Characteristics of Logging Businesses that Harvest Biomass for Energy Production

Scott M. Barrett
M. Chad Bolding
W. Michael Aust
John F. Munsell

Abstract

Utilization of biomass from logging residues for renewable energy production depends on forest harvesting businesses. As biomass markets emerge, businesses will need to adapt to meet operational requirements. Logging businesses that supplied biomass for energy production in Virginia were surveyed regarding operations and attitudes. Results show that businesses across a broad range of total production levels (150 to 6250 tons/wk) harvested biomass and roundwood using integrated harvesting operations with whole tree chippers. Businesses had produced biomass 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 percent of each respondents total reported production and was often produced with relatively large (median = 600 horsepower) chippers with an average age of 12.5 years. Characteristics of operations where business owners agreed they profited from biomass production were compared with those that were neutral or disagreed. Business owners that agreed they profited had an average investment of \$188,500 in biomass production equipment, versus \$377,143 for the neutral/disagree group ($P = 0.02$). Respondents indicated they 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.

Woody biomass is an important component of the United States' (US) renewable energy portfolio, serving as feedstock for production of 22 percent of all renewable energy in 2013 (US Energy Information Administration [US EIA] 2014) and demand for biomass in support of renewable energy production is predicted to increase (US EIA 2013). As of March 2014, there were 444 existing or announced wood-to-energy facilities in the United States, representing an estimated consumption of 80 million green tons per y by 2023 (Forisk Consulting 2014). Biomass from logging residues such as limbs, tops, and otherwise unmerchantable trees is viewed as a viable feedstock for meeting increased demand (Perlack and Stokes 2011). Increased utilization of logging residues could be an important step toward supplying biomass for energy markets (Galik et al. 2009, Conrad et al. 2011).

Conventional forest harvesting operations produce roundwood (e.g., pulpwood, sawtimber, veneer) and generate logging residues during the course of the harvesting operation. Biomass harvesting operations utilize the biomass from logging residues and transport them to facilities where they are used for energy. Biomass harvesting can be directly integrated into roundwood harvesting operations or can occur separately from the roundwood operation. Integrated biomass harvesting operations produce roundwood as well as biomass from logging residues concurrently in the same operation. In a study of regional approaches to biomass harvesting across the United States, Greene et al. (2011) found that strategies for utilizing biomass varied by region.

The authors are, respectively, Assistant Professor and Extension Specialist, Forest Operations and Biomass Utilization (sbarrett@vt.edu [corresponding author]), Associate Professor, Forest Operations/Engineering (bolding@vt.edu), Professor of Forestry (waust@vt.edu), and Associate Professor and Forest Management Extension Specialist (jfmunsel@vt.edu), Dept. of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg. This paper was received for publication in March 2014. Article no. 14-00033.

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Previous research indicates that biomass harvesting is feasible within existing markets (Conrad et al. 2010). 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). Studies have documented productivity and analyzed delays on chipping operations (Spinelli and Hartsough 2001, Spinelli and Visser 2009). A 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 businesses that harvest biomass has important implications for forest operations and 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.

Methods

Study area

There are multiple biomass markets in the Piedmont region of Virginia (Fig. 1). Regional wood energy facilities consume biomass for purposes of direct combustion to generate electricity and heat. The largest biomass consumer is a 79.5-Megawatt (MW) power plant that began operation in 1994. At the time of construction, this facility was the world's largest stand-alone power plant using 100 percent wood fuel; however, it was originally operated primarily during peak demand periods and initially operated at less than 20 percent 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 1 million green tons per y of biomass. 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+ y) 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 percent of all existing logging operations in the Piedmont of Virginia produced biomass. A survey of these logging businesses provides details on the characteristics of their operations at the time of the survey. Markets and harvesting operations change over time and will be different in other regions. However operations in this region would be similar to other regions with predominantly mechanized harvesting operations and competitive markets for roundwood and biomass.

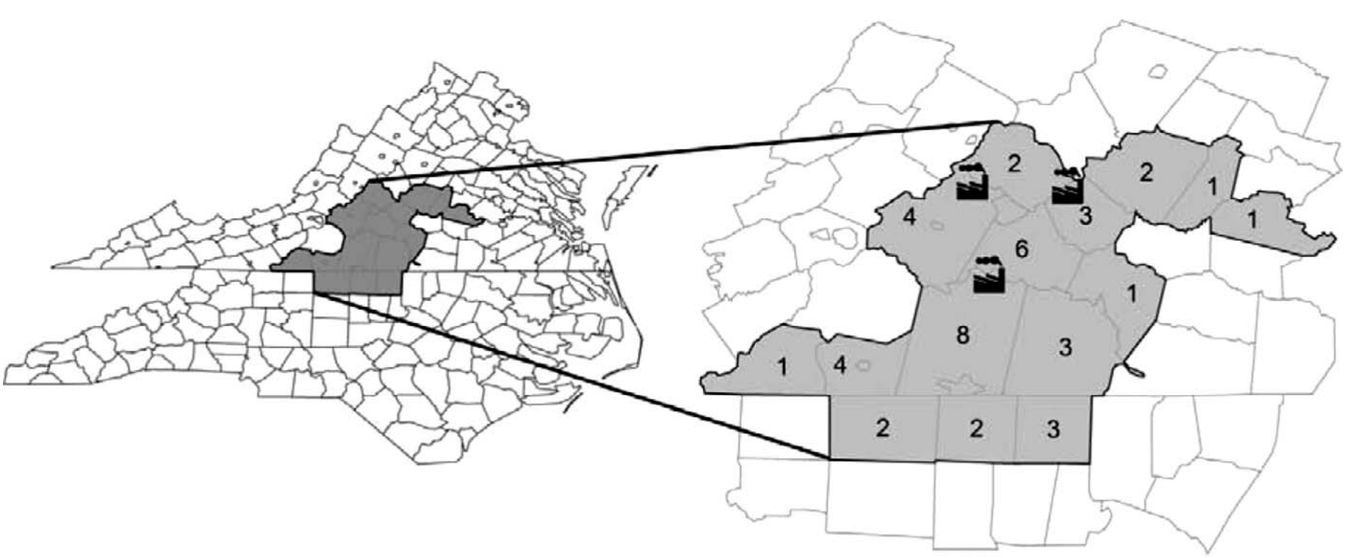

Figure 1.—Biomass harvesting study area in Virginia and North Carolina, including biomass consuming mills, and number of survey responders reporting a particular county as the center of their harvesting operations.

Survey methods

We surveyed logging businesses that supplied biomass to renewable energy facilities in the study area (Fig. 1). Mailing lists for biomass suppliers (94 businesses) were provided by the biomass power plant and one of two paper mill consumers. This approach excluded suppliers of mill residues and urban wood waste, thereby focusing on businesses that produce wood for energy from forest harvesting operations. While other consumers of biomass exist within this region (e.g., residential firewood, small scale boilers, or mulch production) this survey method focused on the large-scale consumers and in-woods producers of biomass for energy and likely represents the vast majority of in-woods biomass production within the region.

A questionnaire was developed and administered based on the Tailored Design Method (Dillman 2000). The survey included 45 questions designed to collect data on operational characteristics, 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 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. Reviewers indicated that logging business owners that produce biomass often do not refer to it as biomass. The term *wood fuel* was identified as most common among businesses in the region and was used on the questionnaire to refer to biomass. 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. *Wood fuel* as used in the questionnaire is considered synonymous with biomass and is reported as biomass in the results.

Ninety-four logging businesses were contacted during November and December 2010 first using a prenotice letter followed 3 days later by the questionnaire. A third mailing, 10 days after the questionnaire, thanked those that responded and reminded others to complete and return the questionnaire. The final mailing, approximately 2.5 weeks after the reminder, consisted of a second questionnaire mailed to those that had yet to respond. The questionnaires were mailed to the individual identified by the biomass consuming facilities as the primary contact for the logging business. The first statement on the questionnaire asked if they were the primary decision maker for a business that produced biomass from forest harvesting sites in the past year. All reported data came from respondents who indicated they were the primary decision maker for the business; however, there was no direct control over who actually completed the questionnaire.

Survey data were analyzed using JMP statistical software (JMP 2010). Statistical analyses were performed at the $\alpha = 0.05$ level. Nonresponse bias was assessed by comparing responses from early responders to late responders (Groves et al. 2002). A conversion factor of 25 tons per truckload was used to convert production levels reported in truckloads into tons. 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 biomass* and *biomass production level* were used to divide businesses into two groups that were evaluated using *t* tests to compare average chipper ages of the two groups. Respondents who indicated biomass production was profitable were grouped together and compared with 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 percentage 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, percentage of responses reported do not total 100 percent.

Results

Survey response

Fifty of the 94 questionnaires mailed were returned. Forty-four of the 50 respondents indicated they were conventional logging operations that produced biomass. 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 percent. The 44 responses used in this study were received from logging businesses with operations centered in 12 Virginia and 3 North Carolina counties (Fig. 1). A nonresponse bias check indicated there were no significant demographic or operational differences between early and late respondents, and respondents were distributed throughout the procurement regions for all three of the biomass consuming facilities

Biomass harvesting strategies

For our study area, virtually all logging businesses integrated biomass production directly into conventional operations, with roundwood and biomass produced at the same time using a whole tree chipper as opposed to a grinder (Table 1). The single respondent indicating biomass production did not occur during roundwood harvesting operations produced both roundwood and biomass, but apparently these operations occurred separately.

Owners were asked to report the sources of material used within the previous year to produce biomass. Responses indicate that on average, 82 percent of the material used to produce biomass came from logging residues derived from their own roundwood harvesting operations. Over 16 percent of the material used to produce biomass came from standing timber that was bought primarily for chipping. An average of 1 percent of biomass came from land clearing activity. None of the respondents indicated that they chipped residues from other loggers' harvesting operations.

Table 1.—Operational and owner characteristics of respondents (n = 44) delivering biomass to facilities in the southern Piedmont of Virginia.

Characteristics	Value
Percent integrated harvesting operations with roundwood and biomass produced concurrently	98
Percentage of operations with a single loader utilized for roundwood and biomass	61
Average length of time operating a conventional logging operation (y)	23.1
Average length of time producing biomass (y)	6.8
Percentage of owners expecting to be producing biomass in 5 y	98
Percentage of owners expecting biomass production to increase in 5 y	53
Percentage of owners expecting biomass production to decrease in 5 y	0

Operational and production characteristics

The number of crews operated per business ranged from one to five; however, 77 percent of businesses consisted of a single crew. Harvests occurred over a variety of stand and harvest types. Reported harvest types during the past year included hardwood clearcuts (47%), pine clearcuts (28%), pine thinnings (11%), hardwood select or partial cuts (9%), and other (5%) harvests types. Respondents reported a wide range of weekly production rates for both biomass and roundwood production (Table 2).

For each respondent, biomass was calculated as a percentage of their total production volume. Biomass production ranged from 4 to 60 percent of the respondent's total production. An average of the respondents' biomass production percentages showed that biomass accounted for 28 percent of the respondents total production volume. Baker et al. (2010) reported similar biomass production ranges between 5 and 47 percent of total production in a study of southern pine harvesting. Saunders et al. (2012) found an average biomass production level of 30 percent of total production in Missouri hardwood harvests.

Seventy-seven percent of operations reported they accumulate biomass material and periodically start the chipper to process the material. The remainder chipped material as it was skidded to the landing. Of businesses with multiple crews, half (five businesses) indicated they rotated a chipper between crews. The most frequently reported average haul distances for biomass ranged between 41 and 60 miles (68%); 20 percent of the businesses reported average haul distances greater than 60 miles.

Table 2.—Average weekly production of roundwood, biomass, and clean (pulp quality) chips per crew for respondents delivering biomass to facilities in the Piedmont region of Virginia.

Product	n[a]	Tons/wk/crew Mean	Median	Min	Max	SD
Roundwood	43	590	500	60	3,125	514
Biomass	43	189	175	25	500	108
Clean/pulp chips	6	367	388	200	500	120
Total production[b]	43	798	725	135	3,375	545

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

[b] Total production per crew calculated based on each respondent's reported total production level of (roundwood + biomass + clean chips)/number of crews.

Impact of biomass markets on harvesting operations

Biomass harvesting often refers to utilizing logging residues or otherwise unmerchantable wood for energy because it cannot be used for higher value products. However, if market conditions justify, roundwood such as pulpwood can also be used for energy. Respondents were asked to report the percentage of time during the past year that biomass prices were competitive enough to justify producing biomass from pulpwood (Fig. 2). Although many respondents indicated there were periods when markets justified use of pulpwood for biomass, 24 of 44 also reported that additional biomass markets would enable them to increase total production from logging residues without using pulpwood.

Only half of the respondents produced biomass on all harvest sites in the past year. Those who had not produced biomass on all sites were provided an open-ended question to describe the most common reason for not producing biomass. Common responses included lack of markets, quota restrictions, or lack of profit based on biomass prices relative to transportation costs. The questionnaire also included open-ended questions pertaining to the most significant barriers to producing biomass profitably and asked respondents to identify the most substantial advantages of producing biomass. Landowner satisfaction was one of the most common advantages cited by business owners (Table 3). Profitability barriers identified in the open-ended questions were primarily related to prices and markets, rather than operational feasibility or logistical challenges.

Utilizing logging residues for biomass can provide additional revenue; 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 commercial timber harvests are inspected to ensure compliance (Virginia Department of Forestry 2011). Sixty-four percent of respondents reported encountering situations where only a portion of available residues were chipped

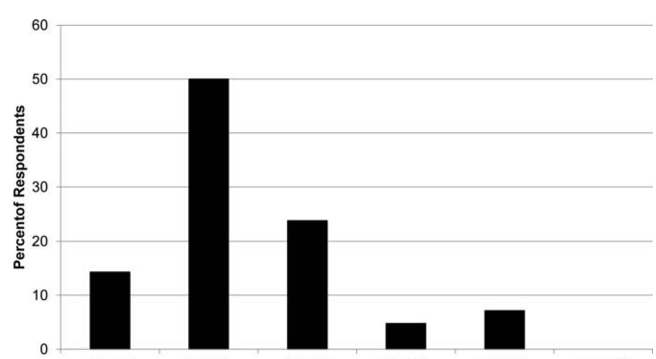

Figure 2.—Percentage of time during 2010 when prices justified producing biomass from roundwood/pulpwood.

Table 3.—Responses from open-ended questions related to advantages of producing biomass and barriers to producing biomass more profitably.

	% of responses related to this category[a]
Advantages of producing biomass	
Landowner satisfaction or improved postharvest aesthetics	50
Helps with procurement or acquiring tracts to harvest	23
Facilitates reforestation	20
Reduces waste/producing renewable energy from an otherwise unused resource	18
Increased profit/diversification of business	16
Barriers to producing biomass more profitably	
Delivered prices received for biomass	48
Costs associated with producing biomass	45
Need for additional biomass markets	23
More stable market pricing with less fluctuation	14
Production restrictions due to quotas	9

[a] Respondents could potentially provide multiple answers, so response categories total greater than 100 percent.

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.

Owner attitudes and operational impacts

The questionnaire included 12 measures regarding the owner's decision to harvest biomass and the impacts of this decision on operations (Table 4). The lowest response mean (least agreement) occurred when asked if they began producing biomass because a mill representative encouraged them to do so. The two overall highest mean responses indicated they began producing biomass to satisfy landowners who wanted residues chipped and to be competitive on timber sales that required residue chipping.

Pairwise comparisons were performed to identify significant differences in response means. Respondents were significantly more likely to begin harvesting biomass to satisfy landowners rather than in response to encouragement from a mill ($P < 0.01$). There were no significant differences between response means when queried if they began harvesting biomass to satisfy landowners compared with being competitive on timber sales that required chipping ($P = 0.96$), to diversify their business ($P = 0.74$), or to increase total profit ($P = 0.21$).

Chipper characteristics and investment in biomass production

Average chipper age was 12.5 years and ranged from 1 to 40 years (Fig. 3). Chipper horsepower ranged from 250 to 950 with a median of 600. Business owners reported a median investment in biomass production equipment including chippers, chip vans, extra loaders, or other necessary equipment of $200,000 and investments ranged between $40,000 and $1.2 million. Most operations utilized a single loader for biomass and roundwood, so additional investments in biomass production were often limited to the chipper and chip vans.

Chipper ages were evaluated to determine if age was consistent across the owners' length of time producing biomass and biomass production level. Businesses were categorized into two biomass production levels. Smaller operations producing less than 250 tons of biomass per wk had an average chipper age of 18.7 years, which was significantly older than for operations that produced over 250 tons of biomass per wk and had an average chipper age of 7.7 years ($P < 0.01$). Businesses that produced biomass

Table 4.—Logging business owner attitudes related to statements about their decision to begin producing biomass, and the impact it has on their operation.[a]

Statement	Mean response	Wilcoxon signed-rank	% of respondents who agree or strongly agree
I began producing biomass to satisfy landowners that wanted logging residues chipped.	4.25	398.0 ($P < 0.01$)	88.6
I began producing biomass so I could be competitive on timber sales that require logging residues to be chipped.	4.23	360.0 ($P < 0.01$)	84.1
I began producing biomass so I could diversify my business.	4.18	422.5 ($P < 0.01$)	93.2
Given the overall impacts to my operation, deciding to produce biomass was a good decision.	4.11	351.5 ($P < 0.01$)	84.1
I began producing biomass so I could increase my total profit.	4.09	375.0 ($P < 0.01$)	88.4
Producing biomass makes my overall business stronger.	4.09	375.5 ($P < 0.01$)	86.4
I began producing biomass so I could contribute to renewable energy production using a resource that would otherwise be wasted.	4.00	253.5 ($P < 0.01$)	75.0
I have to be able to produce biomass from logging residues for my business to remain competitive.	3.86	302.5 ($P < 0.01$)	79.5
Producing biomass makes running my business more challenging.	3.75	270.0 ($P < 0.01$)	72.7
On average, I make a profit from the biomass I produce.	3.52	184.5 ($P < 0.01$)	61.4
I have never harvested biomass at a financial loss in order to satisfy a landowner.	3.16	56.0 ($P = 0.38$)	47.7
I began producing biomass because a mill that I do business with encouraged me to do so.	2.59	−101.5 ($P = 0.01$)	15.9

[a] 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).

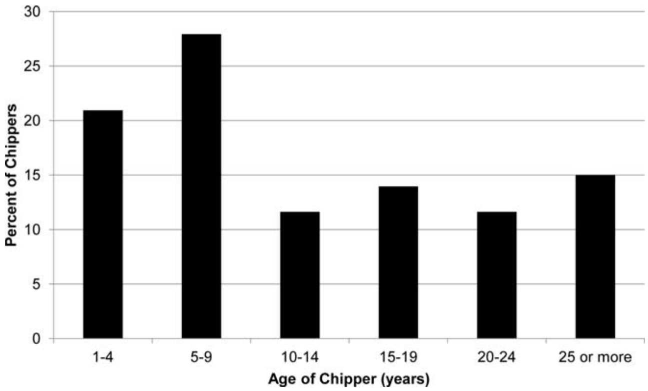

Figure 3.—Age of chipper used for biomass production as reported by logging business owners.

for 5 years or less had an average chipper age of 16 years and those that had produced biomass for over 5 years had an average chipper age of 10.5 years ($P = 0.09$).

Characteristics of businesses indicating profit from biomass

Owners indicated landowner preference and other competitive factors were important reasons for producing biomass. This can be an important marketing strategy, yet for the long-term viability of integrated biomass production, making a profit on biomass is important. Respondents that were neutral or disagreed with the statement that they profited from biomass production were grouped together and compared with respondents who agreed or strongly agreed (Table 5). Respondents who agreed they profited had significantly less capital invested in biomass production equipment, versus the neutral/disagree group ($P = 0.02$). The two groups had similar biomass production levels and although not significant at the $\alpha = 0.05$ level, those who agreed they profited had lower roundwood production levels than those who disagreed. Additional market or operational variables not measured with the survey could also be impacting the owners opinions related to profit on biomass production.

Table 5.—Response means for operational variables grouped based on agreement to the statement "On average I make profit on biomass I produce."[a]

	Agree (n^b) ($n = 27$)	Neutral or disagree (n^b) ($n = 17$)	P value
Years producing biomass	6.8 (27)	6.8 (17)	0.98
Total years logging	21.4 (25)	25.5 (17)	0.32
Roundwood production level (tons/wk)	626.9 (26)	1,219.1 (17)	0.06
Biomass production level (tons/wk)	228.7 (27)	256.3 (16)	0.58
Average chipper age (y)	13.6 (25)	12.0 (14)	0.64
Average chipper horsepower	480.6 (27)	530.8 (17)	0.52
Total investment in biomass production equipment	$188,500 (26)	$377,143 (14)	0.02

[a] Responses for the group that agreed (strongly agree or agree) compared with the group that was neutral or disagreed using *t* tests.

[b] Some respondents did not provide a response for all operational variables, so the number for each variable may total less than the total group number.

Discussion

Business owner attitudes related to profitability of biomass harvesting

For integrated biomass harvesting operations, biomass is typically a by-product of their primary operations. Biomass markets enable businesses to generate additional revenue from this by-product that may otherwise be left behind on site if there was no market for it. However, changes in market conditions such as quota restrictions, or reductions in price that limit profitability of biomass, limit the ability to produce biomass from residues. Biomass markets appeared to fluctuate in this region and there likely were periods of time when the biomass harvesting equipment was not utilized. Overall, those operations that had less invested in biomass harvesting equipment may have been better prepared to handle periods of time without utilizing the equipment.

The overall average age of chippers was 12.5 years, which was older than the average length of time businesses reported they had been producing biomass (6.8 y). While the questionnaire did not capture data related to the age of chippers when purchased, this appears to indicate that many operations purchased used chippers for use in biomass production. Starting out with a used chipper appeared to be especially common among the smaller biomass producers (<250 tons/wk), which had significantly older chippers (18.7 y) compared with the larger producers (7.7 y). Most operations reported they typically accumulate residues on the landing and only periodically chip residues. In situations where the volume of residues produced is relatively low, chipper utilization is likely low, and businesses that are able to invest less capital by utilizing an older used chipper as opposed to a newer more expensive chipper may be more likely to report that on average they profited from biomass production.

Biomass markets and forest management

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. However, changes in forest management and silvicultural methods could impact the total quantity of biomass available from harvest sites and could also affect operational feasibility of biomass harvesting. For example, shifts from clearcuts to partial harvests or thinnings could potentially result in less biomass available for harvesting and might reduce the feasibility of the biomass harvesting operation if there was not enough biomass available to justify having a chipper. Virginia currently does not have specific biomass harvesting guidelines and BMPs relate primarily to protection of water quality. The survey found that in many cases loggers left residues that otherwise could have been utilized for biomass because they realized they were more valuable for BMP implementation. Biomass harvesting guidelines that require a percentage of residues left on site could decrease the total potential supply of biomass and impact the feasibility of biomass harvesting by limiting total volume of residues available for harvest.

Respondents indicated that many landowners prefer harvests by a logger with a chipper. Responses to open-ended questions indicated that loggers felt the landowners preferred the appearance of sites where residues were harvested. Improved postharvest aesthetics could allow more options for management and harvesting of stands where private landowners might otherwise be opposed to harvesting operations. Strong markets for biomass may also allow for additional forest management activities and harvesting of low-quality stands that might not otherwise be feasible to harvest. With respondents indicating 16 percent of material used for biomass came from tracts bought specifically for chipping, some business owners appear to be taking biomass markets into account in their procurement strategies. These businesses may be acquiring lower quality stands that may not otherwise be feasible to harvest and waiting until biomass prices make them feasible to harvest.

Competition among biomass consumers can impact markets for biomass as well as roundwood products since biomass can potentially be produced from roundwood as well as logging residues. While differences in product prices typically prevent this from happening, markets can fluctuate and at times market prices may result in pulpwood being used for biomass energy. Some respondents indicated market prices at times justified using pulpwood for biomass (Fig. 2), while at other times respondents indicated the biomass prices did not justify the cost of harvesting the biomass. Increased competition from additional biomass consumers could cause changes in the markets that would impact pulpwood markets and potentially could impact sawtimber markets as well.

Conclusions

In a region with active markets for biomass and roundwood, a variety of logging operations were able to integrate biomass harvesting into ongoing operations to produce biomass from logging residues. Business owners generally believed that deciding to produce biomass was a good decision for their business. Owners were more likely to decide to produce biomass to satisfy landowner demand than because a mill had encouraged them to do so. This could be an important factor for logging businesses, especially in regions where harvests primarily occur on nonindustrial private landowner properties. Where biomass markets develop, utilization of logging residues among existing logging businesses may become more widely adopted over time as landowners express a preference for utilizing harvest residues.

Biomass production levels on integrated harvesting operations were typically less than 200 tons per crew per wk. Many operations chose to utilize used chippers, especially among smaller operations that generate less residue. This strategy of purchasing used chippers allowed businesses to begin harvesting biomass to diversify operations, produce an additional product and satisfy landowners, yet invest less capital in equipment than if they had purchased new chippers.

Respondents who agreed they profited from biomass production also tended to have a lower overall investment in biomass production equipment. This could indicate that for businesses that decide to integrate biomass harvesting into their operations, minimizing the investment in biomass production equipment could be an important factor for being able to profit from biomass harvesting. This appears to be especially true among smaller operations.

Integrated biomass harvesting in this region appeared to be advantageous for logging operations of varying sizes. However, even with additional markets, not all logging operations will decide to integrate biomass harvesting into their operations. If biomass consumption increases substantially, additional biomass could be produced by utilizing logging residues generated from logging businesses that do not integrate residue harvesting into their operations. Additional research could be needed to identify strategies and best practices for utilizing logging residues generated by conventional operations that do not utilize their own residues.

Acknowledgments

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