aeo/pdf/0383 (2012).pdf Last accessed on 11/30/12.

Virginia Department of Forestry (VDOF). 2011. Virginia's Forestry Best Management Practices for Water Quality, 5th ed. Virginia Department of Forestry, Charlottesville, VA. 165 p. March 2011. Available online at http://www.dof.virginia.gov/wq/resources/ManualBMP/2011_Manual_BMP.pdf Last accessed on 12/21/12.

Westbrook, M.D. Jr., W.D. Greene, and R.L. Izlar. 2007. Utilizing forest biomass by adding a small chipper to a tree-length southern pine harvesting operation. Southern Journal of Applied Forestry 31(4):165-169.

Wiltsee, G. 2000. Lessons learned from existing biomass power plants. Technical Report NREL/SR-570-26946. National Renewable Energy Laboratory. 143 p.

3.0 POTENTIAL EROSION, GROUND COVER, AND BMP AUDIT DETAILS FOR POST-HARVEST EVALUATIONS OF BIOMASS AND CONVENTIONAL CLEARCUT HARVESTS

3.1 Abstract

Increased use of biomass for energy will likely result in greater utilization of logging residues. Reduced levels of logging residues due to biomass harvesting could be considered a potential concern for post harvest erosion rates and BMP implementation. Twenty operational harvests consisting of ten biomass and ten conventional clearcuts, with an average size of 39.9 acres, were evaluated in the Virginia Piedmont for potential erosion rates, residual ground cover, and Best Management Practices (BMP) implementation. Harvests were subdivided into operational areas and the Universal Soil Loss Equation (USLE) was applied to estimate potential erosion within each operational category on the 20 sites. No significant differences were found for estimated erosion rates in any of the operational categories. Overall predicted erosion rates were relatively low for both biomass (0.7 tons ac^{-1} yr^{-1}) and conventional harvests (0.8 tons ac^{-1} yr^{-1}) ($p=0.8282$). BMP audits were conducted following the Virginia Department of Forestry procedures and no significant differences were found for overall BMP implementation on biomass (85.2%) versus conventional operations (81.3%) ($p= 0.5930$). Comparison of BMP audit data and potential erosion rates indicate significant correlation ($R^2=0.7994$, $p < 0.001$) between the two indices of BMP efficacy.

Key words: Best Management Practices, Harvesting Effects, Soil Erosion, Biomass Harvests

3.2 Introduction

Woody biomass plays an important role in US renewable energy production and utilization of wood for energy is expected to increase substantially (US EIA 2012). Woody biomass from logging residues in the form of limbs, tops, small diameter trees, and otherwise non-merchantable portions of trees are probable feedstocks to supply increasing demands of wood for energy. More intensive utilization of trees and logging residues from harvesting operations has the potential to change the post-harvest characteristics of sites where biomass harvesting occurs. As the use of woody biomass for energy becomes more widespread, there are concerns about how altered harvesting removals could impact harvest sites (Hall 2002).

Biomass harvesting concerns are often related to soil and site productivity, water quality, biodiversity, and wildlife habitat (Hall 2002, Janowiak and Webster 2010). In response to these concerns, a number of states have enacted biomass harvesting guidelines (e.g., Maine, Minnesota, Missouri, Pennsylvania, and South Carolina). Guidelines may make recommendations that address wildlife and ecological values in addition to water quality (Forest Stewards Guild 2012). However, for many state forestry agencies, their primary focus for BMP programs is protecting water quality (Shepard 2006).

The effectiveness of forestry BMPs for protecting water quality have been widely documented (e.g., Aust and Blinn 2004, NCASI 2009, Lakel et al. 2010, Anderson and Lockaby 2011, Aust et al. 2011). However, there has been little research on the effectiveness of BMPs to protect water quality during biomass harvesting. BMPs were typically developed for conventional harvesting operations. Since biomass harvesting operations generally utilize traditional harvesting techniques, the BMPs should be effective at protecting water quality on sites where logging residues are harvested for energy (Shepard 2006). Ice et al. (2010)

hypothesized that there would be few differences between conventional and biomass harvests unless there were differences in soil conditions and conventional BMPs should be effective for protecting water quality on both sites. This assumption appears reasonable, yet additional research focusing on soil disturbance and erosion related to biomass harvesting would be useful for agencies and forest management professionals involved in monitoring and implementing BMPs to protect water quality during forest harvesting operations.

BMPs typically include measures used to protect and stabilize bare soil areas (Aust and Blinn 2004). Harvesting operations often utilize logging residues for protecting bare soil areas because they are readily available on site and are effective at preventing erosion (Sawyers et al. 2012, Wade et al. 2012, Wear et al. 2013). One concern with biomass harvesting is that logging residues harvested and transported offsite would not be available for BMP implementation to protect bare soil in harvest areas. A lack of harvest residues could result in increased erosion if insufficient residues remained to protect bare soil. Another concern related to biomass harvesting is the potential increased trafficking and resultant soil disturbance caused by the additional volume removals on biomass harvests as compared conventional harvesting. Integrated biomass harvesting operations may also require larger deck/landing areas that could result in additional site disturbance to accommodate the chipper and additional trucks and chip vans required for utilizing biomass fuel chips.

Soil erosion attributed to bare soil in harvest areas is a primary concern related to water quality and harvesting operations (Anderson and Lockaby 2011). Sedimentation occurs when eroded soil is deposited in a stream (Yoho 1980). The Virginia Department of Forestry (VDOF) audits BMP implementation on harvesting sites across the state (Lakel and Poirot 2012) to assess the potential for sedimentation and to ensure compliance with Virginia’s Silvicultural Water

Quality Law. The harvest site audits assess the technical quality of BMP implementation as outlined in Virginia's BMP manual (VDOF 2011) but do not provide a quantitative estimate of erosion for harvest sites.

Demand for biomass energy is predicted to increase substantially in Virginia (Dominion 2011, MeadWestvaco 2011, NOVEC 2011), thus whole tree harvesting and utilization of logging residues is also expected to become more widespread. A better understanding of the impacts associated with biomass harvesting is needed. Characterization of sites following biomass harvesting could provide forest managers with additional information to make decisions associated with protecting water quality when harvesting biomass.

This study was designed to evaluate post-harvest site conditions on conventional and biomass harvest sites in the Piedmont region of Virginia in order to characterize factors contributing to soil erosion on each type of harvest. Specific objectives were to:

1. Estimate (USLE) the potential erosion rates for conventional versus biomass harvests,
2. Evaluate and compare the harvest operational areas (roads, decks, skid trails, harvest area, stream crossings, streamside management zones, and fire lines) as a percentage of total harvest area for conventional and biomass harvests,
3. Evaluate post-harvest ground cover (litter, light slash, heavy slash, piles, bare soil, and rock) on conventional and biomass harvest areas, and
4. Correlate the VDOF BMP implementation score for each tract with estimated erosion rates.

3.3 Methods

Potential erosion rates were estimated on twenty sites in the Piedmont region of Virginia (Figure 3.1). The Piedmont region was selected because of its active markets for woody biomass and integrated harvesting operations are relatively common (Chapter 2). Twenty sites were evaluated, including ten conventionally harvested sites (Conventional) and ten sites where wood fuel was produced (Biomass). Potential erosion rates were estimated using the Universal Soil Loss Equation as modified for forest land (USLE-Forest) by Dissmeyer and Foster (1984). Sites were evaluated using the methodology recommended by Christopher and Visser (2007) for estimating soil erosion on forest land. This approach has been successfully used for several erosion studies including evaluations of skyline yarding operations versus conventional skidding operations in Virginia (Worrell et al. 2011), on harvest sites in the Piedmont (Lakel et al. 2010), on overland skid trails (Sawyers et al. 2012), on stream crossings (Aust et al. 2011, Wear et al. 2013) and on harvests in Appalachian hardwoods (Hood et al. 2002).

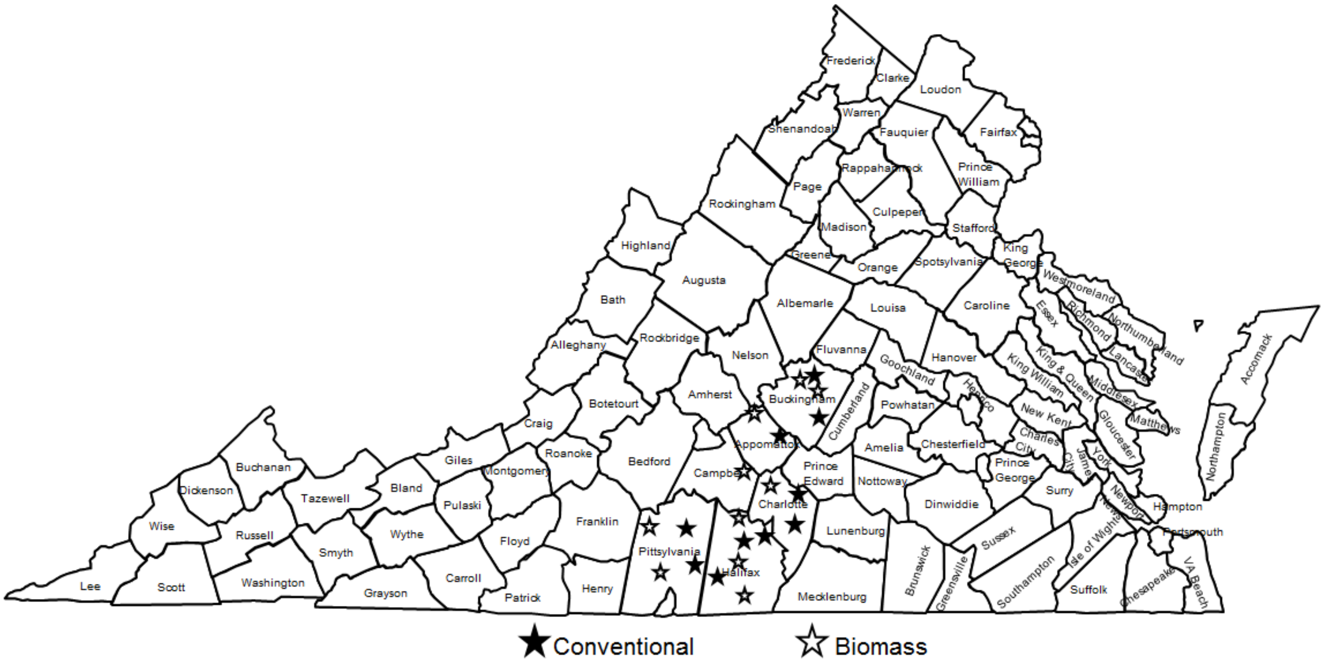

Figure 3.1. Harvest site locations in the Piedmont region of Virginia for biomass and conventional harvesting sites.

3.3.1 Site Selection

Harvest sites with desired attributes were randomly selected from a list of candidate sites provided by the VDOF for final harvest inspections performed in the Piedmont region in the first quarter of 2012. Candidate sites were eligible for auditing in the third quarter of 2012 based on procedures outlined by Lakel and Poirot (2012) whereby sites are evaluated approximately 6 months post-harvest. Selected sites were evaluated in July and August 2012. In order to enhance consistency across harvest sites, only clearcuts were evaluated. Tracts where whole trees were harvested using a flail and chipper combination (clean chipping) were excluded. Sites were classified as biomass harvests based on the VDOF harvest inspection form data and were field checked to verify that logging residues or whole trees had been harvested. The VDOF harvest notifications include an estimated harvest size provided by the logging contractor, which may be considerably different from the actual area. Tracts selected for evaluation had harvest sizes reported to VDOF from 15 to 80 acres.

Because of the time lapse between final harvest and the audit inspections, some sites were rejected due to confounding effects of subsequent agricultural conversions. Additionally, some tracts were considerably larger than reported. Some candidate sites were substantially larger than 80 acres, or had post-harvest agriculture or subsequent forest harvesting operations that had impacted portions of the harvest area. Where there were distinct operational units with clear boundaries, tracts were divided and only a portion of the total harvest area was evaluated.

Tract selection was designed to distribute sites throughout the southern Piedmont region of Virginia and to provide for a balance between pine and hardwood harvests. All sites had a mixture of pine and hardwood, but both biomass and conventional sites had approximately half of their tracts that were predominantly pine and half that were predominantly hardwood. Pine and hardwood designations were based on data provided in the harvest notification, aerial photographs, and on-site inspections.

3.3.2 Estimating Erosion

Harvests were divided into the following seven operational / disturbance categories:

1. Access roads included forest roads used to transport equipment and wood to and from the sites. In situations where access to the site was directly from state maintained roads or active driveways, erosion rates for access roads were not evaluated. Area occupied by forest roads used to access the harvest site was included as a component of the total harvest area.

2. Decks or landings were areas where wood was skidded to a centralized location for processing and loading onto trucks for transportation off site.
3. Skid trails included trails where skidding traffic was obviously concentrated.
4. Stream crossings included the approaches on either side of a stream crossing.
5. Clearcut harvest area included the harvested area of the tract, excluding areas occupied by other operational areas such as roads, decks and skid trails.
6. Streamside Management Zones (SMZs) were areas adjacent to streams where harvest disturbances were minimized by leaving an intact or partially intact overstory. In situations where partial harvesting occurred in SMZs, erosion estimates for the SMZ was included as part of the total site erosion.
7. Fire lines included post-harvest fire lines used for site preparation burns to remove harvesting debris from the site.

Area estimates for each operational category were obtained using a combination of handheld recreational grade GPS, tape measures, pacing, and area obtained from web based measurement tools utilized by the VDOF (InForest 2013). The USLE-Forest method was utilized to obtain erosion estimates for each of the disturbance categories. An erosion estimate was obtained within a representative segment of each disturbance area. Representative segments were selected to represent the predominant site conditions including slope, ground cover and disturbance. Multiple erosion estimates were obtained and averaged to represent larger areas. Clearcut harvest areas had a minimum of 10 estimates. Decks typically had 1 to 2 estimates depending on size. Skid trails, roads, and SMZs typically had at least 3 estimates, and stream crossings had 2 estimates (1 per side).

Erosion estimates were obtained using the USLE-Forest method (Dissmeyer and Foster 1984). The USLE is a relatively simple and widely used method for predicting sheet and rill erosion (Croke and Nethery 2006). The USLE-Forest method utilizes rainfall, soil, and site factors to predict erosion. The formula for predicting erosion using the USLE-Forest is as follows: $A = R\ K\ LS\ CP$ where A = estimated erosion per unit area (tons/ac/year). Erosion, as predicted by the USLE-Forest method is defined as soil delivered to the toe of the slope where deposition begins or where runoff becomes concentrated (Dissmeyer and Foster 1984).

The rainfall and runoff factor (R) was determined using an index map provided in the USLE-Forest handbook (Dissmeyer and Foster 1984). All sites had an R factor of 175. Soil erodibility factors (K) were determined using Web Soil Survey (USDA NRCS 2013). Slope length and slope steepness factors (LS) were determined using a hand held clinometer for slope and distances were measured by pacing, tape measures, and visual estimation. Cover and management practices (CP) factors were determined using methods outlined by Dissmeyer and Foster (1984). Point samples were used to estimate percent ground cover.

3.3.3 Ground Cover Evaluation

Ground cover in the clearcut harvest areas was evaluated using methods adapted from Eisenbies et al. (2005). Ground cover categories included: bare soil, litter, light slash (woody debris <1 inch diameter), heavy slash (woody debris ≥1 inch diameter), piles of woody debris (> 1 foot deep), and rock. All woody debris on the ground was included in either light slash (<1 inch diameter) or heavy slash (≥1 inch diameter), and no attempt was made to determine if the woody debris had been broken off or knocked down as a result of the harvesting operation, or was already on the forest floor prior to harvesting. Ground cover data were collected at a minimum of 10 sampling points per tract within the clearcut harvest area. Data were collected by establishing quadrants at each sampling point, and visually classifying ground cover within quadrants extending 33 feet from plot center. Ground covers were visually estimated and recorded as the percentage of area within the quadrant occupied by each ground cover category. Ground cover estimates obtained in each of the 4 quadrants at 10 points throughout the clearcut harvest area resulted in a minimum of 40 ground cover estimates per tract. Prior to data collection visual area estimates were calibrated using the guide for estimating density of bare soil included in the USLE Manual (Dissmeyer and Foster 1984).

3.3.4 BMP Implementation Audit Scores

Each of the 20 tracts was audited for BMP compliance using the current VDOF auditing system which includes a total of 7 categories for BMP implementation related to logging (roads, decks, stream crossings, SMZs, wetlands, harvest planning and skidding) (Lakel and Poirot 2012). The audit contains a total of 84 questions specifically related to BMPs for logging (excluding site preparation categories). Specific questions are listed in the BMP implementation audit report by Lakel and Poirot (2012). Audits were completed by VDOF personnel involved in ongoing auditing of tracts in the region. Audit scores are reported as the percent of applicable BMPs which received a “Yes” on the audit. This percent represents the proportion of applicable audit questions that were appropriately implemented by the operator (Lakel and Poirot 2012). Tract audits were performed by the VDOF employees typically responsible for water quality audits in the location the harvest occurred. This resulted in tract inspections performed by 5 different VDOF auditors. Every VDOF auditor attends regular training to maintain consistency in audit scoring across the state (Lakel and Poirot 2012).

3.3.5 Data Analysis

Potential soil erosion estimates for each tract were averaged by operational / disturbance category and weighted based on the proportion of the harvest area in each disturbance category. This weighted average provided an erosion estimate for the entire tract as well as an estimate of erosion within each of the disturbance categories. T-tests were performed on these data to test the null hypothesis that there is no difference in erosion rates between biomass and conventional harvesting operations. Tests were conducted at the $\alpha \leq 0.05$ level using JMP (JMP 2012). Simple linear regression was utilized to predict overall erosion rates based upon BMP implementation score using JMP (JMP 2012).

3.4 Results and Discussion

Of the 20 sites (10 conventional, 10 biomass) the overall average tract size was 39.9 acres with an average size of 37.6 acres for biomass harvests and 42.1 acres for conventional harvests (p=0.7300). These harvest sizes were similar to the statewide average of 41.5 acres for harvest inspections reported by the Virginia Department of Forestry in 2012 (VDOF 2012).

3.4.1 Harvest Area Ground Cover

Ground cover observations indicated that harvest areas where logging residues were harvested for biomass fuel chips (Table 3.1) had significantly less cover from heavy slash (p=0.0045) and woody debris piles (p=0.0414), and had significantly more area occupied by litter (p=0.0031). Interestingly, while not significant at the $\alpha \leq 0.05$ level, biomass harvests had less bare soil (7.4%) than conventional harvests (11.3%) (p = 0.0752). As expected, when residues are utilized for fuel chips, some of the heavy slash (> 1 inch diameter) would likely have been chipped for fuel instead of scattered across the harvest site or left in piles. While biomass harvest sites had significantly less ground cover from heavy slash, they were not devoid of heavy slash and woody material. On average, these sites had over 12% of the harvest area covered with woody material > 1 inch in diameter. Similar results for post-harvest ground cover were found by Groover (2012) in North Carolina pine stands. Groover (2012) found integrated biomass harvests to have significantly less heavy slash and piles, more of the harvest area covered by litter only, and no difference in bare soil between conventional and integrated biomass harvesting operations. However, Groover (2012) also found significantly less light slash on integrated biomass harvests than on conventional harvests.

Table 3.1. Percent of clearcut harvest area occupied by each category of ground cover for biomass (n=10) versus conventional (n=10) harvesting sites.

Ground cover	Overall (%)	Biomass (%)	SE	Conventional (%)	SE	P-value
Bare soil	9.4	7.4	1.37	11.3	1.58	0.0752
Litter	55.6	62.2	1.91	49.1	3.34	0.0031
Light slash	17.6	17.4	0.69	17.9	0.94	0.6709
Heavy slash	15.5	12.5	0.90	18.5	1.61	0.0045
Piles	1.6	0.5	0.11	2.7	0.99	0.0414
Rock	0.3	0.0	0.01	0.5	0.44	0.2559
Total	100	100		100		

3.4.2 Use of Slash and Chips as a BMP

Slash was used as a BMP to protect bare soil areas on 15 of 20 sites (75%). No sites utilized slash to close out temporary haul roads. Slash was utilized as a BMP on deck areas on 60% of sites, on skid trails on 75% of sites, and on stream crossings on 2 of the 5 sites with stream crossings. There were no significant differences (p=0.6056) between biomass and conventional sites related to use of slash as a BMP. There was no attempt to quantify whether an adequate amount of slash was utilized, or if additional slash would have been helpful to protect the bare soil area. The observations simply noted whether or not slash was purposefully utilized as a ground cover to protect bare soil areas.

While limited availability of slash for use as a BMP is a potential concern related to biomass harvesting, sites were observed with slash piles remaining on the deck post-harvest (Figure 3.2). The material may have been abandoned on the deck rather than utilized for fuel because it consisted primarily of small branches and pieces that would not easily feed through the type of chipper utilized by the logging operation. Another explanation is that these residues could have been contaminated by excessive amounts of dirt or rocks and the operator did not want to put the material through the chipper. Regardless, these residue piles remaining after biomass harvests illustrate that operational biomass removals tend to still leave some logging residues which could be used as a BMP to protect bare soil areas.

Figure 3.2. Example of a slash pile remaining on the deck following a biomass harvest.

For biomass harvesting operations where the harvesting contractor has a chipper on site, chips can also be utilized as a ground cover for protecting bare soil areas (Figure 3.3). A survey of Piedmont region logging businesses (Chapter 2) showed that 63% of logging businesses had utilized chips as a BMP on their logging operations. Chips were utilized as a BMP for ground cover on the deck area for 4 of 10 biomass harvesting sites.

Figure 3.3. Example of biomass fuel chips utilized as ground cover to protect bare soil on a deck area following a biomass harvest.

Although it would be possible to utilize chips for ground cover on skid trails and other areas of bare soil, loggers would not typically have a way of transporting chips from the deck area where the chipper is located to other parts of the tract where they may be needed for BMP implementation. For all sites where chips were utilized as a BMP, they were utilized only at the deck where the chipper was already positioned and could blow chips out onto the exposed soil, and then equipment could be used to evenly spread the chips if needed.

3.4.3 Potential Erosion Rates by Operational Category

Roads and skid trails are frequently noted as large contributors to erosion and sedimentation (e.g., Aust and Blinn 2004, Anderson and Lockaby 2011, Worrell et al. 2011, Sawyers et al. 2012). The highest overall estimated potential erosion rates in this study occurred in operational areas related to roads and skid trails (Table 3.2). Roads had an overall average erosion rate of 10.9 tons ac^{-1} yr^{-1} and skid trails had an average of 10.0 tons ac^{-1} yr^{-1}. Christopher and Visser (2007) estimated similar erosion rates of 9.4 tons ac^{-1} yr^{-1} for roads and 5 tons ac^{-1} yr^{-1} for skid trails on 50 sites across Virginia.

Table 3.2. Overall average estimated erosion by operational category and comparison of estimated erosion on biomass versus conventional harvest sites.

	Estimated erosion rate in tons ac^{-1} yr^{-1} (n)					
Operational category	Overall	Biomass	SE	Conventional	SE	P-value
Roads	10.9 (13)	9.3 (5)	3.9	11.8 (8)	4.6	0.7168
Decks	5.1 (20)	3.7 (10)	1.5	6.4 (10)	3.1	0.4476
Skid trails	10.0 (20)	9.1 (10)	3.4	10.8 (10)	6.0	0.8073
SMZ	0.1 (9)	0.1 (4)	0.1	0.1 (5)	0.1	0.8194
Stream crossings	6.0 (5)	7.7 (3)	5.2	3.4 (2)	1.6	0.5726
Clearcut harvest area	0.2 (20)	0.2 (10)	0.1	0.2 (10)	0.0	0.7310
Fire lines	7.4 (1)	7.4 (1)	-	-	-	-
Overall weighted ave.	0.8 (20)	0.7 (10)	0.3	0.8 (10)	0.4	0.8282

Stream crossings had an average potential erosion rate of 6.0 tons ac^{-1} yr^{-1}. All observed stream crossings were temporary skidder crossings as opposed to truck haul road crossings. In effect, stream crossings were also skid trails, but consisted of the section of skid trail approaches directly linked to the crossing. Fire lines were observed on only one tract and had average erosion rates similar to those observed for roads, decks, and skid trails. The lowest estimated potential erosion rates occurred in the partially harvested SMZ areas at 0.13 tons ac^{-1} yr^{-1} and in the clearcut harvest areas at 0.2 tons ac^{-1} yr^{-1}. Christopher and Visser (2007) found similar average estimated erosion rates for cut-over harvest areas of 0.3 tons ac^{-1} yr^{-1} across 54 harvest sites in Virginia using similar methods. Worrell et al. (2011) estimated slightly higher harvest area erosion levels in the Appalachian mountains of 0.6 tons ac^{-1} yr^{-1}. While increased erosion is a common concern related to biomass harvesting, we found no significant differences between erosion rates for any of the operational categories on biomass versus conventional harvesting operations.

3.4.4 Overall Weighted Tract Erosion

Erosion rates (tons ac^{-1} yr^{-1}) for each operational category were weighted by the area occupied by each operational category to determine total weighted tract erosion. The average overall weighted erosion rate across all sites was 0.8 tons ac^{-1} yr^{-1}. The overall weighted erosion rate for biomass harvests was 0.7 tons ac^{-1} yr^{-1} and 0.8 tons ac^{-1} yr^{-1} for conventional harvests (Table 3.2). There were no significant differences in overall weighted tract erosion rates for biomass versus conventional harvests ($p = 0.8282$). Similar overall weighted tract erosion rates were found by Christopher and Visser (2007) who studied 39 sites in the Piedmont of Virginia and found a weighted average erosion rate of 1.1 tons ac^{-1} yr^{-1}.

3.4.5 Area Occupied by Each Operational Category

The estimated percentage of the total harvest site occupied by each operational category is provided in Table 3.3. On average, the clearcut harvest area occupied 91.2% of the total harvest site. Skid trails occupied 3.7% of the total harvest area, followed by SMZs where harvesting occurred (2.78%), decks (1.3%), and roads (0.81%). A concern with integrated biomass harvesting operations could be that the addition of a chipper along with added chip vans could require additional space for decks or more roads and skid trails. However, no significant differences were observed in the percent of harvest site occupied in each operational category for biomass versus conventional harvesting operations.

Table 3.3. Overall percentage of total harvest area occupied by each operational category and comparison of area in each operational category for biomass versus conventional operations.

Operational category	Overall	Biomass	SE	Conventional	SE	p-value
	(%)	(%)		(%)		
Roads	0.81	0.67	0.33	0.95	0.41	0.6008
Decks	1.30	1.31	0.27	1.30	0.23	0.9785
Skid trails	3.73	3.93	0.46	3.53	0.71	0.6391
SMZ (partially harvested)	2.78	1.07	0.53	4.49	2.62	0.2174
Stream crossings	0.09	0.06	0.04	0.12	0.09	0.5769
Clearcut harvest area	91.25	92.87	0.85	89.61	2.63	0.2543
Fire lines	0.04	0.09		-		-
Overall	100.00	100.00		100.00		

3.4.6 Contribution of Erosion from Each Operational Category to Total Erosion Rates

While roads, decks, and skid trails accounted for less than 6% of the total harvest area, these operational areas accounted for nearly 64% of total potential erosion associated with the harvest sites. Skid trails alone accounted for over 43% of total estimated potential erosion (Table 4). Similarly, Christopher and Visser (2007) found that roads, decks, and skid trails contributed an average of 57% of erosion on 39 Piedmont sites that ranged from 1 to 8 years post-harvest. This illustrates that problems associated with erosion can be focused on relatively small portions of the harvest area. It also illustrates that when focusing BMP implementation efforts, these areas are critical for implementing BMPs to reduce overall erosion rates. Relative contributions of each operational category to overall area and erosion are highlighted in Figure 3.4. No significant differences were found in the overall contribution of erosion coming from these operational areas for biomass versus conventional operations.

Table 3.4. Percentage contribution of total estimated erosion by operational category.

Operational category	Overall (%)	Biomass (%)	SE	Conventional (%)	SE	p-value
Roads	11.74	7.52	4.46	15.96	6.80	0.3135
Decks	7.51	6.66	1.66	8.37	3.50	0.6640
Skid trails	43.25	48.62	8.4	37.88	4.97	0.2858
SMZ (partially harvested)	0.41	0.11	0.07	0.71	0.35	0.1146
Stream crossings	1.45	2.40	2.30	0.50	0.34	0.4255
Clearcut harvest area	35.25	33.91	6.31	36.58	6.53	0.7721
Fire lines	0.39	0.78	-	-	-	-
Overall	100.00	100.00		100.00		

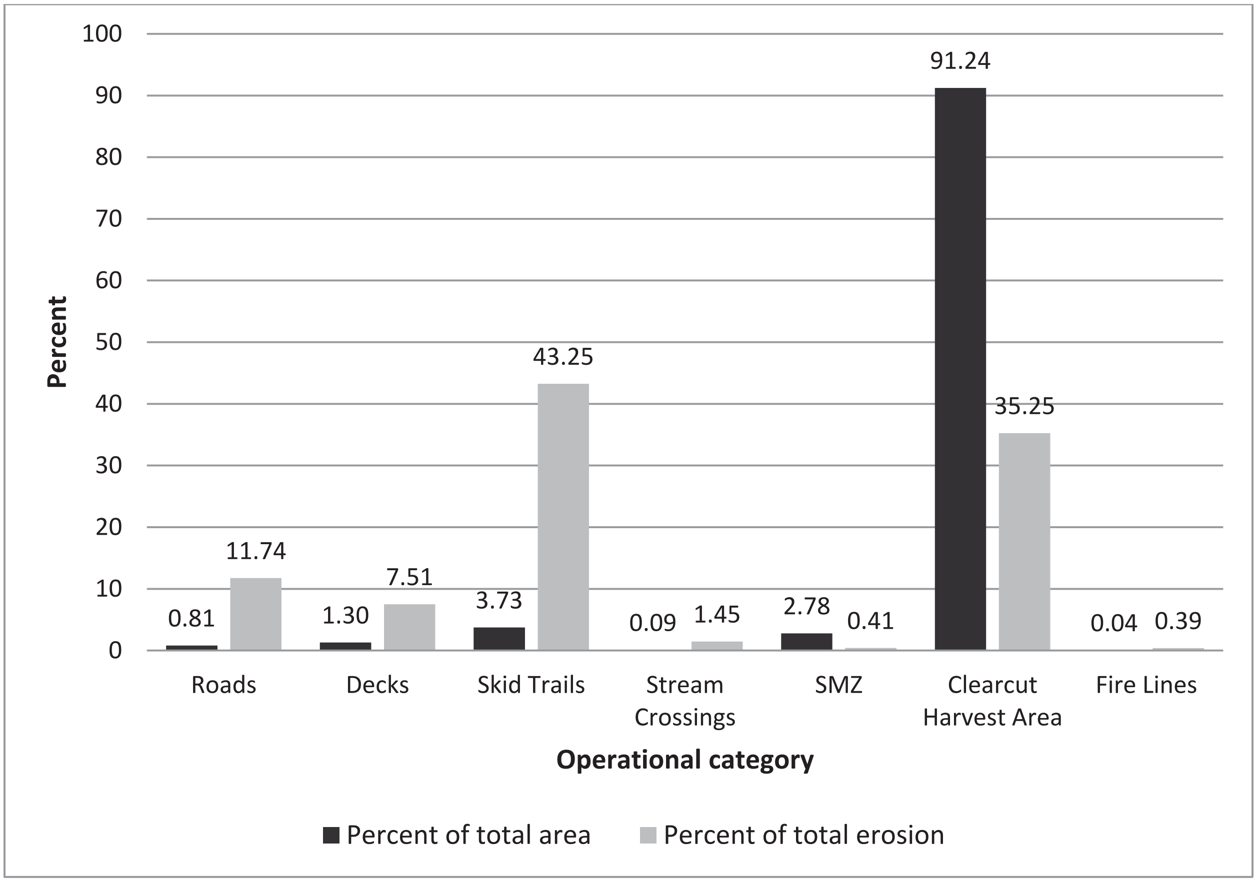

Figure 3.4. Percentage of total harvest area occupied by each operational category and percentage contribution to total erosion by each operational category for combined biomass and conventional harvests (N=20).

3.4.7 BMP Implementation Audit Scores

BMP implementation audits were performed by trained VDOF auditors. Implementation scores were calculated for each logging related BMP category and an overall BMP score was calculated. Audit results by category and overall scores were calculated for biomass versus conventional operations (Table 3.5). No significant differences were observed for any of the BMP categories or for the overall scores.

Table 3.5. BMP audit scores by category for biomass (n=10) versus conventional harvests (n=10) in the Piedmont of Virginia.

	Biomass			Conventional			
BMP Category	n	Percent "Yes"	SE	n	Percent "Yes"	SE	p-value
Roads	5	75.42	9.14	8	79.55	8.30	0.7525
Decks	10	93.61	3.31	10	82.62	5.16	0.0899
Crossings	3	91.67	8.33	2	76.39	1.39	0.2524
SMZs	9	82.35	8.38	8	97.22	7.86	0.1304
Planning	10	78.33	8.98	10	80.00	8.16	0.8923
Skidding	10	81.50	6.09	10	71.09	8.01	0.3142
Overall BMP Score	10	85.23	4.76	10	81.25	5.54	0.5930

3.4.8 Comparison of BMP Audit Scores and Estimated Erosion Rates

The VDOF BMP audit examines all applicable BMPs on the harvest site and evaluates site conditions to determine if BMPs were implemented as suggested in existing guidelines. The BMP audit results in a score which represents the percent of all applicable BMPs appropriately implemented. Research projects have compared harvests sites with BMPs and without BMPs and concluded that BMPs protect water quality (e.g., Kochendorfer et al. 1997, Arthur et al. 1998, Wynn et al. 2000), yet few studies have linked BMP compliance level with quantifiable indices of water quality. Although BMPs are designed to prevent erosion and resulting sedimentation, the BMP audit provides no direct quantification of the amount of erosion potentially occurring on the site. Conversely, the USLE erosion estimate provides no quantification of whether or not appropriate BMPs were installed to prevent erosion and sedimentation, but does estimate potential erosion.

By comparing the BMP audits with USLE-Forest potential erosion estimates, the relative relationship between BMP compliance and potential erosion can be evaluated. Simple linear regression was used to relate potential erosion based on a BMP audit score. Data for biomass and conventional tracts were combined for regression analysis. The BMP implementation scores were significant predictors of overall tract erosion rates (Figure 3.5). The linear fit for overall weighted tract erosion (tons ac^{-1} yr^{-1}) = 5.2590797 – 0.0539565 * BMP Implementation Score ($R^2 = 0.7994$, $F = 71.7375$, $p < 0.0001$). These data illustrate that effective implementation of BMPs for timber harvesting reduces potential soil erosion. Sites with low BMP implementation scores typically resulted in more potential erosion from the site. With these data it is important to note that potential erosion and sedimentation are not necessarily synonymous. Lakel et al. (2010) evaluated harvested watersheds in the Piedmont of Virginia and found that between 86 and 97% of total potential erosion was trapped before it entered the stream. Ward and Jackson (2004) found a sediment delivery ratio of approximately 25% on site prepared Piedmont sites.

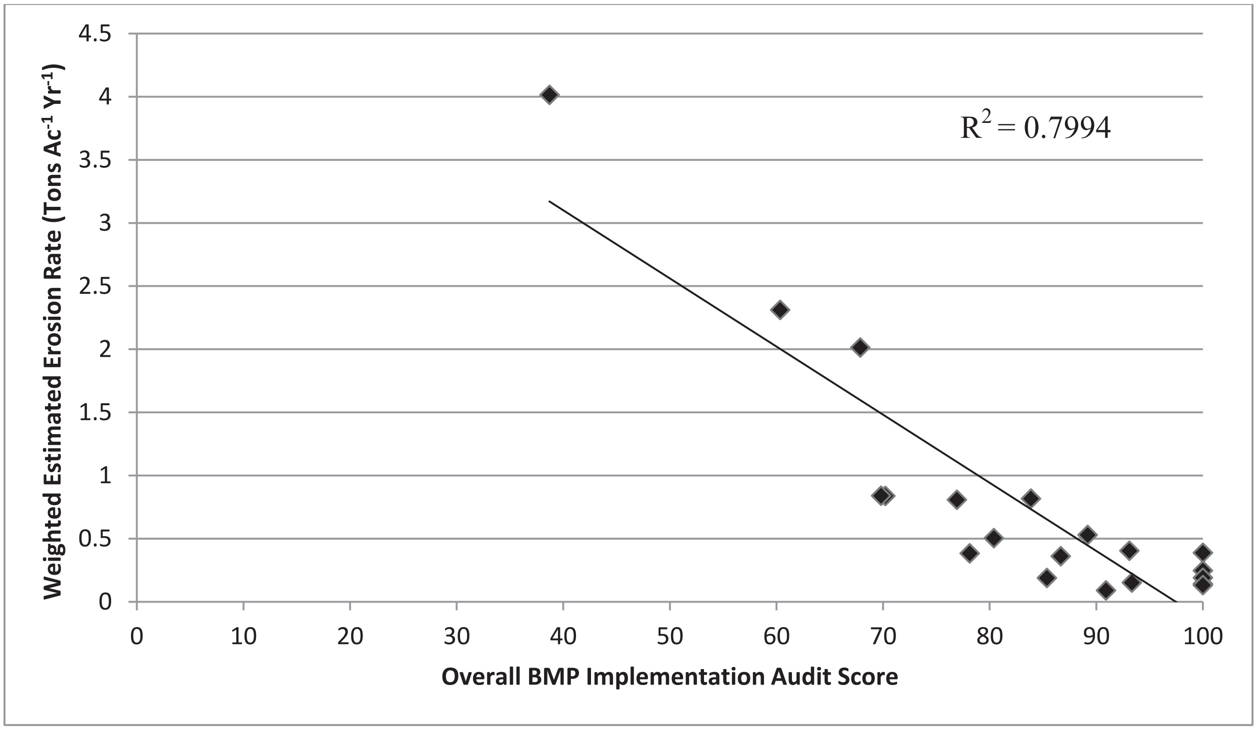

Figure 3.5. Overall BMP implementation score for biomass and conventional sites combined (N=20) as a predictor of estimated erosion rate in tons ac^{-1} yr^{-1}.

3.5 Conclusions

This study estimated potential erosion rates and evaluated ground cover conditions for existing biomass and conventional harvesting operations in the Piedmont of Virginia and found few significant differences. Overall, sites had relatively low potential erosion rates; the overall weighted average erosion rate was 0.8 tons ac^{-1} yr^{-1}. Potential erosion estimates represented a fixed period of time and site condition. Site evaluations occurred approximately six months after harvest completion, and erosion rates would be expected to decrease over time unless the site was disturbed again.

Sites harvested by integrated biomass harvesting operations had significantly less heavy logging slash/woody debris and piles yet still had heavy slash occupying over 12% of the total harvest area. This indicates that while some heavy slash is utilized for fuel, there are still substantial amounts of logging slash and downed woody debris left on site because they are not currently operationally feasible to harvest for energy. Although biomass harvest sites had less ground cover from heavy slash and piles, there was no significant difference in the percent of area covered by light slash between biomass and conventional operations. Apparently, as trees were harvested and small branches were broken, these smaller residues are left on site because they are not operationally feasible to utilize for fuel.

This study highlighted the importance of properly implementing BMPs on roads, decks, skid trails, and stream crossings. As also noted by previous studies (e.g., Aust and Blinn 2004, Lakel et al. 2010, Wear et al. 2013), these areas contribute a disproportionate amount of erosion relative to their total area. No differences were observed related to the use of slash as a BMP ($p=0.6056$). However, for harvesting operations utilizing logging residues for biomass energy, consideration should be given to residue management during harvest planning. As harvests are underway, operators should evaluate the need for utilizing slash to stabilize bare soil areas on decks, skid trails, and stream crossings. In situations with a greater need to utilize residues as a BMP, careful planning can help to maintain adequate residues for stabilization of critical areas. Adequate planning for the use of logging residues can minimize the need to use other potentially more costly methods of soil stabilization such as using seed and mulch, silt fencing, or other methods to meet BMP requirements.

Additional research could focus on expanding the scope of these findings to include a larger sample of operations, and to include harvesting operations in additional regions (e.g., coastal plain and mountains). This project estimated erosion rates, however, more intensive data collection would be required to measure actual erosion rates and delivery of sediment to streams.

This research focused on estimation of erosion rates, therefore harvest area ground cover was a primary metric. Residual woody debris volume, mass, or features for wildlife habitat were not considered and would require a different approach to quantify.

This research found no significant differences in estimated erosion rates between biomass and conventional harvesting operations in the Piedmont of Virginia. Additionally this research demonstrated that the overall rate of BMP implementation is correlated to estimated erosion rates. Therefore, when effectively implemented, existing BMPs appear adequate to reduce erosion and protect water quality on biomass harvesting operations where logging residues are utilized for energy.

Biomass harvesting operations are varied (Chapter 2) and markets and utilization standards can change, so additional monitoring of BMP implementation would be beneficial to ensure that existing BMPs are adequate to protect water quality when utilizing logging residues for energy. A broader statewide evaluation of BMP implementation on biomass harvesting sites compared to conventional operations would help to further evaluate BMP implementation on biomass harvesting operations and determine if specific additional considerations may be necessary when harvesting woody biomass for energy.

3.6 References

Anderson, C.J. and B.G. Lockaby. 2011. The effectiveness of forestry Best Management Practices for sediment control in the southeastern United States: A literature review. Southern Journal of Applied Forestry 35(4):170-177.

Arthur, M. A., G.B. Coltharp, and D.L. Brown. 1998. Effects of best management practices on forest streamwater quality in Eastern Kentucky. Journal of American Water Resources Association 34(3):481–495.

Aust, W.M. and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, & Soil Pollution: Focus 4(1):5-36.

Aust, W. M., M.B. Carroll, M.C. Bolding, and C.A. Dolloff. 2011. Operational forest stream crossings effects on water quality in the Virginia Piedmont. Southern Journal of Applied Forestry 35(3):123-130.

Christopher, E.A. and R. Visser. 2007. Methodology for evaluating post harvest erosion risk for the protection of water quality. New Zealand Journal of Forestry 52(2):20-25.

Croke, J., and M. Nethery. Modeling runoff and soil erosion in logged forests: Scope and application of some existing models. Catena 67(1):35-49.

Dissmeyer, G.E. and Foster, G.R. 1984. A guide for predicting sheet and rill erosion on forestland. USDA For. Ser. Gen. Tech. Publ. R8-TP 6.

Dominion Virginia Power. 2011. Dominion Virginia Power plans to convert three coal-fired stations to renewable biomass. Dominion press release. April 1, 2011. Available online at http://dom.mediaroom.com/index.php?s=43&item=976 ; last accessed on June 8, 2013.

Eisenbies, M.H., J.A. Burger, W.M. Aust, and S.C. Patterson. 2005. Soil physical disturbance and logging residue effects on soil productivity in five-year-old pine plantations. Soil Science Society of America Journal 69(6):1833-1843.

Forest Stewards Guild Southeast Biomass Working Group, 2012. Forest biomass harvesting and retention guidelines for the southeast. Available online at www.forestguild.org/publications/research/2012/FG_Biomass_Guidelines_SE.pdf ; last accessed June 8, 2013.

Groover, M. C. 2011. A Comparison of Chipper Productivity, Chip Characteristics, and Nutrient Removals from Two Woody Biomass Harvesting Treatments. Master of Science Thesis. Virginia Tech. Blacksburg Virginia. http://scholar.lib.vt.edu/theses/available/etd-12202011-070135/

Hall, J.P. 2002. Sustainable production of forest biomass for energy. The Forestry Chronicle 78(3):391-396.

Hood, S. M., S.M. Zedaker, W.M. Aust, and D.W. Smith. 2002. Universal Soil Loss Equation (USLE)-Predicted soil loss for harvesting regimes in Appalachian hardwoods. Northern Journal of Applied Forestry 19(2):53–58.

Ice, G., M. McBroom, and P. Schweitzer. 2010. A review of best management practices for forest watershed biomass harvests with an emphasis on recommendations for leaving residual wood onsite. Center for Bioenergy Sustainability, Oak Ridge National Laboratory, Oak Ridge TN. 5 p.

InForest. 2013. InForest, available online at http://inforest.frec.vt.edu/. Last accessed February 21, 2013.

Janowiak, M.K. and C.R. Webster. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry 108(1):16-23.

JMP Version 10.0. 2012. SAS Institute Inc., Cary, NC, 1989-2012.

Kochenderfer, J. N., P.J. Edwards, and F. Wood. 1997. Hydrologic impacts of logging an Appalachian watershed using West Virginia's best management practices. Northern Journal of Applied Forestry 14(4):207–218.

Lakel, W. A., W.M. Aust, M.C. Bolding, C.A. Dolloff, P. Keyser and R. Feldt. 2010. Sediment trapping by streamside management zones of various widths after forest harvest and site preparation. Forest Science 56(6):541-551.

Lakel, W. and M. Poirot. 2012. Silvicultural best management practices implementation monitoring for Virginia - 2011. Virginia Department of Forestry. Charlottesville, VA. 8 p.

MeadWestvaco, 2011. MWV to improve power infrastructure at Covington, VA mill. Press release from MeadWestvaco Corporation. June 27, 2011. Richmond Virginia. Available online at http://www.meadwestvaco.com/mwv/groups/content/@corp/@newsevts/documents/document/mwv031745.pdf ; last accessed June 8, 2013.

National Council for Air and Stream Improvement, Inc. (NCASI). 2009. Compendium of Forestry Best Management Practices for Controlling Nonpoint Source Pollution in North America. Technical Bulletin No. 0966. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc. 208 p.

Northern Virginia Electric Cooperative. 2011. Biomass generation plant approved. NOVEC What's Current. September 2011. Available online at http://www.novec.com/books/WC9-11/WC9-11.pdf ; last accessed June 8, 2013.

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. Journal of Soil and Water Conservation 67(4):300-310.

Shepard, J.P. 2006. Water quality protection in bioenergy production: the US system of forestry best management practices. Biomass and Bioenergy 30(4):378-384.

USDA Natural Resources Conservation Service (NRCS) Web Soil Survey. 2013. Available online at http://websoilsurvey.nrcs.usda.gov/app/ Last accessed February 21, 2013.

U.S. Energy Information Administration (EIA). 2012. Annual energy outlook 2012. DOE/EIA-0383(2012) June 2012. Available online at http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf Last accessed on June 8, 2013.

Virginia Department of Forestry. 2012. 2012 State of the Forest. Virginia Department of Forestry. Charlottesville, VA. 21 p.

Virginia Department of Forestry. 2011. Virginia's Forestry Best Management Practices For Water Quality Technical Manual. 5th Edition. Virginia Department of Forestry. Charlottesville, VA. 165 p.

Ward, J.M., and C.R. Jackson. 2004. Sediment trapping within forestry streamside management zones: Georgia Piedmont, USA. Journal of the American Water Resources Association 40(6):1421–1431.

Wade, C. R., M.C. Bolding, W.M. Aust, and W.A. Lakel. 2012. Comparison of five erosion control techniques for bladed skid trails in Virginia. Southern Journal of Applied Forestry 36(4):191-197.

Wear, L.R., W.M. Aust, M.C. Bolding, B.D. Strahm, and C. A. Dolloff. 2013. Effectiveness of best management practices for sediment reduction at operational forest stream crossings. Forest Ecology and Management 289:551-561.

Worrell, W.C., M.C. Bolding, and W.M. Aust. 2011. Potential soil erosion following skyline yarding versus tracked skidding on bladed trails in the Appalachian region of Virginia. Southern Journal of Applied Forestry 35(3):131-135.

Wynn, T. M., S. Mostaghimi, J.W. Frazee, P.W. McClellan, R.M. Shaffer, and W.M. Aust. 2000. Effects of forest harvesting best management practices on surface water quality in the Virginia coastal plain. Transactions of the American Society of Agricultural Engineers 43(4):927–936.

Yoho, N.S., 1980. Forest management and sediment production in the South – A review. Southern Journal of Applied Forestry 4(1):27-36.

4.0 IMPLEMENTATION OF FORESTRY BEST MANAGEMENT PRACTICES ON BIOMASS AND CONVENTIONAL HARVESTING OPERATIONS

4.1 Abstract

Logging residues often provide ground cover and may be utilized as a Best Management Practice (BMP) for stabilizing soil on forest harvesting operations. As utilization of woody biomass for energy has increased concern has developed regarding the potential lack of residues for implementing BMPs. The Virginia Department of Forestry (VDOF) inspects all logging operations for BMP compliance related to water quality and randomly selects a portion of harvests for more intensive audits to evaluate implementation trends. Recent audits have differentiated biomass and conventional harvesting operations. The VDOF BMP audit process intensively evaluates implementation of seven logging related categories of BMPs (84 specific BMPs) on 240 harvest sites per year. This research analyzed 3 years of audit data (2010 – 2012) to quantify differences in BMP implementation scores for biomass harvesting operations. Among 720 tracts, 97 were biomass harvests with 88 of those 97 occurring in the Piedmont region. Within the seven logging related BMP categories, only SMZs had significant differences between biomass (83.1%) and conventional harvests (91.4%) (p=0.0010) in the Piedmont region. Specific BMP areas where biomass harvesting operations had lower implementation scores were generally not related to a lack of slash available for implementing BMPs, but rather were from a lack of appropriate SMZs, over harvesting within SMZs, or inadequate construction of roads, skid trails and stream crossings. With appropriate attention to harvest planning and implementation, existing BMPs appear adequate to protect water quality on biomass harvesting operations in the Virginia Piedmont when appropriately utilized.

4.2 Introduction

Utilization of biomass for energy is increasing throughout the US (US EIA 2012). In Virginia, as in many other areas, there are multiple biomass energy facilities currently under construction and are nearing completion (e.g., MeadWestvaco 2011, Dominion Virginia Power 2011, Northern VA Electric Cooperative 2013). Much of the feedstock for these energy facilities is anticipated to come from logging residues (Conrad et al. 2010). Therefore, utilization of woody biomass from logging residues including limbs, tops, and otherwise non-merchantable trees or portions of trees is expected to increase rapidly. Integrated biomass harvesting operations which harvest roundwood and biomass for energy are expected to comprise a larger percentage of future forest harvests. As more intensive biomass harvesting occurs there have been concerns related to the impacts of biomass harvesting (Hall 2002, Shepard 2006, Janowiak and Webster 2010, Abbas et al. 2011).

Whole tree harvesting has not typically been considered a substantial risk to water quality (Martin and Hornbeck 1994) and existing BMPs for water quality are generally considered adequate for protecting water quality on biomass harvesting operations (Shepard 2006). 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. Harvesting guidelines often address non-water quality related issues such as wildlife habitat or nutrient removals (e.g., Forest Stewards Guild 2012).

Forest harvesting operations have the potential to negatively impact water quality (Yoho 1980, Kochenderfer et al. 1997, Aust and Blinn 2004, Anderson and Lockaby 2011a). Following the Federal Water Pollution Control Act of 1972 and subsequent amendments, states throughout the US have adopted voluntary or mandatory BMP guidelines for protecting water quality during timber harvests (Aust and Blinn 2004, NCASI 2009). Individual states have been charged with monitoring BMP implementation rates for forest harvesting operations (Ice et al. 2010). Research regarding the use of forestry BMPs has supported their use for protecting water quality (Aust and Blinn 2004, NCASI 2009, Lakel et al. 2010, Anderson and Lockaby 2011b, Aust et al. 2011).

The Virginia Department of Forestry has not developed specific BMPs for biomass harvesting; however, the current BMP manual (VDOF 2011) 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 (VDOF 2011).

BMPs for protecting water quality often involve soil protective measures such as utilizing logging residues as a BMP for protecting water quality (e.g., VDOF 2011, Wade et al. 2012, Wear et al. 2013). Integrated biomass harvesting operations utilize logging residues for energy; therefore, 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 and skid trails. The addition of chippers to integrated harvesting operations might require larger decks to accommodate the chipper and chip vans required for transporting biomass off site.

The Virginia Department of Forestry has an active BMP monitoring program to evaluate statewide implementation of BMPs (Lakel and Poirot 2013). Beginning in 2010, the VDOF began collecting data on biomass harvesting during harvest inspections. 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 (Bolding et al. 2010).

The increased biomass harvesting activity within the region and the recent inclusion of biomass data within 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 BMP implementation 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 BMP implementation rates on biomass harvest sites indicate the need for additional specific BMP recommendations for biomass harvests?

4.3 Methods

The Virginia Department of Forestry (VDOF) water quality program requires all logging businesses to notify the VDOF within three days of 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) (VDOF, 2011). After harvest completion VDOF personnel conduct a final tract inspection. Annually, these water quality inspections are completed on over 5000 timber harvests throughout Virginia (VDOF 2012). 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 out 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 (Lakel and Poirot 2013). Selected tracts are evaluated based on BMP implementation related to specific BMPs from the VDOF BMP Technical Manual (2011). The VDOF BMP auditing and reporting methods are based upon methods outlined by the Southern Group of State foresters (SGSF 2007). The complete audit includes ten 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 7 categories with 84 questions which consist of (number of questions):

> Roads (19), Decks (9), Stream or Wetland Crossings (19), Streamside Management Zones (SMZs) (13), Wetlands (8), Harvest Planning (3), Skidding (13).

Data collected during VDOF BMP audits also include information on the location and site characteristics and whether or not biomass harvesting occurred. Tracts were classified as biomass harvest 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 personnel across Virginia. Every VDOF auditor attends regular training to maintain consistency in audit scoring across the state (Lakel and Poirot 2013). Audit scores are reported as the percent of applicable BMPs which received a “Yes” on the audit. This percent represents the proportion of applicable audit questions that were appropriately implemented by the operator (Lakel and Poirot 2013). 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 fully. A more detailed analysis was performed to compare implementation on each of the specific questions in the BMP audit for logging related BMPs.

VDOF BMP audit data from three years were compiled and reconfigured into a single dataset and analyzed using JMP version 10 (JMP 2012). Each tract received an average implementation score for each of the BMP categories based on methods outlined by Lakel and Poirot (2013). The score for each category was calculated as the percent 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 (Figure 4.1) based upon US Forest Service classification of physiographic regions by county (Cooper and Becker 2009). 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. T-tests were used to test the null hypothesis that population means for biomass and conventional harvests are equal versus the alternative hypothesis that the means are different (Ott and Longnecker 2010). Each of the 84 individual questions were 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 by 2 contingency table and were tested using a Chi square test (Ott and Longnecker 2010). Tests were conducted at the alpha ≤ 0.05 level using JMP (JMP 2012).

4.4 Results

Biomass harvests were conducted on 97 of the 720 BMP audits performed over three years (Table 4.1). 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 (Figure 4.1). 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 (Chapter 2).

Table 4.1. 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

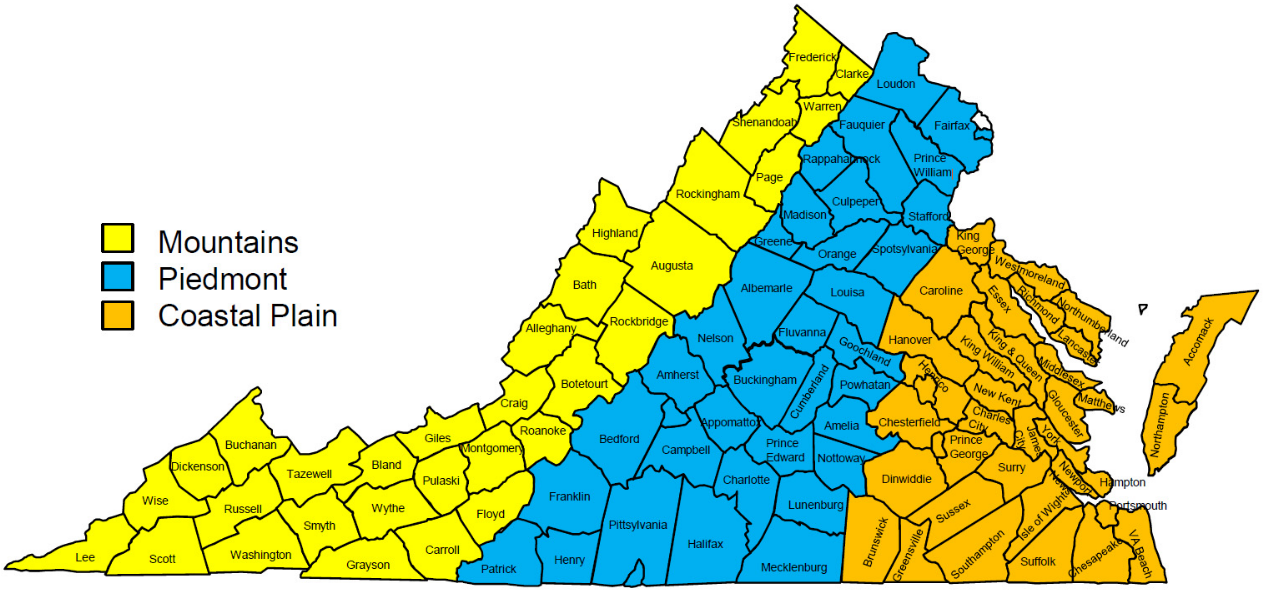

Figure 4.1. Classification of physiographic provinces by county.

4.4.1 BMP Implementation by Category and Overall

There were few biomass harvests observed in the Mountain and Coastal Plain regions, therefore comparisons of BMP implementation on biomass and conventional harvests was limited to the Piedmont region. Comparisons of BMP implementation percentages by category (Table 4.2) indicated that biomass harvests had significantly lower BMP implementation scores for the SMZs category (p=0.0010).

Table 4.2. BMP audit scores by category for biomass (n=88) versus conventional harvests (n=284) over a three year period (2010-2012) in the Piedmont of Virginia.

	Biomass			Conventional			
BMP Category	n	Percent "Yes"	SE	n	Percent "Yes"	SE	p-value
Roads	84	77.61	2.42	259	81.05	1.24	0.1832
Decks	88	92.66	1.36	284	91.64	0.83	0.5450
Crossings	39	90.21	3.03	123	90.36	1.60	0.9626
SMZs	73	83.05	2.67	224	91.35	1.13	0.0010
Wetlands	2	100.00	0	0	-	-	-
Planning	87	86.78	2.39	283	82.80	1.44	0.1731
Skidding	88	83.72	2.00	280	85.69	1.14	0.3962
Overall BMP Score	88	83.99	1.44	284	86.66	0.70	0.0739

4.4.2 Potential Deficiencies if Adequate Slash was not Available for BMP Implementation

The complete lists of VDOF BMP audit questions are provided in Appendices A-G. The audits examined multiple aspects of BMP implementation on forest harvesting sites. 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. Table 4.3 provides seven of the 84 questions that might be expected to differ between biomass and conventional operations. These differences could be expected based on availability of logging residues to protect disturbed areas or because biomass harvesting operations might require additional space to accommodate additional equipment and more intensive harvesting practices. Only one of the seven questions that could be expected to relate to availability of logging residues for BMPs 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 4.3. BMP Questions that might be expected to differ between conventional and biomass based on availability of logging residues or intensity of harvesting operation.

BMP Question	Biomass n	% Yes	Conventional n	% Yes	p-value
SMZ 10 - Was exposed soil in the SMZ revegetated or covered with organic materials?	20	85.00	50	92	0.3778
Skidding Q7 - Were brush mats used to stabilize trails and prevent erosion where needed?	70	74.29	223	69.51	0.4437
Crossings Q17 - Are stream banks and approaches re-claimed 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

4.4.3 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 4.4). These differences related primarily to SMZs as well as road and skid trail layout. There were five SMZ related questions that indicated lower SMZ implementation scores for biomass harvests because the SMZ width was insufficient, inadequate proportions of trees remained in the SMZ, the SMZ was partially clearcut, or sediment entered the stream due to inadequate SMZs.

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.

Stream crossings were the final category where significantly lower implementation on biomass harvests occurred. 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 were 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.

Table 4.4. VDOF BMP audit questions with significant differences at the $\alpha \leq 0.05$ level between biomass and conventional harvests.

BMP Question	Biomass n	% Yes	Conventional n	% 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

4.5 Discussion

Due to well established markets for woody biomass for over 15 years 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 (Bolding et al. 2010). 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 which incorporate logging residues for protection of disturbed soil areas. However, this analysis revealed few significant differences between conventional and biomass harvesting operations. However, 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. It is important to note that existing BMP recommendations already address these issues and that better compliance would have minimized problems.

The analysis of all BMP audit questions indicates that the significant differences between biomass and conventional harvests were generally not related to the availability of logging slash 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 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 the stream (e.g., Taylor et al. 1998, Witmer at al. 2009, Aust et al. 2011, Wade et al. 2012, Wear et al. 2013). Similarly, SMZs are important BMPs because they are the last major BMP that has the potential to trap sediment before it can enter streams (Ward and Jackson 2004, Lakel et al. 2010).

Analysis of the BMP 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 that 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 (2008) found BMP application and effectiveness was higher on industry owned lands than on private lands and was higher when a professional forester was involved. Loggers also report that many landowners often require harvest of logging residues (Chapter 2). 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 not specifically related to biomass harvesting operations, Vanbrakle et al. (2013) 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.

4.6 Conclusions

Although hypothesized, lack of residues for protecting disturbed areas and needs for additional area required to accommodate biomass harvesting equipment did not appear to reduce BMP implementation on biomass harvests. However, BMP implementation related to SMZs was significantly lower for biomass (83.05%) versus conventional harvests (91.35%) (p= 0.0010). Additional differences on specific BMP questions related 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 appear to result from operational decisions made by harvesting contractors, foresters, or landowners. These decisions related to installation of roads, skid trails, 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 BMPs appear adequate to protect water quality on biomass harvesting operations when appropriately utilized.

Logging business owners and foresters involved in harvest planning for biomass harvests should be aware that there could be a greater likelihood for overharvesting of SMZs. SMZs should be clearly identified prior to harvest and acceptable harvesting levels within the SMZ should be clearly defined. Additionally, during harvest planning, roads and skid trails should be appropriately located, installed, and then closed after harvest completion. Additional attention should be focused on ensuring that roads and skid trails have appropriately installed drainage structures to avoid channelized flow. 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. Overall, residue removal on biomass harvest sites does not appear to cause BMP concerns or require additional water quality BMPs. However, it appears that biomass harvesting operations need to pay additional attention to existing BMPs related to SMZs, roads, skid trails, and crossings. When adequately installed, existing BMPs should be effective at protecting water quality on biomass harvesting operations.

4.7 References

Anderson, C. J., and B.G. Lockaby. 2011a. Research gaps related to forest management and stream sediment in the United States. Environmental Management 47(2):303-313.

Anderson, C.J. and B.G. Lockaby. 2011b. The effectiveness of forestry Best Management Practices for sediment control in the southeastern United States: A literature review. Southern Journal of Applied Forestry 35(4):170 177.

Abbas, D., D. Current, M. Phillips, R. Rossman, H. Hoganson, and K.N. Brooks. 2011. Guidelines for harvesting forest biomass for energy: a synthesis of environmental considerations. Biomass and Bioenergy 35(11):4538-4546.

Aust, W.M. and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, & Soil Pollution: Focus 4(1):5-36.

Aust, W. M., M.B. Carroll, M.C. Bolding, and C.A. Dolloff. 2011. Operational forest stream crossings effects on water quality in the Virginia Piedmont. Southern Journal of Applied Forestry 35(3):123-130.

Bolding, M. C., S.M. Barrett, J.F. Munsell, and M.C. Groover. 2010. Characteristics of Virginia’s logging businesses in a changing timber market. Forest Products Journal 60(1):86-93.

Conrad, J. L., M.C. Bolding, W.M. Aust, and R.L. Smith. 2010. Wood-to-energy expansion, forest ownership changes, and mill closure: Consequences for US South's wood supply chain. Forest Policy and Economics 12(6):399-406.

Cooper, J. A. and C. W. Becker. 2009. Virginia's timber industry - An assessment of timber product output and use, 2007. Resource Bulletin SRS-155. USDA Forest Service, Southern Research Station, Asheville, North Carolina. 33 p.

Dominion Virginia Power. 2011. Dominion Virginia Power plans to convert three coal-fired stations to renewable biomass. Dominion press release. April 1, 2011. Available online at http://dom.mediaroom.com/index.php?s=43&item=976 ; last accessed June 8, 2013.

Forest Stewards Guild: Southeast Biomass Working Group, 2012. Forest biomass harvesting and retention guidelines for the southeast. Available online at www.forestguild.org/publications/research/2012/FG_Biomass_Guidelines_SE.pdf ; last accessed June 8, 2013.

Hall, J.P. 2002. Sustainable production of forest biomass for energy. The Forestry Chronicle 78(3):391-396.

Ice, G. G., E. Schilling, and J. Vowell. 2010. Trends for forestry best management practices implementation. Journal of Forestry 108(6):267-273.

Janowiak, M.K. and C.R. Webster. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry 108(1):16-23.

JMP Version 10.0. 2012. SAS Institute Inc., Cary, NC, 1989-2012.

Kochenderfer, J. N., P.J. Edwards, and F. Wood. 1997. Hydrologic impacts of logging an Appalachian watershed using West Virginia's best management practices. Northern Journal of Applied Forestry 14(4):207–218.

Lakel, W. A., W.M. Aust, M.C. Bolding, C.A. Dolloff, P. Keyser and R. Feldt. 2010. Sediment trapping by streamside management zones of various widths after forest harvest and site preparation. Forest Science 56(6):541-551.

Lakel, W. and M. Poirot. 2013. Silvicultural best management practices implementation monitoring for Virginia - 2012. Virginia Department of Forestry. Charlottesville, VA. 10 p.

Martin, C. W., and J.W. Hornbeck. 1994. Logging in New England need not cause sedimentation of streams. Northern Journal of Applied Forestry 11(1):17-23.

MeadWestvaco, 2011. MWV to improve power infrastructure at Covington, VA mill. Press release from MeadWestvaco Corporation. June 27, 2011. Richmond Virginia. Available online at http://www.meadwestvaco.com/mwv/groups/content/@corp/@newsevts/documents/document/mwv031745.pdf ; last accessed June 8, 2013.

National Council for Air and Stream Improvement, Inc. (NCASI). 2009. Compendium of Forestry Best Management Practices for Controlling Nonpoint Source Pollution in North America. Technical Bulletin No. 0966. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc. 208 p.

Northern Virginia Electric Cooperative. 2013. Halifax County Biomass Plant. Available online at https://www.novec.com/About_NOVEC/SBE.cfm ; last accessed June 8, 2013.

Ott, L., and M. Longnecker. 2010. An introduction to statistical methods and data analysis. Sixth Edition. Belmont, CA: Brooks/Cole Cengage Learning. 1273 p.

Shepard, J.P. 2006. Water quality protection in Bioenergy production: the US system of forestry best management practices. Biomass and Bioenergy 30(4):378-384.

Southern Group of State Foresters (SGSF) 2007. Silviculture Best Management Practices Implementation Monitoring. A framework for State Agencies. Available online at http://www.southernforests.org/publications/SGSF%20Regional%20BMP%20Framework%20Protocol%20publication_2007.pdf/at_download/file; last accessed March 26, 2013.

Taylor, S.E., R.B. Rummer, K.H. Yoo, R.A. Welch, and J.D. Thompson. (1999). What We Know--and Don't Know--About Water Quality at Stream Crossings. Journal of Forestry, 97(8):12-17.

U.S. Energy Information Administration (EIA). 2012. Annual energy outlook 2012. DOE/EIA-0383(2012) June 2012. Available online at http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf Last accessed June 8, 2013.

VanBrakle, J.D., R.H. Germain, J.F. Munsell, and S.V. Stehman. 2013. Do forest management plans increase Best Management Practices implementation on family forests? A formative evaluation in the New York City Watershed. Journal of Forestry 111(2):108-114.

Virginia Department of Forestry. 2011. Virginia’s Forestry Best Management Practices for Water Quality Technical Manual. 5th Edition. Virginia Department of Forestry. Charlottesville, VA. 165 p.

Virginia Department of Forestry. 2012. 2012 State of the Forest. Virginia Department of Forestry. Charlottesville, VA. 21 p.

Wang, J.X. and W. A. Goff. 2008. Application and effectiveness of forestry best management practices in West Virginia. Northern Journal of Applied Forestry 25(1):32-37.

Ward, J.M., and C.R. Jackson. 2004. Sediment trapping within forestry streamside management zones: Georgia Piedmont, USA. Journal of the American Water Resources Association 40(6):1421–1431.

Wade, C. R., M.C. Bolding, W.M. Aust, and W.A. Lakel. 2012. Comparison of five erosion control techniques for bladed skid trails in Virginia. Southern Journal of Applied Forestry 36(4):191-197.

Wear, L.R., W.M. Aust, M.C. Bolding, B.D. Strahm, and C. A. Dolloff. 2013. Effectiveness of best management practices for sediment reduction at operational forest stream crossings. Forest Ecology and Management 289:551-561.

Witmer, P.L., P.M. Stewart and C.K. Metcalf. Development and use of a sedimentation risk index for unpaved road-stream crossings in the Choctawhatchee watershed. Journal of American Water Resources Association 45(3):734–747.

Yoho, N.S. 1980. Forest management and sediment production in the South – A review. Southern Journal of Applied Forestry 4(1):27-36.

5.0 SUMMARY AND CONCLUSIONS

The overall purpose of this research was to characterize existing biomass harvesting operations in the Virginia Piedmont region and to evaluate potential impacts of increases in biomass utilization. Biomass energy markets are expanding rapidly in Virginia as evidenced by the six new biomass energy facilities that are nearly complete. Expanding markets indicate that there will be a substantial increase in utilization of biomass for energy in Virginia as well as other regions. This relatively rapid increase in utilization of biomass for energy will require additional biomass that could be provided by utilizing logging residues on more sites throughout the region. A study of existing logging business already involved in biomass harvesting provided information useful to logging business owners and procurement personnel adapting to new markets. While markets, harvesting operations, and stand conditions differ by region, characterizing adaptations among existing biomass harvesting operations provided useful information.

Increasing the number of biomass harvesting operations and the geographic region where biomass harvesting occurs will not only impact the logging businesses, but has the potential to change post-harvest site conditions. As the extent of biomass harvesting increases, concerns have been raised related to biomass harvesting (Janowiak and Webster 2010). Concerns related to soil erosion and water quality are a primary concern with state forest water quality agencies such as the Virginia Department of Forestry (VDOF). Potential water quality degradation related to biomass harvesting is of concern to water quality enforcement staff. Additional information related to potential erosion or implementation of BMPs on biomass harvesting operations would also be beneficial to industry foresters, logging business owners, logger training programs, and others involved in forest harvesting operations.

This chapter summarizes results of the three related studies and provides conclusions related to the impacts of integrating biomass harvesting in forest harvesting operations. Conclusions are discussed in more detail in previous chapters related to characteristics of biomass harvesting operations, the potential for increased soil erosion on biomass harvest sites, and BMP implementation on biomass harvesting sites.

5.1 Biomass Harvesting and Logging Businesses

As consumption of biomass for energy increases, the existing wood supply chain will likely emerge as the largest supplier of biomass to new industries. Mill residues from within the existing wood supply chain will be a component of biomass used for energy production, however this supply is influenced by other markets and quantities of materials manufactured at the primary mill. As demand for wood energy exceeds the supply of readily available mill residues, underutilized sources of biomass for energy will be sought. Facilities could elect to utilize higher cost roundwood products for energy, but it seems more likely that logging residues from ongoing harvesting operations will be a primary source of biomass for energy. Generally, the most cost effective and operationally feasible method of utilizing logging residues for energy has been shown to be one pass, integrated, biomass harvesting operations using whole tree chippers to process residues at the landing (Miller et al. 1987, Stokes et al. 1989, Baker et al. 2010). The willingness and ability of the existing logging workforce to utilize logging residues for energy will be important for developing a supply network that can harvest and deliver biomass for energy without simply harvesting additional roundwood.

This research found that biomass harvesting operations typically integrated biomass harvesting into existing conventional operations with roundwood and biomass produced at the same time on 98% of operations. Integrated biomass harvesting operations occurred across a wide variety of production levels and harvest types. Sixty-one percent of operations utilized a single loader for roundwood and fuel, and loggers frequently used older chippers with an average chipper age of 12.5 years. Loggers generally reported that biomass harvesting was a good fit for their operations and planned to continue harvesting biomass in the future.

Within this study area, where biomass markets have existed for over 15 years, landowners have apparently noticed a difference in appearance between biomass and conventional harvests. This was reflected by loggers' reports that landowners often express a preference for biomass harvests. Satisfying landowners that wanted logging residues chipped was the highest ranked response related to reasons they began harvesting biomass. Written comments in response to open ended questions related to advantages of biomass harvesting indicate having a chipper provided a competitive procurement advantage over loggers that did not have a chipper. As biomass markets expand in areas that previously had limited biomass markets, landowners and loggers will need time to adapt to new market conditions. Over time, especially in competitive timber markets dominated by non-industrial private landowners, the aesthetic benefits and potential site preparation advantages of harvesting logging residues may become an important factor as logging businesses integrate biomass harvesting into their operations.

Biomass markets are expected to expand, thus additional logging businesses will probably view integrated biomass harvesting operations as an advantage for their business and begin harvesting biomass for renewable energy to diversify their operations and over time logging residue harvesting will become more of a standard practice on harvest sites across the region. Even within existing markets such as the southern Piedmont of Virginia, where biomass markets have existed for significant periods of time, only around 20 percent of the overall logging workforce has adopted biomass harvesting (Bolding et al. 2010). If total consumption of biomass increases, additional logging businesses will likely integrate biomass harvesting into their operations and utilize biomass for energy. However not all logging businesses will decide to purchase a chipper to utilize biomass. If the amount of residues utilized by additional logging businesses harvesting biomass is not sufficient to meet additional demand, then higher valued roundwood products may be utilized for energy. To avoid using higher value products for energy, alternative methods may need to be considered to utilize residues from logging operations that do not integrate biomass harvesting into existing operations. Additional research could be focused on operational strategies and equipment for utilizing residues from harvest sites among the portion of the logging workforce that does not want to harvest biomass.

In addition to adapting to biomass markets and landowner preferences, logging businesses developed strategies that enabled them to produce biomass for energy, and to comply with BMP requirements as they harvested and implemented BMPs to close out harvesting sites. Existing biomass harvesting operations considered BMP implementation as part of their overall harvesting operation. Survey data showed that 64% of logging operations had encountered situations where they left logging residues that otherwise would have been chipped for biomass fuel because they felt it was more important for BMP implementation.

5.2 Potential Erosion on Harvesting Sites

Potential concerns related to biomass harvesting and water quality are often of interest to state forestry agencies that are responsible for protection of public water resources. Ice et al. (2010) hypothesized that there would be few differences between conventional and biomass harvests unless there were differences in soil conditions and conventional BMPs should be effective for protecting water quality on both sites.

Soil erosion might increase on biomass harvesting operations if biomass harvesting required additional road networks, additional disturbance in harvest areas, larger landings to accommodate additional equipment, or if loggers were not using slash to stabilize exposed soil where needed. This research on operational harvests found no significant differences in overall BMP implementation between biomass and conventional harvests ($p=0.5930$) and no indication of increased soil erosion on biomass harvesting operations. There were no significant differences observed in overall weighted soil erosion rates between biomass (0.7 tons ac^{-1} yr^{-1}) and conventional sites (0.8 tons ac^{-1} yr^{-1}) ($p=0.8282$). Additionally, there was no apparent increase in soil disturbance on biomass harvest sites.

Biomass harvesting operations should consider residue management as part of their harvest planning to ensure that adequate quantities of residues are available to stabilize bare soil areas and stabilize skid trails where needed. There were no differences detected between biomass and conventional harvest sites regarding use of logging residues as a BMP for soil stabilization. Even after harvests were complete, biomass sites commonly had additional residues remaining on the landing that appeared suitable for BMP implementation. This study found that predicted soil erosion rates are related to overall BMP implementation rates ($R^2= 0.7994$). Sites with higher overall BMP implementation rates had less potential erosion. As long as residues are appropriately utilized where needed to implement BMPs there does not appear to be reason for concern related to increases in erosion on biomass harvesting sites as a result of harvesting logging residues for energy.

5.3 BMP Implementation on Biomass Harvest Sites

Numerous studies have documented the effectiveness of forestry BMPs for protecting water quality (e.g. Aust and Blinn 2004, Anderson and Lockaby 2011). Logging residues are often recommended and utilized as a BMP for stabilizing bare soil on logging operations (VDOF 2011, Wade et al. 2012, Wear et al. 2013). For biomass harvest sites where residues are harvested and utilized for energy, there is a potential concern that BMP implementation could be reduced if residues are unavailable for BMP implementation.

BMP implementation related to SMZs was significantly lower for biomass (83.05%) versus conventional harvests (91.35%) (p= 0.0010). The deficiencies did not appear to be because biomass harvesting causes additional soil disturbance on harvest sites or because of a lack of residues available for BMP implementation. Instead the lower BMP implementation scores were primarily a result of operational decisions by loggers, landowners, and foresters involved in harvesting that decreased the use of appropriate streamside management zones (SMZs). Lower SMZ implementation scores on biomass harvests were caused by leaving SMZs with an inadequate width and overharvesting in retained SMZs. Lower levels of BMP implementation also occurred with specific BMPs related to design and installation of roads, skid trails, and stream crossings. Existing BMPs appear adequate for protecting water quality on integrated biomass harvesting operations; however, on these sites with lower implementation scores, biomass harvesting operators did not adhere to existing BMPs designed to maintain water quality.

As with all forest operations, technology and utilization standards will change over time and will vary across physiographic regions. Statewide BMP implementation audit data should be re-evaluated in the future to determine if existing BMPs continue to be adequate as operations change. As biomass markets expand and become established in other regions additional research could focus on BMP implementation by physiographic region to insure that BMP implementation is adequate in other regions.

5.4 Summary

Existing biomass harvesting operations generally found biomass harvesting to be a good decision and plan to continue operations. Integrating biomass harvesting into existing logging operations appears to be feasible for logging businesses of different operational types and production levels. While there will likely be opportunities for other types of biomass harvesting operations, integrated biomass harvesting operations producing roundwood and utilizing logging residues for energy appear to be likely sources of biomass for energy as markets expand. While not all existing logging operations will decide to integrate biomass harvesting into their operations, integrated harvests will likely become more common in regions where demand for biomass increases.

This research, focused in the Piedmont region of Virginia, found no significant differences in overall erosion rates or BMP implementation on biomass harvests versus conventional harvests. Additionally there was no significant increases in the area occupied by roads decks, and skid trails on biomass harvesting sites. Proper attention to logging residue management should ensure that adequate quantities of logging residues are available for BMP implementation on sites where biomass harvesting occurs.

Biomass harvests had lower SMZ related BMP implementation primarily related to operational decisions rather than a lack of residues for BMP implementation. Proper implementation of existing BMPs appear sufficient to protect water quality on biomass harvesting operations. Forestry professionals involved in harvest planning and logger training programs should focus efforts on encouraging logging business owners to adhere to existing BMPs with a special emphasis on retaining SMZs, and properly installing roads, skid trails, and stream crossings.

5.5 References

Anderson, C.J. and B.G. Lockaby. 2011. The effectiveness of forestry Best Management Practices for sediment control in the southeastern United States: A literature review. Southern Journal of Applied Forestry 35(4):170-177.

Arthur, M. A., G.B. Coltharp, and D.L. Brown. 1998. Effects of best management practices on forest streamwater quality in Eastern Kentucky. Journal of American Water Resources Association 34(3):481–495.

Aust, W.M. and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, & Soil Pollution: Focus 4(1):5-36.

Baker, S.A., M.D. Westbrook Jr., and W.D. Greene. 2010. Evaluation of integrated harvesting systems in pine stands in the southern U.S. Biomass and Bioenergy 34(5):720-727.

Bolding, M. C., S.M. Barrett, J.F. Munsell, and M.C. Groover. 2010. Characteristics of Virginia's logging businesses in a changing timber market. Forest Products Journal 60(1):86-93.

Ice, G., M. McBroom, and P. Schweitzer. 2010. A review of best management practices for forest watershed biomass harvests with an emphasis on recommendations for leaving residual wood onsite. Center for Bioenergy Sustainability, Oak Ridge National Laboratory, Oak Ridge TN. 5 p.

Janowiak, M.K. and C.R. Webster. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry 108(1):16-23.

Miller, D.E., T.J. Straka, B.J. Stokes, and W.F. Watson. 1987. Productivity and cost of conventional understory biomass harvesting. Forest Products Journal 37(5):39-43.

Stokes, B.J., D.L. Sirois, and W.F. Watson. 1989. Recovery of forest residues in the southern United States. In: Stokes, B.J., ed. Proceedings of the International Energy Agency, Task VI, Activity 3 Symposium "Harvesting Small Trees and Forest Residues"; 1989 June 5-7; Auburn, AL: Auburn AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1989:32-43.

Virginia Department of Forestry. 2011. Virginia's Forestry Best Management Practices for Water Quality Technical Manual. 5th Edition. Virginia Department of Forestry. Charlottesville, VA. 165p.

Wade, C. R., M.C. Bolding, W.M. Aust, and W.A. Lakel. 2012. Comparison of five erosion control techniques for bladed skid trails in Virginia. Southern Journal of Applied Forestry 36(4):191-197.

Wear, L.R., W.M. Aust, M.C. Bolding, B.D. Strahm, and C. A. Dolloff. 2013. Effectiveness of best management practices for sediment reduction at operational forest stream crossings. Forest Ecology and Management 289:551-561.

REFERENCES

Abbas, D., D. Current, M. Phillips, R. Rossman, H. Hoganson, and K.N. Brooks. 2011. Guidelines for harvesting forest biomass for energy: a synthesis of environmental considerations. Biomass and Bioenergy 35(11):4538-4546.

Abt, R.C., K.L. Abt, F.W. Cubbage, and J.D. Henderson. 2010. Effect of policy-based bioenergy demand on southern timber markets: a case study of North Carolina. Biomass and Bioenergy 34(12):1679-1686.

Aguilar, F.X., and H.E. Garrett. 2009. Perspectives of woody biomass for energy: survey of state foresters, state energy biomass contacts, and National Council of Forestry Association Executives. Journal of Forestry 107(6):297-306.

Aguilar, F.X., N. Song, and S. Shifley. 2011. Review of consumption trends and public policies promoting woody biomass as an energy feedstock in the U.S. Biomass and Bioenergy 35(8):3708-3718.

Allred, S.B. 2009. Logging firm succession and retention. Forest Products Journal 59(6):31-36.

Anderson, C. J., and B.G. Lockaby. 2011. Research gaps related to forest management and stream sediment in the United States. Environmental Management 47(2):303-313.

Anderson, C.J. and B.G. Lockaby. 2011. The effectiveness of forestry Best Management Practices for sediment control in the southeastern United States: A literature review. Southern Journal of Applied Forestry 35(4):170 177.

Arthur, M. A., G.B. Coltharp, and D.L. Brown. 1998. Effects of best management practices on forest streamwater quality in Eastern Kentucky. Journal of American Water Resources Association 34(3):481–495.

Aust, W. M., M.B. Carroll, M.C. Bolding, and C.A. Dolloff. 2011. Operational forest stream crossings effects on water quality in the Virginia Piedmont. Southern Journal of Applied Forestry 35(3):123-130.

Aust, W.M. and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, & Soil Pollution: Focus 4(1):5-36.

Bain, R.L., and R.P. Overend. 2002. Biomass for heat and power. Forest Products Journal 52(2):12-19.

Baker, S.A., and W. D. Greene. 2008. Changes in Georgia's Logging Workforce, 1987-2007. Southern Journal of Applied Forestry 32(2):60-68.

Baker, S.A., M.D. Westbrook Jr., and W.D. Greene. 2010. Evaluation of integrated harvesting systems in pine stands in the southern U.S. Biomass and Bioenergy 34(5):720-727.

Becker, D.R., D. Larson, and E.C. Lowell. 2009. Financial considerations of policy options to enhance biomass utilization for reducing wildfire hazards. Forest Policy and Economics 11(8):628-635.

Becker, D.R., J.J. Klapperich, G.M. Domke, M.A. Kilgore, A.W. D'Amato, D.A. Current, and A.R. Ek. 2010. 2010 outlook for forest biomass availability in Minnesota: Physical, environmental, economic, and social availability. Staff paper series No. 211. Department of Forest Resources, College of Food, Agricultural and Natural Resource Sciences, University of Minnesota, St. Paul, MN. 96 p.

Benjamin, J.G., R.J. Lilieholm, and C.E. Coup. 2010. Forest biomass harvesting in the northeast: A special-needs operation? Northern Journal of Applied Forestry 27(2):45-49.

Bergman R., and J. Zerbe. 2004. Primer on wood biomass for energy. USDA Forest Service, State and Private Forestry Technology Marketing Unit, Forest Products Laboratory, Madison, WI. 10 p.

Bolding, M.C., S.M. Barrett, J.F. Munsell, and M.C. Groover. 2010. Characteristics of Virginia's logging businesses in a changing timber market. Forest Products Journal 60(1):86-93.

Brinckman, M.D. and J.F. Munsell. 2012. Disproportionality, social marketing, and biomass availability: A case study of Virginia and North Carolina family forests. Southern Journal of Applied Forestry 36(2):85-91.

Christopher, E.A. and R. Visser. 2007. Methodology for evaluating post harvest erosion risk for the protection of water quality. New Zealand Journal of Forestry 52(2):20-25.

Conrad, J. L. IV, M.C. Bolding, W.M. Aust, and R.L. Smith. 2010. Wood-to-energy expansion, forest ownership changes, and mill closure: consequences for U.S. South's wood supply chain. Forest Policy and Economics 12(6):399-406.

Conrad, J.L. IV, M.C. Bolding, R.L. Smith, and W.M. Aust. 2011. Wood-energy market impact on competition, procurement practices, and profitability of landowners and forest products industry in the U.S. South. Biomass and Bioenergy 35(1):280-287.

Conrad, J.L. IV. 2011. Anticipated impact of a vibrant wood-to-energy market on the U.S. South's wood supply chain. Ph.D. Dissertation. Virginia Tech, Blacksburg, VA. 149 p.

Cooper, J. A. and C. W. Becker. 2009. Virginia's timber industry - An assessment of timber product output and use, 2007. Resource Bulletin SRS-155. USDA Forest Service, Southern Research Station, Asheville, North Carolina. 33 p.

Croke, J., and M. Nethery. Modeling runoff and soil erosion in logged forests: Scope and application of some existing models. Catena 67(1):35-49.

Demirbas, M. Fatih. 2009. Biorefineries for biofuel upgrading: A critical review. Applied Energy 86(1):151-161.

Dillman, D.A. 2000. Mail and Internet Surveys: The Tailored Design Method. John Wiley and Sons. New York. 480 p.

Dirkswager, A.L., M.A. Kilgore, D.R. Becker, C. Blinn, and A. Ek. 2011. Logging business practices and perspectives on harvesting forest residues for energy: a Minnesota case study. Northern Journal of Applied Forestry 28(1):41-46.

Dissmeyer, G.E. and G.R. Foster. 1984. A guide for predicting sheet and rill erosion on forestland. USDA For. Ser. Gen. Tech. Publ. R8-TP 6. 40 p.

Dominion Virginia Power. 2011. Dominion Virginia Power plans to convert three coal-fired stations to renewable biomass. Dominion press release. April 1, 2011. Available online at http://dom.mediaroom.com/index.php?s=43&item=976 ; last accessed June 8, 2013.

Dominion Virginia Power. 2013. Virginia City Hybrid Energy Center. Available online at http://www.dom.com/about/stations/fossil/virginia-city-hybrid-energy-center.jsp; last accessed June 8, 2013.

Egan, A., D. Taggert, and I. Annis. 2007. Effect of population pressures on wood and procurement and logging opportunities in northern New England. Northern Journal of Applied Forestry 24(2):85-90.

Eisenbies, M.H., J.A. Burger, W.M. Aust, and S.C. Patterson. 2005. Soil physical disturbance and logging residue effects on soil productivity in five-year-old pine plantations. Soil Science Society of America Journal 69(6):1833-1843.

Forest Products Laboratory (FPL) 2004. Wood biomass for energy. USDA Forest Service, Forest Products Laboratory, State and Private Forestry Technology Marketing Unit, Madison WI. 3 p.

Forest Stewards Guild: Southeast Biomass Working Group, 2012. Forest biomass harvesting and retention guidelines for the southeast. Available online at www.forestguild.org/publications/research/2012/FG_Biomass_Guidelines_SE.pdf ; last accessed June 8, 2013.

Forisk Consulting. 2013. Forisk Bioenergy Research - Estimated wood use by announced facilities in the U.S. Available online at http://forisk.com/Forisk-Bioenergy-Research-v-42.html Last accessed April 19, 2013.

Fox, T. R. 2000. Sustained productivity in intensively managed forest plantations. Forest Ecology and Management 138(1):187-202.

Galik, C. S., R.C. Abt, and Y. Wu. 2009. Forest biomass supply in the Southeastern United States – implications for industrial roundwood and bioenergy production. Journal of Forestry 107(2):69-77.

Gan, J., and C.T. Smith. 2006. Availability of logging residues and potential for electricity production and carbon displacement in the USA. Biomass and Bioenergy 30(12):1011-1020.

Gan, J., and C.T. Smith. 2007. Co-benefits of utilizing logging residues for bioenergy production: The case for east Texas, USA. Biomass and Bioenergy 31(9):623-630.

Greene, D., S. Baker, J. Cutshall, and A. Enrich. 2011. Regional approaches for harvesting forest biomass: a report on field studies to the Wood Supply Research Institute. Forest Operations Review. Forest Resources Association. Rockville, MD. 13(1):14-25.

Groover, M. C. 2011. A Comparison of Chipper Productivity, Chip Characteristics, and Nutrient Removals from Two Woody Biomass Harvesting Treatments. Master of Science Thesis. Virginia Tech. Blacksburg Virginia. http://scholar.lib.vt.edu/theses/available/etd-12202011-070135/

Groves, R.M., D.A. Dillman, J.L. Eltinge, and R.J.A. Little (Eds.). 2002. Survey nonresponse. John Wiley and Sons, New York. 500 p.

Hall, J.P. 2002. Sustainable production of forest biomass for energy. The Forestry Chronicle 78(3):391-396.

Hood, S. M., S.M. Zedaker, W.M. Aust, and D.W. Smith. 2002. Universal Soil Loss Equation (USLE)-Predicted soil loss for harvesting regimes in Appalachian hardwoods. Northern Journal of Applied Forestry 19(2):53–58.

Hubbard, W.; L. Biles; C. Mayfield; S. Ashton (Eds.). 2007. Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook. Athens, GA: Southern Forest Research Partnership, Inc. 316 p.

Hudson, J.B. 1995. Integrated harvesting systems. Biomass and Bioenergy 9(1):141-151.

Huyler, N.K. 1989. Fuel supply structure of wood-fired power plants in the northeast: logger's perspective. USDA Forest Service. Research paper NE-624. Northeastern Forest Experiment Station. Broomall, PA. 19 p.

Ice, G. G., E. Schilling, and J. Vowell. 2010. Trends for forestry best management practices implementation. Journal of Forestry 108(6):267-273.

Ice, G., M. McBroom, and P. Schweitzer. 2010. A review of best management practices for forest watershed biomass harvests with an emphasis on recommendations for leaving residual wood onsite. Center for Bioenergy Sustainability, Oak Ridge National Laboratory, Oak Ridge TN. 5 p.

InForest. 2013. InForest, available online at http://inforest.frec.vt.edu/. Last accessed February 21, 2013.

Internal Revenue Service. 2008. Internal Revenue Bulletin 2008-30. July 28, 2008. 96 p. Available online at http://www.irs.gov/pub/irs-irbs/irb08-30.pdf; last accessed June 8, 2013.

Jackson, B., R. Schroeder, and S. Ashton. 2007. Pre-processing and Drying Woody Biomass. In: Hubbard, W.; L. Biles; C. Mayfield; S. Ashton (Eds.). 2007. Sustainable Forestry for Bioenergy and Bio-based Products: Trainers Curriculum Notebook. Athens, GA: Southern Forest Research Partnership, Inc. 316 p.

Janowiak, M.K. and C.R. Webster. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry 108(1):16-23.

JMP Version 9.0. 2010. SAS Institute Inc., Cary, NC, 1989-2010.

JMP Version 10.0. 2012. SAS Institute Inc., Cary, NC, 1989-2012.

Johnson, D.W. and D.E Todd Jr. 1998. Harvesting effects on long-term changes in nutrient pools of mixed oak forest. Soil Science Society of America Journal 62(6):1725-1735.

Koch, P., and T.E. Savage. 1980. Development of the swathe-felling mobile chipper. Journal of Forestry 78(1):17-21.

Kochenderfer, J. N., P.J. Edwards, and F. Wood. 1997. Hydrologic impacts of logging an Appalachian watershed using West Virginia's best management practices. Northern Journal of Applied Forestry 14(4):207–218.

Lakel, W. A., W.M. Aust, M.C. Bolding, C.A. Dolloff, P. Keyser and R. Feldt. 2010. Sediment trapping by streamside management zones of various widths after forest harvest and site preparation. Forest Science 56(6):541-551.

Lakel, W. and M. Poirot. 2012. Silvicultural best management practices implementation monitoring for Virginia - 2011. Virginia Department of Forestry. Charlottesville, VA. 8 p.

Lakel, W. and M. Poirot. 2013. Silvicultural best management practices implementation monitoring for Virginia - 2012. Virginia Department of Forestry. Charlottesville, VA. 10 p.

Lehtikangas, P. 2001. Quality properties of pelletised sawdust, logging residues, and bark. Biomass and Bioenergy 20(5):351-360.

MacCarty, N., D. Ogle, D. Still, T. Bond, and C. Roden. 2008. A laboratory comparison of the global warming impact of five major types of biomass cooking stoves. Energy for Sustainable Development 12(2):56-65.

Manley, A. and J. Richardson. 1995. Silviculture and economic benefits of producing wood energy from conventional forestry systems and measures to mitigate negative impacts. Biomass and Bioenergy 9(1):89-105.

Mann, L.K., D.W. Johnson, D.C. West, D.W. Cole, J.W. Hornbeck, C.W. Martin, H. Riekerk, C.T. Smith, W.T. Swank, L.M. Tritton, and D.H. Van Lear. 1988. Effects of whole-tree and stem-only clearcutting on postharvest hydrologic losses, nutrient capital, and regrowth. Forest Science 34(2):412-428.

Markowski-Lindsay, M., T. Stevens, D.B. Kittredge, B.J. Butler, P. Catanzaro, and D. Damery. 2012. Family forest owner preferences for biomass harvesting in Massachusetts. Forest Policy and Economics 14(1):127-135.

Martin, C. W., and J.W. Hornbeck. 1994. Logging in New England need not cause sedimentation of streams. Northern Journal of Applied Forestry 11(1):17-23.

Meadows, S., T. Gallagher, and D. Mitchell. 2011. A new slash bundling concept for use in a southern US logging system. Forest Products Journal 61(3):210-215.

MeadWestvaco, 2011. MWV to improve power infrastructure at Covington, VA mill. Press release from MeadWestvaco Corporation. June 27, 2011. Richmond Virginia. Available online at http://www.meadwestvaco.com/mwv/groups/content/@corp/@newsevts/documents/document/mwv031745.pdf ; last accessed June 8, 2013.

Milauskus, S., and J. Wang, 2006. West Virginia logger characteristics. Forest Products Journal 56(2):19-24.

Miller, D.E., T.J. Straka, B.J. Stokes, and W.F. Watson. 1987. Productivity and cost of conventional understory biomass harvesting. Forest Products Journal 37(5):39-43.

Mitchell, D., and T. Gallagher. 2007. Chipping whole trees for fuel chips: A production study. Southern Journal of Applied Forestry 31(4):176-180.

Moldenhauer, M.C. and M.C. Bolding. 2009. Parcelization of South Carolina's private forestland: Loggers' reactions to a growing threat. Forest Products Journal 59(6):37-43.

Munsell, J. F. and R.H. Germain. 2007. Woody biomass energy: an opportunity for silviculture on nonindustrial private forestlands in New York. Journal of Forestry 105(8):398-402.

Munsell, J.F. and T.R. Fox. 2010. An analysis of the feasibility for increasing woody biomass production from pine plantations in the Southern United States. Biomass and Bioenergy 34(12):1631-1642.

Munsell, J.F., S.M. Barrett, and M.C. Bolding. 2011. An Exploratory study of biomass harvesting among logging firms in Virginia and North Carolina. Forest Science 57(5):427-434.

National Council for Air and Stream Improvement, Inc. (NCASI). 2009. Compendium of Forestry Best Management Practices for Controlling Nonpoint Source Pollution in North America. Technical Bulletin No. 0966. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc. 208 p.

Northern Virginia Electric Cooperative. 2011. Biomass generation plant approved. NOVEC What's Current. September 2011. Available online at http://www.novec.com/books/WC9-11/WC9-11.pdf ; last accessed June 8, 2013.

Northern Virginia Electric Cooperative. 2013. Halifax County Biomass Plant. Available online at https://www.novec.com/About_NOVEC/SBE.cfm ; last accessed June 8, 2013.

Ott, L., and M. Longnecker. 2010. An introduction to statistical methods and data analysis. Sixth Edition. Belmont, CA: Brooks/Cole Cengage Learning. 1273 p.

Pellet Fuels Institute. 2013. What are Pellets? Available online at http://pelletheat.org/pellets/what-are-pellets/ ; Last accessed June 8, 2013.

Perlack, R. D. and B.J. Stokes. 2011. US billion-ton update: biomass supply for a bioenergy and bioproducts industry. Oak Ridge National Laboratory. Oak Ridge, TN. 227 p.

Perlack, R.D., L.T. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. Oak Ridge National Lab., Oak Ridge, TN. 59 p.

Riffell, S., J. P. Verschuyl, D. Miller, and T. B. Wigley. 2011. Biofuel harvests, coarse woody debris, and biodiversity – a meta-analysis. Forest Ecology and Management 261(4):878-887.

Saunders, A.M., F.X. Aguilar, J.P. Dwyer, and H.E. Stelzer. 2012. Cost structure of integrated harvesting for woody biomass and solid hardwood products in southeastern Missouri. Journal of Forestry 110(1):7-15.

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. Journal of Soil and Water Conservation 67(4):300-310.

Schuler, J. L., and R.D. Briggs. 2000. Assessing application and effectiveness of forestry best management practices in New York. Northern Journal of Applied Forestry 17(4):125-134.

Shepard, J.P. 2006. Water quality protection in Bioenergy production: the US system of forestry best management practices. Biomass and Bioenergy 30(4):378-384.

Southern Group of State Foresters (SGSF) 2007. Silviculture Best Management Practices Implementation Monitoring. A framework for State Agencies. Available online at http://www.southernforests.org/publications/SGSF%20Regional%20BMP%20Framework%20Protocol%20publication_2007.pdf/at_download/file; last accessed March 26, 2013.

Spelter, H., and D. Toth. 2009. North America's wood pellet sector. Research Paper FPL-RP-656. Madison WI: USDA Forest Service, Forest Products Laboratory. 21 p.

Spinelli, R. and B. Hartsough. 2001. A survey of Italian chipping operations. Biomass and Bioenergy 21(6):433-444.

Spinelli, R., and R.J.M. Visser. 2009. Analyzing and estimating delays in wood chipping operations. Biomass and Bioenergy 33(3):429–433.

Stokes, B.J. 1992. Harvesting small trees and forest residues. Biomass and Bioenergy 2(1):131-147.

Stokes, B.J., D.L. Sirois, and W.F. Watson. 1989. Recovery of forest residues in the southern United States. In: Stokes, B.J., ed. Proceedings of the International Energy Agency, Task VI, Activity 3 Symposium "Harvesting Small Trees and Forest Residues"; 1989 June 5-7; Auburn, AL: Auburn AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1989:32-43.

Stuart, W., C. Porter, T. Walbridge, and R. Oderwald. 1981. Economics of modifying harvesting systems to recover energy wood. Forest Products Journal 31(8):37-42.

Timber Mart-South. 2012. Norris Foundation, Univ. of Georgia, Athens, GA.

U.S. Energy Information Administration (EIA). 2012. Annual energy outlook 2012. DOE/EIA-0383(2012) June 2012. Available online at http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf Last accessed on 11/30/12.

U.S. Energy Information Administration (EIA). 2012. November 2012 Monthly Energy Review. DOE/EIA-0035(2012/11). Available online at http://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf Last accessed on 11/30/12.

USDA Natural Resources Conservation Service (NRCS) Web Soil Survey. 2013. Available online at http://websoilsurvey.nrcs.usda.gov/app/ Last accessed February 21, 2013.

VanBrakle, J.D., R.H. Germain, J.F. Munsell, and S.V. Stehman. 2013. Do forest management plans increase Best Management Practices implementation on family forests? A formative evaluation in the New York City Watershed. Journal of Forestry 111(2):108-114.

Virginia Department of Forestry. 2011. Virginia's Forestry Best Management Practices for Water Quality Technical Manual. 5th Edition. Virginia Department of Forestry. Charlottesville, VA. 165 p.

Virginia Department of Forestry. 2012. 2012 State of the Forest. Virginia Department of Forestry. Charlottesville, VA. 21 p.

Wade, C. R., M.C. Bolding, W.M. Aust, and W.A. Lakel. 2012. Comparison of five erosion control techniques for bladed skid trails in Virginia. Southern Journal of Applied Forestry 36(4):191-197.

Wang, J.X. and W. A. Goff. 2008. Application and effectiveness of forestry best management practices in West Virginia. Northern Journal of Applied Forestry 25(1):32-37.

Ward, J.M., and C.R. Jackson. 2004. Sediment trapping within forestry streamside management zones: Georgia Piedmont, USA. Journal of the American Water Resources Association 40(6):1421–1431.

Watson, W.F., and B.J. Stokes. 1989. Harvesting small stems—A southern USA perspective. In: Stokes, B.J., ed. Proceedings of the International Energy Agency, Task VI, Activity 3 Symposium "Harvesting Small Trees and Forest Residues"; 1989 June 5-7; Auburn, AL: Auburn AL: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1989:131-139.

Watson, W.F., B.J. Stokes, and I.W. Savelle. 1986. Comparison of two methods of harvesting biomass for energy. Forest Products Journal 36(4):63-68.

Wear, L.R., W.M. Aust, M.C. Bolding, B.D. Strahm, and C. A. Dolloff. 2013. Effectiveness of best management practices for sediment reduction at operational forest stream crossings. Forest Ecology and Management 289:551-561.

Westbrook, M.D. Jr., W.D. Greene, and R.L. Izlar. 2007. Utilizing forest biomass by adding a small chipper to a tree-length southern pine harvesting operation. Southern Journal of Applied Forestry 31(4):165-169.

Wiltsee, G. 2000. Lessons learned from existing biomass power plants. Technical Report NREL/SR-570-26946. National Renewable Energy Laboratory. 143 p.

Witmer, P.L., P.M. Stewart and C.K. Metcalf. Development and use of a sedimentation risk index for unpaved road-stream crossings in the Choctawhatchee watershed. Journal of American Water Resources Association 45(3):734–747.

Worrell, W.C., M.C. Bolding, and W.M. Aust. 2011. Potential soil erosion following skyline yarding versus tracked skidding on bladed trails in the Appalachian region of Virginia. Southern Journal of Applied Forestry 35(3):131-135.

Wynn, T. M., S. Mostaghimi, J.W. Frazee, P.W. McClellan, R.M. Shaffer, and W.M. Aust. 2000. Effects of forest harvesting best management practices on surface water quality in the Virginia coastal plain. Transactions of the American Society of Agricultural Engineers 43(4):927–936.

Yoho, N.S. 1980. Forest management and sediment production in the South – A review. Southern Journal of Applied Forestry 4(1):27-36.

Zerbe J., and K. Skog, 2007. Sources and uses of wood for energy. USDA Forest Products Laboratory, Madison WI. 10p .

Zerbe, John I. 2006. Thermal energy, electricity, and transportation fuels from wood. Forest Products Journal 56(1):6-14.

APPENDIX

Appendix A. BMP audit questions related to streamside management zones (SMZs).

BMP Question	Biomass n	% Yes	Conventional n	% 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 Q2 - Do all intermittent and perennial streams have an SMZ?	73	87.67	222	94.14	0.0678
SMZ Q3 - Do all sinkholes or karst features have an SMZ?	1	0.00	2	100.00	-
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 Q7 - In tidal areas, has a 50 foot SMZ been maintained from the grass or marsh edge?	-	-	5	80.00	-
SMZ Q8 - Are SMZ widths modified to accommodate cold water fisheries and municipal water supplies?	1	100.00	9	100.00	-
SMZ Q9 - Did the logger avoid exposing large sections of soil in the SMZ?	73	94.52	221	96.83	0.3668
SMZ 10 - Was exposed soil in the SMZ revegetated or covered with organic materials?	20	85.00	50	92.00	0.3778
SMZ Q11 - Is the SMZ free of roads and landings where possible?	73	94.52	222	96.85	0.3628
SMZ Q12 - Did the logger avoid silvicultural debris in the stream that would warrant a law enforcement action under the "debris in the stream law"?	73	100.00	224	99.55	0.5674
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

Appendix B. BMP audit questions related to skidding.

BMP Question	Biomass n	% Yes	Conventional n	% Yes	p-value
Skidding Q1 - Are bladed skid trails limited to less than 26% grade unless absolutely necessary?	32	93.75	81	87.65	0.3433
Skidding Q2 - Are bladed skid trails limited to sideslopes less than 60%?	29	96.55	80	98.75	0.4498
Skidding Q3 - Are un-bladed trails limited to sideslopes less than 36% in general?	87	98.85	269	100.00	0.0783
Skidding Q4 - Are all skid trails free from channelized flow that is likely to cause sedimentation?	86	88.37	273	95.97	0.0088
Skidding Q5 - Are all skid trails located outside the SMZ?	78	94.87	227	95.59	0.7924
Skidding Q6 - Did the logger avoid skidding logs through intermittent or perennial streams?	74	97.30	233	97.00	0.8934
Skidding Q7 - Were brush mats used to stabilize trails and prevent erosion where needed?	70	74.29	223	69.51	0.4437
Skidding Q8 - Do trails avoid long, continuous grades?	88	92.05	269	90.71	0.7027
Skidding Q9 - Do trails avoid rutting that will likely cause channelized erosion near a stream?	80	95.00	245	95.51	0.8502
Skidding Q10 - Are water bars established on trails where erosion is likely at recommended intervals?	63	47.62	158	43.67	0.5941
Skidding Q11 - Are water turnouts built to ensure drainage of skid trails where needed?	46	50.00	125	48.00	0.8165
Skidding Q12 - Are appropriate cross drainages installed where springs or seeps crossed the trails?	6	83.33	20	60.00	0.2920
Skidding Q13 - Is vegetation established where needed on trails to prevent erosion and sedimentation?	63	41.27	168	52.98	0.1130

Appendix C. BMP audit questions related to harvest planning.

BMP Question	Biomass n	% Yes	Conventional n	% Yes	p-value
Planning Q1 - Is there evidence or knowledge of a harvest plan (painted lines, flagging, delineated hazards, SMZs, or decks, engineered roads, etc…)?	85	75.29	283	67.49	0.1714
Planning Q2 - Is there evidence that the logger utilized a harvesting system that is generally appropriate for the site and timber conditions?	86	98.84	283	99.29	0.6800
Planning Q3 - In the case of severe site conditions (very wet or steep) was the harvesting system modified to reduce damage to soil, site, and water?	7	71.43	33	66.67	0.8070

Appendix D. BMP audit questions related to stream or wetland crossings.

BMP Question	Biomass n	% Yes	Conventional n	% Yes	p-value
Crossings - Q1 Are stream crossings minimized?	39	94.87	123	98.37	0.2194
Crossings Q2 - Are stream crossings installed at or near to right angles where possible?	39	100.00	123	99.19	0.5722
Crossings Q3 - Are culverts and bridges of adequate length?	24	87.50	81	92.59	0.4338
Crossings Q4 - Are culverts properly sized according to the BMP manual Tables 6 and 7 or Talbot's formula?	6	83.33	30	80.00	0.8506
Crossings Q5 - Are permanent bridge abutments adequate and stable?	1	100.00	6	66.67	0.4945
Crossings Q6 - Are culverts covered with adequate and appropriate fill material?	6	66.67	32	87.50	0.1991
Crossings Q7 - Are culverts covered with gravel to reduce erosion near the stream?	6	83.33	29	82.76	0.9729
Crossings Q8 - Are headwalls stabilized with vegetation, rock, or fabric to minimize cutting?	6	66.67	31	77.42	0.5742
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 Q10 - Are fords used only where a natural rock base (or geoweb) and gentle approaches allow?	4	25.00	11	72.73	0.0952
Crossings Q11 - Is the addition of unnatural materials in the stream to facilitate the use of a ford minimized?	4	100.00	11	81.82	0.3596
Crossings Q12 - Do all ford crossings avoid restricting the natural flow of water?	4	100.00	11	90.91	0.5325
Crossings Q13 - Do all ford crossings have a 50 foot approach of clean gravel?	3	0.00	10	70.00	0.0329
Crossings Q14 - Do all ford crossings have underlying geo-textile where needed (on approaches)?	3	0.00	5	20.00	0.4076
Crossings Q15 - Are approaches stable and unlikely to contribute sediment to the stream?	38	89.47	112	90.18	0.9004
Crossings Q16 - Are temporary culverts, pole bridges, and bridges removed?	29	100.00	88	96.59	0.3138
Crossings Q17 - Are stream banks and approaches re-claimed with sufficient vegetation, rock, or slash?	37	89.19	112	86.61	0.6831
Crossings Q18 - Were pole bridges used only in appropriate circumstances?	0	-	7	85.71	-
Crossings Q19 - Are water diversion structures present when needed on approaches?	31	87.10	95	81.05	0.4415

Appendix E. BMP audit questions related to wetlands.

BMP Question	Biomass n	% Yes	Conventional n	% Yes	p-value
Wetlands Q1 - Did operations in wetlands avoid altering hydrology of the site to such a degree as to convert a wetland to a non wetland?	2	100	0	-	-
Wetlands Q2 - Is water movement maintained on the site?	2	100	0	-	-
Wetlands Q3 - Were the 15 mandatory road BMPs followed for wetland roads?	2	100	0	-	-
Wetlands Q4 - Were the six mandatory site-prep BMPs followed as needed?	0	-	0	-	-
Wetlands Q5 - Was the harvesting system appropriate for the site conditions?	2	100	0	-	-
Wetlands Q6 - Was low ground pressure equipment (LGP) utilized where needed?	0	-	0	-	-
Wetlands Q7 - Did the operation avoid activities during particularly wet weather?	2	100	0	-	-
Wetlands Q8 – Are landings located on appropriate ground?	2	100	0	-	-

Appendix F. BMP audit questions related to decks.

BMP Question	Biomass n	% Yes	Conventional n	% Yes	p-value
Decks Q1 - Are log decks located on relatively well drained ground with low to moderate slopes?	88	100.00	284	98.59	0.2630
Decks Q2 - Are appropriate soil protection measures in place to prevent erosion on the deck?	84	78.57	267	79.03	0.9290
Decks Q3 - Are all log decks located at least 50 feet from the nearest SMZ.	76	97.37	246	97.56	0.9249
Decks Q4 - Are water diversion structures installed to prevent water from crossing the deck?	52	67.31	152	57.24	0.2011
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
Decks Q7 - Are fluid spills from equipment minimal?	87	98.85	281	97.15	0.3704
Decks Q8 - Are decks reshaped where needed to ensure drainage?	66	89.39	182	90.11	0.8686
Decks Q9 - Is the deck free of trash, garbage, and other non-slash debris related to the harvest operation?	88	97.73	282	94.68	0.2334

Appendix G. BMP audit questions related to roads.

BMP Question	Biomass n	% Yes	Conventional n	% Yes	p-value
Roads Q1 - Was road construction and use minimized?	81	98.77	248	99.19	0.7249
Roads Q2 - Are roads on the contour where practical?	84	97.62	236	97.46	0.9351
Roads Q3 - Are new roads located and constructed to allow for proper drainage?	45	86.67	86	84.88	0.7832
Roads Q4 - Are new roads located to avoid erodible, wet, and sensitive ground?	45	97.78	90	95.56	0.5192
Roads Q5 - Are grades between 2% and 10% except for necessary deviations?	84	100.00	255	98.43	0.2482
Roads Q6 - Are roads outsloped where needed and conditions allow?	58	81.03	170	79.41	0.7903
Roads Q7 - Are roads daylighted where needed and feasible?	78	93.59	232	90.52	0.4051
Roads Q8 - Is access being controlled with a functional gate or barrier?	80	40.00	245	48.98	0.1622
Roads Q9 - Are under road culverts installed, spaced, and maintained properly?	4	75.00	47	80.85	0.7772
Roads Q10 - Is water diverted from the road surface at specified intervals using dips, bars or traps?	59	47.46	179	58.66	0.1329
Roads Q11 - Is construction of dips, bars, turnouts and traps adequate to maintain function?	44	45.45	129	65.89	0.0165
Roads Q12 - Is gravel or vegetation present to protect water bars from erosion?	60	56.67	148	64.86	0.2685
Roads Q13 - Are temporary roads retired with properly constructed water bars or tank traps?	36	47.22	66	60.61	0.1933
Roads Q14 - Is water being “turned out” into surrounding landscape with appropriate structures?	55	58.18	168	63.10	0.5149
Roads Q15 - Is there rock or vegetation on slopes where needed to prevent erosion?	78	62.82	224	70.98	0.1800
Roads Q16 - Are turnouts directing water and/or sediment away from riparian areas?	30	76.67	98	87.76	0.1350
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
Roads Q19 - Are roads in SMZs as far from the channel as possible and built to prevent stream sedimentation?	28	85.71	75	96.00	0.0650