Operational Characteristics and Business Perspectives of Wood Pellet Producers and Feedstock Suppliers in the Southeastern US

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Abstract

Wood pellet mills purchase millions of tons of timber in the southeastern United States, yet little is known about their fiber sourcing practices or suppliers. The objectives of this study were to (1) characterize wood pellet feedstock suppliers (i.e., logging businesses); (2) assess the perceived impact of supplying wood pellet feedstock on sustainability, harvesting costs, and overall business performance; (3) document raw material sourcing practices of wood pellet mills; and (4) compare the outlook of wood pellet feedstock suppliers and wood pellet producers. We conducted a survey of wood pellet feedstock suppliers and wood pellet mill procurement personnel. The supplier survey was conducted via e-mail, with questionnaires mailed to nonrespondents. The wood pellet producer survey was conducted by e-mail. Adjusted response rates were 14 percent for suppliers and 83 percent for producers. Suppliers were generally satisfied with their decision to harvest and deliver timber to pellet mills. Business diversification and increased competitiveness were frequently cited benefits of delivering timber to pellet mills. Suppliers and pellet producers considered harvesting practices to be sustainable and consistent with conventional harvesting practices in terms of effects on soil quality, water quality, and ease of forestry best management practices implementation. Most procurement managers (70%) believed that the pellet industry would increase timber purchases in the region. Suppliers and pellet producers perceived that timber supplied to pellet mills was harvested sustainably and that this market strengthened suppliers' businesses, although harvesting and delivering timber to pellet mills did present unique challenges.

During the past decade, heightened concern related to climate change and consumption of fossil fuels has led to an increasing worldwide demand for renewable sources of energy (Camia et al. 2018, Aguilar et al. 2020, Kittler et al. 2020, Franco 2022). The European Union's recent Renewable Energy Directive III (RED III; European Commission 2023) outlined significant targets for the proportion of renewable energy consumed by its member nations, requiring a minimum of 42.5 percent of all energy to be produced from renewable sources by 2030. To meet these targets, many European nations are integrating biofuels into their national energy budgets, with wood pellets serving as one of the primary sources of imported and consumed energy feedstock (Aguilar et al. 2020, Kittler et al. 2020, Franco 2022).

The United States is currently the largest exporter of wood pellets to the European Union, with most of its wood pellet exports sourced from the southeastern United States (Aguilar et al. 2020, Bays et al. 2024). Several significant factors, including the highly productive forests in the southeastern United States, existing wood product facilities and markets, and proximity to European seaports, have led to the growth of a significant market for wood pellet production and export within the region (Parish et al. 2018). In 2023, the United States exported over 9.6 million tons of wood pellets, with exports having steadily increased each year since 2013 (Aguilar et al. 2020). A robust market system for wood pellet feedstock production and transport exists within the region to support these exports, involving a network of stakeholder groups including wood

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pellet production facilities, forest landowners, and logging businesses (Parish et al. 2018).

Wood pellet feedstock, or the raw material used by production facilities to make wood pellets, can be procured from several sources (Galik et al. 2009, Aguilar et al. 2020, Kittler et al. 2020). Before the establishment of the RED III, wood pellet mills in the southeastern United States primarily used mill residues, or excess fibers sourced from primary wood product mills (e.g., sawdust and shavings), for wood pellet production (Aguilar et al. 2020). Implementation of the RED III and the subsequent increase in international demand for wood pellets led to greater demand for feedstock from the United States, resulting in pellet mills procuring raw material from forest harvesting operations (Kittler et al. 2020, Bays et al. 2024). Wood pellet feedstock is harvested from forests in forms such as pulpwood-sized roundwood stems or forest residues (tree limbs and tops) processed into in-woods chips or grindings (Kline et al. 2021, Lundbäck et al. 2021). Currently, pulpwood-sized roundwood and mill residuals make up the majority of feedstock consumed by pellet mills in the United States, with approximately 7 million green tons of roundwood consumed by southeastern US pellet mills in 2015 (Brandeis and Abt 2019, Kittler et al. 2020).

In the southeastern United States, most forestland (86%) is privately owned, with independent logging contractors serving as key contributors to the region's supply of wood fiber (Wear and Greis 2013). The typical logging business owner in the southeastern United States is about 50 to 60 years old and employs an average of 12 to 14 people (Conrad et al. 2024). Harvests of loblolly pine (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm. var. *elliottii*) from planted forests are common and represent a significant amount of the region's timber harvest volume (Schultz 1999). "Whole-tree" harvesting systems are prevalent throughout the region, where stems are felled within the harvest area and then transported to logging decks by skidders, where stems undergo processing before being loaded for transport to wood product facilities (Conrad et al. 2018a). Equipment mixes for these types of harvesting systems often consist of rubber-tired drive-to-tree feller-bunchers, grapple skidders, and trailer-mounted loaders (Barrett et al. 2014, Hanzelka et al. 2016, Conrad et al. 2018a).

When biomass harvesting occurs in the southeastern United States, it is generally "integrated" into conventional operations, with conventional timber products and raw material for bioenergy production harvested simultaneously on the same site (Garren et al. 2022a, Bays et al. 2024). In this context, biomass or bioenergy harvesting refers to forest operations that chip and harvest logging residues (such as nonmerchantable tree limbs and tops) for bioenergy production. In-woods chipping or grinding units represent potential additions to the equipment mix of biomass harvesting businesses, allowing them to process raw material on-site into a usable pellet feedstock form (Barrett et al. 2014, Hanzelka et al. 2016, Conrad et al. 2018b, Garren et al. 2022a, Smidt et al. 2023). In the Virginia Coastal Plain, biomass harvesting businesses were found to own and utilize at least one chipper, with the average chipper age being seven years (Garren et al. 2022a). Chip vans are used to transport chips from logging sites to pellet facilities (Barrett et al. 2014, Garren et al. 2022a).

The ability of pellet feedstock harvest operations to utilize otherwise nonmerchantable material has led to concerns regarding their environmental sustainability (Bays et al. 2024). Logging slash is often distributed throughout site access features, such as landings and skid trails, to stabilize the soil and reduce the potential for postharvest soil erosion as a component of state forestry best management practices (BMPs) (Virginia Department of Forestry 2011, Georgia Forestry Commission 2019, Fielding et al. 2022, Hawks et al. 2023). It has been suggested that high levels of forest residue harvesting by bioenergy harvesting could leave harvest sites with insufficient levels of slash necessary to implement forestry BMPs (Vance et al. 2018). Recent studies evaluating postharvest biomass harvest site conditions have found no evidence to support these claims, however (Garren et al. 2022a, Hawks et al. 2023, Parajuli et al. 2024). Alongside water-quality BMPs, the southeastern states of Virginia and South Carolina have implemented biomass harvesting guidelines (BHGs) that provide recommendations for conducting sustainable biomass harvests (Fritts et al. 2014, Kittler et al. 2020, Bays et al. 2024). These guidelines seek to preserve soil quality, water quality, and biodiversity after a biomass harvest (Titus et al. 2021). As biomass harvesting is a relatively new component of the southeastern US wood supply chain, it is crucial to further understand how these harvesting operations may result in different environmental effects on a forest stand than conventional harvesting operations.

The environmental sustainability of bioenergy harvesting operations is addressed using certification programs such as the Sustainable Biomass Program (SBP; Sustainable Biomass Program 2019, Bays et al. 2024). Wood bioenergy mills certified by these programs make a commitment to ensure that wood supplied to their facility is sourced from sustainable logging operations that adhere to a set of sourcing criteria, as well as state and regional BMPs (Sustainable Biomass Program 2019). These criteria are evaluated through regular audits of logging sites from which bioenergy mills source raw materials (Sustainable Biomass Program 2019, Bays et al. 2024). Bioenergy producers that adhere to SBP or other European Commission-approved voluntary certification schemes receive a "sustainable" designation and are viewed preferentially for bioenergy trade and subsidies (Kittler et al. 2020).

The cost of harvesting raw forest materials for bioenergy production is a topic of frequent evaluation. Several field-based time and motion studies have evaluated per-unit costs of biomass harvesting activities in the southeastern United States and found them to be greater than regional prices for feedstock materials (Conrad et al. 2013, Hanzelka et al. 2016, Garren et al. 2022b). Several other studies, however, have suggested that bioenergy harvesting operations may be profitable under certain market factors and operating conditions (Conrad et al. 2011, Saunders et al. 2012, Conrad 2023). As a bioenergy feedstock, the price for wood pellet feedstocks such as wood chips and grindings is often lower than the price for other types of wood products, despite these feedstocks requiring a greater level of on-site processing than conventional sawtimber and pulpwood products (Barrett et al. 2014). Machines have also been found to be less productive when handling roundwood stems to be marketed for woody biomass production due to the smaller average diameter of those stems (Garren et al. 2022b). Another frequently reported obstacle to biomass harvesting businesses is high equipment costs, with the initial purchase and ongoing maintenance of chippers, grinders, and chip vans representing another significant investment to bioenergy logging businesses (Barrett et al. 2014, North and Pienaar 2021, Garren et al. 2022a, Louis et al. 2024).

Despite these obstacles, bioenergy harvesting activities have been reported to provide several benefits to logging businesses and landowners in addition to representing a supplemental source of income. The results of previous surveys have indicated that loggers and landowners may view sites harvested for bioenergy production as "cleaner-looking" and more aesthetically pleasing than conventional harvested forests, which could represent a competitive advantage in purchasing timber sales for bioenergy logging businesses that can offer to chip forest residues (Barrett et al. 2014, North and Pienaar 2021, Garren et al. 2022a, Louis et al. 2024).

Few studies (Kittler et al. 2020, Parajuli et al. 2024) evaluating characteristics of bioenergy operations in the southeastern United States have distinguished between the characteristics of wood pellet feedstock harvesting operations and those of other biomass harvesting operations. As pellet feedstock harvesting operations have the potential to differ from other operations in methods of feedstock harvesting, processing, and transportation (Spinelli et al. 2019, Kline et al. 2021), evaluation of these characteristics may prove valuable to better understanding bioenergy harvesting operations across the region. Understanding perspectives of logging businesses regarding the environmental sustainability of their operations may also allow for better evaluation of the effectiveness of current biomass harvesting guidelines and sustainability certification programs. Additionally, previous studies (Barrett et al. 2014, North and Pienaar 2021, Garren et al. 2022a, Louis et al. 2024) have evaluated characteristics of biomass logging businesses but not those of the production facilities to which they deliver raw materials. Many of the obstacles to profitable bioenergy feedstock harvesting (such as delivered price for raw material and having reliable markets for feedstock products) are strongly influenced by interactions between wood pellet feedstock suppliers and feedstock-consuming bioenergy mills.

Very little information exists regarding the raw material purchasing practices of wood pellet mills, the characteristics of their suppliers, or the sustainability of harvest timber to supply wood pellet mills. Understanding the perspectives of both pellet feedstock logging businesses in the southeastern United States and the mills to which they supply material may help to provide greater insight into the obstacles to profitable feedstock harvesting operations and how they may be resolved. This study was undertaken to collect data from wood pellet feedstock suppliers (i.e., logging businesses delivering timber to wood pellet mills) and from wood pellet mill procurement representatives to better understand the status, structure, and challenges facing these entities. The objectives of this study were to (1) characterize wood pellet feedstock suppliers; (2) assess the perceived impact of supplying wood pellet feedstock on sustainability, harvesting costs, and overall logging business performance; (3) document the raw material sourcing practices of wood pellet mills; and (4) compare the outlook of wood pellet feedstock suppliers and wood pellet producers.

Materials and Methods

Wood pellet supplier survey

In order to characterize wood pellet feedstock suppliers and assess the perceived impact of supplying wood pellet feedstock on sustainability, harvesting costs, and overall logging business performance, we conducted a survey of wood pellet feedstock suppliers across the southeastern United States (Alabama, Florida, Georgia, Mississippi, Louisiana, North Carolina, South Carolina, and Virginia). We defined "wood pellet feedstock suppliers" as logging businesses in the southeastern United States that harvested raw forest materials (wood chips, roundwood, and forest residues) to deliver to wood pellet mills. A list of suppliers was obtained by contacting regional wood pellet producing companies and requesting a list of suppliers with their contact information. This list was screened to eliminate companies that were no longer in business or did not harvest timber (e.g., sawmills). All suppliers ($N = 218$) that passed this initial screening were included in the survey.

The supplier questionnaire included 25 questions on the topics of operational characteristics (e.g., personnel, equipment) and perceived impact of supplying wood pellet feedstock on sustainability, harvesting costs, and overall logging business performance. The questionnaire included open-ended questions, closed-ended questions, and a series of 5-point Likert scale questions. The questionnaire was adapted from Barrett et al. (2014) and Garren et al. (2022a). The supplier survey was distributed online using Qualtrics software (Qualtrics 2024) with initial distribution in mid-February 2024. Suppliers received an initial e-mail with four follow-up e-mails sent weekly to nonrespondents, resulting in five total contacts, consistent with previous studies (Conrad et al. 2010, Grove et al. 2020). Nonrespondents to the e-mail survey were sent a questionnaire by mail in April 2024 in an attempt to increase the sample size.

Wood pellet producer survey

In order to document the raw material sourcing practices of wood pellet mills and compare the outlook of wood pellet feedstock suppliers and wood pellet producers, we conducted a survey of wood pellet producers (mills) operating within the southeastern United States. Pellet producers were represented by procurement managers that sourced raw forest materials for wood pellet mills in the southeastern United States with an annual pellet production capacity of at least 100,000 US tons. Procurement managers for pellet facilities that did not use raw forest materials (i.e., facilities that only used mill residuals for pellet production) were excluded from the survey. The procurement managers or other senior procurement representatives at all pellet mills with production capacity of more than 100,000 tons of pellets annually ($N = 12$) were included in the survey.

The pellet producer questionnaire contained 18 questions (categorical/continuous, 5-point Likert scale, and open-ended) regarding pellet mill production characteristics and pellet harvesting sustainability perspectives. Eleven 5-point

Likert scale questions were common in both questionnaires to compare logging business owner and pellet mill procurement manager perspectives on sustainability and the impact of harvesting timber to produce wood pellets on logging business performance and harvesting costs. The pellet producer survey was conducted online using Qualtrics software (Qualtrics 2024). Pellet producer representatives ($N = 12$) received an initial e-mail in late-April 2024, with follow-up e-mails sent weekly for four weeks (five total contacts).

Both supplier and producer questionnaires were pretested by biomass procurement managers and authors of previous biomass survey studies prior to distribution to ensure usage of appropriate and consistent terminology. Definitions were provided within the questionnaires for important terms. Roundwood was defined as "pulpwood, logs, or other products sold without being processed by chipping or grinding." Raw forest materials were defined as "products such as wood chips, roundwood, and forest residues that are delivered to pellet mills for the production of wood pellets." Forest residues were defined as "tops, limbs, bark, foliage, and other nonmerchantable materials produced by conventional roundwood timber harvests."

Both the supplier and producer survey protocols were evaluated by the University of Georgia's Institutional Review Board. Neither survey met the federal definition of human subjects research, and both surveys were deemed exempt from a full human subjects research review.

Data analysis

For all 5-point Likert scale questions, the nonparametric Wilcoxon signed-rank tests were used to analyze differences between responses, testing the null hypothesis that the mean response was equal to 3 (neutral response). Differences in mean responses from shared Likert scale questions between feedstock suppliers and pellet producers were evaluated using the nonparametric Kruskal-Wallis test. For open-ended questions, responses were coded and grouped by specific subjects or themes mentioned within each response. Open-ended response themes were summarized by percentage of respondents that provided an answer corresponding to an individual theme.

Analysis for nonresponse bias for the feedstock supplier survey was similarly conducted using the Wilcoxon signed-rank test, which was used to evaluate potential differences in answers from early and late respondents. Responders to the mail survey were considered "late respondents," and their responses were compared to responses received by e-mail from "early respondents" (Armstrong and Overton 1977). No nonresponse testing was conducted on producer survey data because of the small population size. All analyses were performed using JMP statistical software version 17.0 (SAS Institute, Inc. 2024) at $\alpha = 0.05$.

Results

Twenty-five responses were received from pellet feedstock suppliers, 33 responses were received from suppliers outside the target population, and nine invitations were undeliverable, resulting in an adjusted response rate of 14 percent. While a higher response rate would have been preferable, this response rate is comparable to regional logging business owner and mill surveys conducted in the US South (Aguilar 2009, Pokharel et al. 2019, Bowman et al. 2023, Conrad et al. 2024, Conrad and Dwivedi 2025, Khadka et al. 2025).

Responses were received from pellet feedstock suppliers in North Carolina (7), Virginia (6), Georgia (4), Florida (3), South Carolina (3), Mississippi (2), Alabama (1), and Louisiana (1). Each respondent represented a single logging business, with some businesses operating in multiple states. Respondents to the physical mail ($n = 7$) survey had owned their logging businesses for longer than online respondents ($n = 18$; $p = 0.02$), with a mean of 49 years of ownership compared to a mean of 27 years for online respondents. Mail survey respondents were also less likely to use forest residues for feedstock production ($p = 0.04$) than online respondents, with 67 percent of online respondents and 17 percent of physical mail respondents harvesting forest residues during their operations. No significant differences in production levels, equipment mix, crew size, or any other metric were observed between online and mail survey respondents. These results suggest that nonresponse bias may not be a significant issue for most metrics assessed by this study, though care should still be taken in applying the results broadly across the southeastern United States, or to logging businesses that do not supply raw material to pellet mills.

Operational and business characteristics

Mean duration of ownership for pellet feedstock suppliers was 33 years (Table 1). These suppliers operated an average of 3.5 crews, with an average of 7.9 in-woods workers per crew. Fifty-six percent operated two or fewer crews, with 12 percent of businesses operating only one crew. These businesses employed a mean of 18 employees (including foremen, timber cruisers, mechanics, truck drivers, clerical workers, and owners), and a mean of 13 employees excluding truck drivers. Weekly production averaged 747 tons of roundwood per crew. Chipping crews produced a mean of 515 tons wk^{-1} $crew^{-1}$ of chips. The average reported haul distance to wood pellet mills was 43 miles. Suppliers delivered raw material to an average of 1.4 pellet mills, with 58 percent delivering to a single pellet mill. Most (69%) respondents owned at least one whole-tree chipper, with a median of two chippers per operation and an average chipper age of 6 years. No respondent reported owning a horizontal or tub grinder. Sixty-two percent of respondents reported owning one or more chip van(s), with a median of five chip vans per company and an average age of 9 years.

Suppliers reported delivering an average of 55 percent roundwood and 45 percent chips to pellet mills. Most suppliers (56%) delivered both roundwood and chips, while 32 percent delivered only roundwood, and 12 percent delivered only chips. Approximately half (52%) of all respondents indicated they harvested forest residues (tops, limbs, bark, and foliage), while 48 percent did not. All respondents that harvested forest residues utilized an integrated operation, with roundwood and forest residue harvesting occurring simultaneously. Seventy-eight percent of suppliers reported frequently leaving marketable residues on site to ensure proper forestry BMP implementation. Twenty percent of businesses reported not leaving marketable residues behind on any harvest sites, while 33 percent of businesses reported leaving marketable residues behind on 100 percent of harvest sites for BMP implementation. Suppliers harvested wood pellet feedstock from an average of 69 percent of all the tracts that their company harvested. Tracts harvested for wood pellet feedstock had an average area of

Table 1.—Characteristics of pellet feedstock logging businesses obtained from survey responses. Parameters describe material delivered to any type of wood product mill.

Parameter [number of respondents]	Response mean (median)	Standard deviation
Business characteristics		
Duration of logging business ownership (years) [24]	33 (31)	22.4
Total number of employees [25]	18 (19)	9.3
Number of logging crews normally operated [24]	3.5 (2)	3.9
Number of workers per crew [25]	7.9 (7)	3.2
Average haul distance to wood pellet mill (miles) [23]	43 (45)	8.6
Average size of pellet feedstock harvesting tracts (acres) [23]	61 (60)	31.5
Productivity		
Roundwood delivered to mills (tons/wk) [24]	2,481 (1,800)	3,415.7
Roundwood delivered to mills per crew (tons/wk) [24]	747 (770)	486.4
Wood chips delivered to mills (tons/wk) [12]	605 (500)	626.8
Wood chips delivered to mills per crew (tons/wk) [12]	515 (217)	647.4
Total production of roundwood and wood chips (tons/wk) [24]	2,751 (1,810)	3694.4
Total production of roundwood and wood chips per crew (tons/wk) [24]	782 (825)	549.0

61 acres, with approximately two-thirds (69%) of these harvests being clearcuts and one-third (31%) being thinnings. Fifty-five percent of all feedstock harvests were reported to occur within pine (*Pinus* spp.) stands, with an average of 28 percent taking place within mixed stands and 17 percent in hardwood stands.

Wood pellet feedstock supplier perspectives

Most suppliers (79%) began delivering raw materials to wood pellet mills to diversify their business ($p < 0.01$; Table 2). Logging business owners disagreed with the statement that they began harvesting wood pellet feedstock because a mill they do business with encouraged them to do so (29% agreement; $p = 0.04$). Respondents were neutral on whether landowner satisfaction (59% agreement; $p = 0.11$) and competitiveness on purchasing timber sales (48% agreement; $p = 0.17$) were initial reasons for them to begin harvesting wood pellet feedstock.

Most suppliers reported a positive view of their pellet feedstock harvesting operations. Eighty-two percent of respondents indicated that delivering raw material to wood pellet mills made their business stronger ($p < 0.01$). Logging business owners also indicated that they must be able to harvest logging residues to remain competitive when purchasing timber sales ($p = 0.04$). Most respondents indicated that deciding to harvest raw materials to deliver to wood pellet mills had been a good decision (74% agreement; $p < 0.01$). Logging business owners disagreed that they had

Table 2.—Responses from pellet feedstock logging business owners on their reasons to begin and continue harvesting wood pellet feedstock.

Statement	Mean[a]	Wilcoxon signed-rank[b]	% agree or strongly agree
Perspectives on feedstock harvesting			
Delivering raw material to pellet mills makes my overall business stronger.	4.09 A	97.5 ($p < 0.01$)	83
Given the overall impacts to my operation, deciding to harvest raw materials to deliver to pellet mills was a good decision.	3.73 A	85.0 ($p < 0.01$)	74
I must be able to produce raw materials from logging residues for my business to remain competitive in purchasing timber sales.	3.50 AB	53.5 ($p = 0.04$)	59
I have previously harvested raw material to deliver to pellet mills at a financial loss in order to satisfy a landowner.	3.17 AB	18.5 ($p = 0.29$)	57
On most sites, I make a profit on the raw material I deliver to pellet mills.	3.36 AB	43.5 ($p = 0.14$)	56
Pellet harvesting would continue to be economically feasible even if a clean site was not a priority for landowners.	3.22 AB	23.0 ($p = 0.23$)	50
I expect to increase my levels of forest residue harvesting (tree limbs, tops) in the near future.	2.54 B	−47.5 ($p = 0.04$)	18
Reasons to begin pellet feedstock harvesting			
I began delivering raw material to pellet mills to diversify my business.	4.04 A	113.5 ($p < 0.01$)	79
I began delivering raw material to pellet mills to satisfy landowners that wanted logging residues chipped.	3.50 AB	49.5 ($p = 0.11$)	59
I began delivering raw material to pellet mills to increase my total profit.	3.28 AB	28.5 ($p = 0.19$)	57
I began delivering raw material to pellet mills to be competitive on timber sales that require forest residues to be chipped.	3.26 AB	31.5 ($p = 0.17$)	48
I began delivering raw material to pellet mills so that I could contribute to renewable energy production.	3.13 AB	12.5 ($p = 0.34$)	30
I began delivering raw material to pellet mills because a mill that I do business with encouraged me to do it.	2.62 B	−38.5 ($p = 0.04$)	30

[a] Rated on a 5-point Likert scale: 1 = strongly disagree to 5 = strongly agree. Mean responses that do not share letters within groups are significantly different ($\alpha = 0.05$).

[b] P values <0.05 indicate a significant difference from a neutral mean response of 3.

Table 3.—Feedstock logging business owners' perspectives on the cost of conducting feedstock harvesting activities.

Statement	Mean[a]	Wilcoxon signed-rank[b]	% agree or strongly agree
Pellet feedstock processing operations cost more to conduct than conventional operations.	3.59 A	53.0 ($p = 0.04$)	59
Pellet feedstock felling operations cost more to conduct than conventional operations.	3.59 A	79.0 ($p < 0.01$)	50
Pellet feedstock loading operations cost more to conduct than conventional operations.	3.59 A	67.0 ($p < 0.01$)	50
Pellet feedstock skidding operations cost more to conduct than conventional operations.	3.39 A	58.0 ($p = 0.02$)	41
Pellet feedstock hauling operations cost more to conduct than conventional operations.	3.39 A	57.0 ($p = 0.02$)	31

[a] Rated on a 5-point Likert scale: 1 = strongly disagree to 5 = strongly agree. Mean responses that do not share letters within groups are significantly different ($\alpha = 0.05$).
[b] *P* values <0.05 indicate a significant difference from a neutral mean response of 3.

plans to begin or increase their levels of forest residue harvesting (as opposed to pulpwood-sized roundwood harvesting) over the next 5 years ($p = 0.04$). This statement had the lowest overall rate of agreement from respondents, with only 18 percent of respondents indicating agreement or strong agreement. Respondents were significantly more likely to agree that delivering raw materials to pellet mills was a good decision or strengthened their business than they were to agree that they expected to harvest more forest residues in the near future.

Logging business owners were asked to compare the average cost of their pellet feedstock harvesting activities against the cost of their conventional logging activities (Table 3). On most questions, about half of all respondents ($\sim$50%) viewed pellet feedstock harvesting activities as neither more nor less expensive than those of conventional harvesting operations. However, the remaining respondents strongly agreed that pellet feedstock harvesting operations were more expensive. When asked to report how frequently specific factors affected the decision to harvest wood pellet feedstock, logging business owners showed significant agreement that a tract's distance to pellet mills, amount of merchantable material present on a site, and price for delivered feedstock material were all frequent considerations ($p < 0.01$). Distance to the pellet mill was the most commonly reported factor of influence (87%), followed by pellet mill delivered price (83%), and amount of merchantable raw forest materials present (65%).

Suppliers strongly disagreed that harvesting wood pellet feedstock from a site made it more difficult to follow BMPs (75% disagreement; $p < 0.01$). Respondents also disagreed that pellet feedstock harvesting had a greater negative effect on water quality (62% disagreement; $p < 0.01$) or had a greater negative effect on soil quality than conventional operations (59% disagreement; $p < 0.01$). Suppliers largely agreed that pellet feedstock harvesting was a way to contribute to renewable energy production without degrading harvest site quality (71% agreement; $p < 0.01$). Most business owners (71%) also agreed that pellet feedstock harvesting resulted in a more aesthetically pleasing postharvest site than conventional harvests, though this response was not significantly different from neutral ($p = 0.40$).

Wood pellet feedstock supplier interactions with wood pellet mills

Suppliers agreed that wood pellet mills were concerned about BMP implementation (82% agreement; $p < 0.01$). Respondents offered mixed responses on whether there were reliable markets for wood pellet feedstock in their area (52% agreement; $p = 0.32$), and whether wood pellet mills had longer unloading times than other mills (50% agreement; $p = 0.24$). Suppliers disagreed that wood pellet mills offered more consistent wood orders than other types of mills to which they supplied materials (87% disagreement; $p < 0.01$). Suppliers reported being placed on a restrictive quota by pellet mills 61 percent of the year, compared to 46 percent of the year by sawmills and 65 percent of the year by pulp mills ($p = 0.07$).

Advantages and challenges related to pellet feedstock harvesting

Nineteen respondents provided answers to open-ended questions regarding the advantages and disadvantages of delivering raw forest materials to wood pellet mills. The most commonly cited advantages included greater use of raw material and improved aesthetics (49% of respondents provided a response related to either topic (Table 4). Other

Table 4.—Feedstock logging business owners' responses to the advantages and disadvantages of harvesting wood pellet feedstock to supply to pellet mills (n = 19).

	% of responses related to this category[a]
Advantages of harvesting and supplying wood pellet feedstock	
Improved/increased utilization of raw material on-site	49
Improved site aesthetics	49
Landowner satisfaction/competitive advantage for timber sales	32
Access to additional markets	16
Facilitates reforestation activities	16
Challenges to harvesting and supplying wood pellet feedstock	
Chipper initial cost and maintenance	37
Mill delivered price for material	27
Consistency of pellet mill wood orders/restrictive quotas	16
Hauling and fuel costs	16
Pellet mill haul distance and turn times	16

[a] Response categories exceed 100 percent because respondents were able to provide more than one answer per question.

Table 5.—Operational characteristics of wood pellet mills obtained from survey responses ($n = 10$).

Parameter	Response mean (median)	Standard deviation
Facility age (years)	11 (10)	3.7
Annual productions (tons/yr)	590,888 (600,000)	268,047.8
Individual logging business suppliers to facility	48 (30)	43.8
Average haul distance of suppliers to facility (miles)	49 (51)	12.5
Facility procurement radius (miles)	75 (75)	24.9
Average size of harvests supplying raw forest materials (acres)	100 (114)	36.6
Average percent of year facility suppliers are placed on restrictive quota (%)	54 (45)	39.9

common answers included increased landowner satisfaction, access to additional markets and income, and easier facilitation of reforestation activities. Multiple respondents (16%) indicated that local wood pellet mills benefited their logging businesses by replacing dwindling local markets for pulpwood-sized roundwood. When asked about the greatest challenges to conducting profitable wood pellet feedstock harvesting activities, the most frequent response was the initial cost of purchasing and ongoing maintenance costs of operating an in-woods chipper (Table 4). Low prices for delivered material were another frequently reported challenge for pellet feedstock suppliers, as well as high costs of hauling feedstock, increasing fuel costs, inconsistent wood orders, and restrictive quotas from pellet mills.

Wood pellet producers

Ten of 12 procurement managers responded to the survey, yielding a response rate of 83 percent. Wood pellet mills represented by procurement manager respondents had been in operation for an average of 11 years (Table 5). These facilities produced a median of 600,000 tons of wood pellets per year, ranging from 65,000 tons to 1 million tons per year. Pellet mills consumed an average of over 1 million tons of raw forest materials per year, with a minimum of 105,000 tons and a maximum of 2 million tons per year. Pellet mills relied on an average of 48 suppliers per facility. Average reported harvest size among their suppliers was 100 acres. Approximately 57 percent of these harvests were clear-cuts, and 43 percent were thinnings. The average pellet facility procurement radius was 75 miles, with an average haul distance of 49 miles. Mill residues were the most common feedstock used by wood pellet mills (Fig. 1), comprising an average of 39 percent of all feedstock consumed.

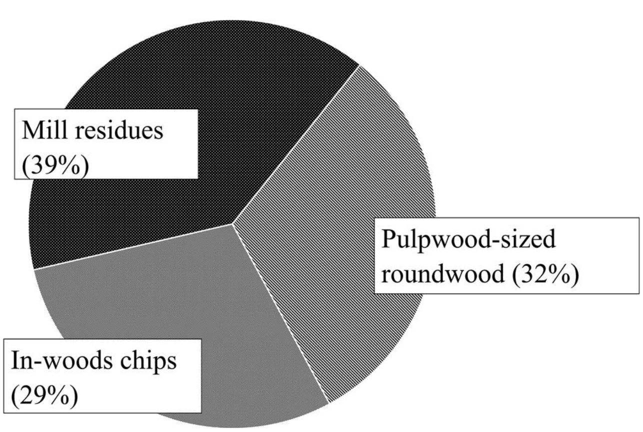

Figure 1.—Mean reported percentages of wood pellet feedstock types used for wood pellet production.

Pulpwood-sized roundwood was the next most common feedstock type (32%), followed by in-woods chips (29%). Only one facility used any proportion of in-woods clean chips (i.e., chips containing no bark).

Procurement manager perspectives

Most pellet mill procurement manager responses were neutral regarding whether their own facility would increase its use of raw forest materials going forward (40% agreement; $p = 0.12$; Table 6). However, most procurement managers believed that the pellet industry would increase its use of raw forest materials over the next 5 years (70% agreement; $p < 0.01$). This could indicate an increasing proportion of raw material procured from in-woods sources, capacity expansions of existing mills, or the construction of new facilities. Procurement managers also believed that wood pellet feedstock harvesting made logging businesses stronger. Managers agreed that harvesting raw materials made a logging business more competitive (80% agreement; $p < 0.01$), and that mill prices allowed suppliers to make a profit (90% agreement; $p < 0.01$). All but one procurement manager (providing a neutral response) reported having strong relationships with their logging business suppliers, and all procurement managers stated that their feedstock suppliers did a good job implementing forestry water-quality BMPs.

When asked about their perspectives on the environmental sustainability of harvesting raw forest materials for wood pellet production, procurement managers showed similar agreement with the perspectives of pellet feedstock logging business owners. Procurement managers disagreed that pellet feedstock harvesting makes it more difficult to follow BMPs ($p < 0.01$), has a greater negative effect on water quality than conventional harvesting operations ($p < 0.01$), or has a greater negative effect on soil quality than conventional harvesting operations ($p < 0.01$). All but one procurement manager disagreed that pellet feedstock harvesting negatively affects postharvest site aesthetics, and all procurement managers agreed that pellet feedstock harvesting represents a way to contribute to renewable energy production without adversely affecting harvest site quality ($p < 0.01$).

Pellet producer and supplier responses related to the effects of feedstock harvesting on site water quality and aesthetics were found to be significantly different from one another ($p = 0.02$; $p = 0.01$), with procurement managers more likely to disagree that feedstock harvesting was detrimental to these factors. Pellet producer and feedstock supplier responses did not differ significantly for questions related to the effects of feedstock harvesting on BMP implementation ($p = 0.81$) or site soil quality ($p = 0.29$), however. Despite these statistical differences in responses related to water quality and aesthetics, both procurement

Table 6.—*Perspectives of wood pellet mill procurement managers regarding the current pellet market and their pellet feedstock suppliers in the southeastern United States.*

Statement	Mean[a]	Wilcoxon signed-rank[b]	% agree or strongly agree
The logging businesses that supply this facility with raw forest materials do a good job of implementing forestry best management practices.	4.8	27.5 ($p < 0.01$)	100
This facility has strong relationships with the logging businesses that supply it with raw forest materials.	4.4	25.0 ($p < 0.01$)	90
This facility's logging and hauling rates for raw forest materials allow suppliers to make a profit.	4.0	27.0 ($p < 0.01$)	90
This facility prioritizes trained logging businesses as its suppliers of raw forest material.	4.5	27.0 ($p < 0.01$)	90
Harvesting raw forest materials to deliver to pellet mills makes a logging business more competitive.	4.1	26.0 ($p < 0.01$)	80
I expect all southeastern pellet facilities' utilization of raw forest materials to increase over the next 5 years.	4.0	24.5 ($p < 0.01$)	70
Harvesting raw forest materials to deliver to pellet mills would be profitable to logging businesses even if a clean site was not a priority to landowners.	3.8	19.0 ($p < 0.01$)	70
I expect this facility's utilization of raw forest materials to increase over the next 5 years.	3.5	12.5 ($p = 0.12$)	40
On average, this facility places its logging business suppliers on quota less frequently than conventional wood product mills.	3.0	0.0 ($p = 0.5$)	40
Raw forest materials are the most economical type of wood pellet feedstock for this facility.	2.5	−14.0 ($p = 0.11$)	20

[a] Rated on a 5-point Likert scale: 1 = strongly disagree to 5 = strongly agree.
[b] P values <0.05 indicate a significant difference from a neutral mean response of 3.

manager and logging business owner responses still showed significant agreement that feedstock harvesting does not negatively affect harvest sites compared to conventional logging operations.

When asked about their facility's greatest challenges to sustainable wood pellet production, five procurement managers reported that few to no significant challenges existed. Three of these procurement managers reported that sustainable sourcing guidelines restricted raw material supply by preventing sourcing from certain forest types (e.g., hardwood swamps, longleaf pine [*Pinus palustris* Mill.] stands). Three other respondents mentioned pellet production being limited by mill size and fixed operational costs such as transportation and labor.

When asked about the greatest challenges faced by logging business suppliers to conduct profitable feedstock harvesting operations, four procurement managers discussed limited local markets for pulpwood, a lack of nearby pellet facilities, or restrictive quotas. One procurement manager reported that their facility was "simply too small to take all residuals processed by local sawmills," and that local feedstock logging businesses would soon be at the point of "leaving residual topwood (pulpwood-sized material) in the woods" because their facility was unable to accommodate the increase in wood utilization provided by local thinning operations. Another procurement manager suggested that logger attrition is likely to become a significant issue in the near future. Two respondents mentioned high costs of chippers and logging equipment as a significant obstacle to feedstock harvesting operations, and another two respondents mentioned rising costs of transportation and competition for labor.

Discussion

Operational characteristics of pellet feedstock logging businesses

Pellet feedstock suppliers had similar productivity to other biomass and conventional logging operations in the southeastern United States. The 2,751 tons per week production level reported by pellet feedstock suppliers was consistent with the median production levels of 2,495 tons per week for biomass logging crews in Virginia's Coastal Plain (Garren et al. 2022a). This level of productivity is also consistent with production levels for all logging businesses in Georgia (2,619 tons wk^{-1}) and Florida (1,956 tons wk^{-1}) (Conrad et al. 2024). Pellet feedstock logging businesses also reported crew counts and sizes consistent with biomass harvesting operations in Alabama (Bowman et al. 2023), the Virginia Coastal Plain (Garren et al. 2022a), and the Coastal Plains of Georgia and Florida (Conrad et al. 2024). Most pellet feedstock logging businesses (65%) owned at least one in-woods chipper, similar to findings reported by Barrett et al. (2014) and Garren et al. (2022a). Mean age of in-woods chippers in this study (6 years) was similar to the average reported by Garren et al. (2022a) of 7 years for Virginia Coastal Plain logging operations and significantly less than the 14-year average age reported by both Barrett et al. (2014) and Garren et al. (2022a) for the Virginia Piedmont. Chipping crews in the Virginia Coastal Plain may achieve higher chipping production levels, larger chip orders, and higher utilization, making it feasible to operate newer chippers than crews located in the Virginia Piedmont, where more challenging terrain, smaller tract sizes, and limited markets exist in some areas.

Perspectives of pellet feedstock logging businesses

Perspectives of wood pellet feedstock suppliers were consistent with those of biomass logging businesses surveyed by previous studies (Barrett et al. 2014, Garren et al. 2022a, Louis et al. 2024, Parajuli et al. 2024). Suppliers harvested and delivered timber to pellet mills to diversify their business, improve landowner satisfaction, and make the business more competitive when purchasing timber sales, not because pellet feedstock harvests are a large profit center. This is logical as pellet feedstock is the least valuable material harvested from a site. Overall, the percentage of logging business owners who reported making a profit on delivered wood pellet feedstock (55%) was similar to the 50 to 60 percent statistics for bioenergy logging businesses reported by Barrett et al. (2014) and Garren et al. (2022a), suggesting that feedstock logging businesses are similarly profitable to other types of biomass harvesting businesses in the southeastern United States. In 2022, around 26 percent of percent of logging businesses in Georgia and 50 percent of logging businesses in Florida reported profitability of their operations as "good" or "excellent," with the remainder reporting break-even or worse profitability (Conrad et al. 2024). Our study suggests that, on average, pellet feedstock logging business owners report higher perceived rates of profitability on pellet feedstock harvests than southeastern logging businesses report from their business's operations overall.

Obstacles for conventional and biomass logging operations, such as high equipment costs, inconsistent mill orders, quotas, and rising hauling and labor costs, have been observed by numerous other studies (Conrad et al. 2011, 2018b, 2024; Saunders et al. 2012; Barrett et al. 2014; Hanzelka et al. 2016; Garren et al. 2022a; Louis et al. 2024) and also serve as significant issues for pellet feedstock suppliers. Responses from this pellet producer survey suggest that procurement managers for wood pellet mills are largely aware of these issues. Several procurement managers reported that their facility's operations were not large enough to consume the available supply of raw forest materials within their region. Whether pellet mills can replace diminishing local markets for pulpwood (as suggested by several logging business respondents) will be dependent upon whether pellet mills are able to expand in both production capacity and abundance throughout the southeastern United States.

Most respondents from the feedstock supplier survey reported similar costs between their conventional and feedstock harvesting activities, though all respondents who did not report similar costs indicated that feedstock harvesting activities were more expensive than conventional operations. Previous studies support this notion, as biomass chips and grindings require more processing than roundwood (Barrett et al. 2014). Feller-bunchers and skidders may also be less productive while handling smaller-diameter stems (Garren et al. 2022b), and increased utilization of on-site raw forest materials may require more skidder passes (Vance et al. 2018). One respondent to the pellet feedstock supplier survey specifically indicated that skidding distance and number of cycles to collect small stems for the pellet market represented a significant challenge. Situations with high fuel prices and low mill delivered prices may further exacerbate these challenges and reduce viability of harvesting low-margin forest residues.

Utilization of roundwood

Roundwood was the most prevalent type of raw forest material (not including mill residues) consumed across all surveyed pellet mill facilities, making up an average of 32 percent of all feedstock consumed, consistent with previous studies (Brandeis and Abt 2019; Kittler et al. 2020). Results of the feedstock supplier and pellet producer surveys support the notion that pulpwood-sized roundwood is the most significant raw forest material feedstock component for wood pellets in the southeastern United States, rather than wood chips or other harvested residuals. About one-third of respondents to the feedstock supplier survey reported harvesting only roundwood to deliver to wood pellet mills. Logging businesses also overwhelmingly reported no intention to increase or expand their use of forest residues over the next 5 years, suggesting that harvesting of pulpwood-sized roundwood, rather than residues, may represent a more profitable endeavor to these operations.

Sustainability of pellet feedstock harvesting operations

Despite concerns noted in the literature regarding the sustainability of forest residue harvesting operations (Vance et al. 2018), wood pellet feedstock suppliers did not view feedstock harvests as damaging to water or soil quality as compared to conventional harvests, a sentiment shared by pellet mill procurement managers. Both groups also disagreed that harvesting raw material to deliver to pellet mills made it more difficult to implement forestry BMPs. Responses from the feedstock supplier and pellet producer surveys indicated that proper BMP implementation was viewed as important by logging businesses and pellet mills alike. Seventy-eight percent of supplier survey respondents reported leaving some merchantable forest residues behind to better implement BMPs, which is slightly higher than the 64 percent and 73 percent statistics reported by Barrett et al. (2014) and Garren et al. (2022a), respectively. All 10 procurement managers reported prioritizing trained logging operations (i.e., Sustainable Forestry Initiative logger training programs; Sustainable Forestry Initiative 2025) as suppliers of wood pellet feedstock. Feedstock suppliers agreed overwhelmingly with the statement that mills they supplied were concerned about proper BMP implementation. As adherence to BMPs is a requirement for participation in certification programs, such as SBP (and is verified by these programs through the use of audits), it is logical that pellet mills wish to ensure BMPs are being properly implemented by the logging businesses that supply them with raw forest materials.

It is important to note that survey respondents were all inherently engaged in the biomass sector, which may have shaped their perspectives regarding the sustainability and economic viability of feedstock harvesting practices. Understanding these perspectives, however, is critical for gaining insight into the motivations, challenges, and business strategies of key stakeholders within the pellet feedstock harvesting and pellet production industries. Surveying stakeholders directly involved within the market for wood pellet production and feedstock harvesting ensures that findings are accurate to the experiences and operational realities of those participating in the market system. Results of this study align with perspectives observed by previous evaluations of biomass feedstock producers and consumers (Barrett et al. 2014, Garren et al. 2022a, Louis et al. 2024, Parajuli et al. 2024), which further reinforces the robustness of these findings.

Conclusions

Overall, wood pellet feedstock suppliers in the southeastern United States reported similar operational characteristics and business perspectives to those of other conventional and biomass harvesting operations in the region. Initial costs of chipper purchase and maintenance continue to be noted obstacles to profitability for pellet feedstock logging operations. Despite these challenges, pellet feedstock suppliers in the southeastern United States look positively on their decision to deliver raw material to pellet mills, citing several reasons for conducting pellet feedstock harvesting operations. These benefits, such as increased business competitiveness and diversification, drive their investment in supplying timber to wood pellet mills.

Suppliers should consider a variety of factors, including price for delivered material, costs to purchase and operate chipping units, and outcomes of benefits such as increased competitiveness and diversification, to best determine the viability of incorporating a pellet feedstock harvesting component into their business. Given the low market value of wood pellets and narrow profit margins in the pellet industry, pellet mill procurement representatives may have limited ability to raise delivered prices to attract and retain suppliers. Nonetheless, they should be aware of the challenges facing suppliers. Improving the consistency of wood orders and clearly communicating expected future demand may cost the pellet mill little or nothing while allowing suppliers to plan more effectively, which may reduce their costs.

Logging business owners and pellet mill procurement managers alike held positive perspectives on the environmental sustainability of pellet feedstock harvesting operations. Proper implementation of forestry BMPs appeared to be an area of regard for both logging business owners and mill procurement managers, with all procurement managers reporting satisfaction with their suppliers' efforts to follow BMPs. Similarly, logging business owners agreed that the pellet mills to which they supplied material were concerned with proper BMP implementation.

Future research could broaden the scope of these findings by incorporating perspectives from other involved stakeholder groups, such as forest landowners that have their property harvested for pellet feedstock, in order to gain a more comprehensive view of perceptions regarding the sustainability of feedstock harvests in the southeastern United States. Additional research evaluating both BMP implementation rates and the environmental effects of residue removals on pellet feedstock harvest sites across the southeastern United States may also provide empirical data regarding the sustainability of these harvests. This may aid policymakers and certification bodies in making informed decisions related to the development of forest residue harvesting standards and sustainability certification frameworks.

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