WOOD PELLET FEEDSTOCK HARVESTING IN THE SOUTHEASTERN US: LOGGING BUSINESS CHARACTERISTICS, MILL PERSPECTIVES, AND POST-HARVEST SITE SUSTAINABILITY CONSIDERATIONS

by

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(Under the Direction of M. Chad Bolding and Joseph Locke Conrad IV)

ABSTRACT

Wood pellet feedstock sourced from southeastern U.S. forests serves a vital role in meeting European renewable energy goals. This study examined 67 recent southeastern pellet feedstock and conventional pulpwood harvests to evaluate the effects of pellet feedstock harvesting on site characteristics and environmental quality. This study also conducted mixed-methods surveys of wood pellet feedstock suppliers and pellet mill procurement managers in the southeastern U.S. to understand their operational characteristics and business perspectives. Characteristics of roundwood harvests for conventional pulpwood and pellet feedstock were found to be similar across all metrics - though pellet feedstock harvests utilizing in-woods chippers displayed slightly more site area in bare soil. Proper implementation of forestry best management practices is important regardless of harvest type. Logging businesses indicated that delivering feedstock to pellet mills strengthened their operations. Feedstock suppliers and mill procurement managers alike expressed strongly positive views on the environmental sustainability of feedstock harvesting operations.

INDEX WORDS: Wood Pellets, Pellet Feedstock Harvesting, Forest Sustainability

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Wood pellets are a type of renewable bioenergy feedstock produced from dried and densified wood fibers. Since their invention in the United States in the 1930's, wood pellets have been used to produce heat and electricity by commercial and industrial operations worldwide (Guo et al. 2015). Demand for renewable sources of energy such as wood pellets has increased significantly over the last decade, largely driven by global concerns regarding the effects of climate change and fossil fuel consumption (Fingerman et al. 2017; Camia et al. 2018; Aguilar et al. 2020; Franco 2022). To address these concerns, government entities have developed policies that seek to substitute consumption of nonrenewable energy with that of renewable energy sources such as bioenergy (Camia et al 2018; European Commission 2024). The most prominent example of this is the European Union's Renewable Energy Directive (RED) III, which requires EU member nations to obtain at least 42.5% of their energy from renewable sources by 2030 (European Commission 2024). Characteristics of wood pellets, including their high energy density and ease of combustion, have led to many European nations attaining progress towards RED goals by "co-firing" wood pellets alongside conventional coal fuels (Kittler et al. 2020; Franco 2022). The EU currently classifies renewable wood pellets as a carbon-neutral source of energy, provided that emissions produced by burning pellet feedstock are recaptured in an equivalent amount by planted or naturally regenerated forest stands (Camia et al. 2018).

Wood pellets are currently the most common bioenergy feedstock consumed to meet renewable policy goals worldwide (Thrän et al. 2018; Flach et al. 2020; Franco et al. 2022). EU member nations consume more wood pellets than they produce, with most imported wood pellets sourced from the United States (U.S.) (Franco et al. 2022). The U.S. is the largest national exporter of wood pellets in the world, having contributed 27% of total worldwide wood pellet exports in 2021 (Aguilar et al. 2020). The U.S.'s current wood pellet production capacity is 10.7 million tons of pellets per year (EIA 2024). The southeastern region of the U.S. has provided the majority of the U.S.'s wood pellet exports since the introduction of the RED in 2009 (Dale et al. 2017; Aguilar et al. 2020). Existing infrastructure for forest products industries, a wide area of private forests to source fiber from, and close proximity to European seaports all contributed to the development of a significant export market for wood pellets in the southeastern U.S. (Parish et al. 2018; Aguilar et al. 2020). While wood pellet exports make up only approximately 4% of all forest removals in the southeastern U.S., they represent a significant market in the region, involving stakeholder groups such as loggers, landowners, and wood pellet mills (Parish et al. 2018). As global demand for wood pellets has steadily increased over the last decade, it is expected that U.S. production and exports of wood pellets will continue to rise over the coming years (Duden et al. 2017; Aguilar et al. 2020; Franco 2022; Bays et al. 2024).

WOOD PELLET FEEDSTOCK PROCUREMENT IN THE SOUTHEASTERN U.S.

Before the introduction of the RED in 2009, most wood pellets produced in the U.S. were consumed domestically for heating and electrical production needs (Parish et al 2018; Kittler et al. 2020). Feedstock used to produce wood pellets was primarily composed of "mill residues" such as sawdust and shavings procured from local wood product mills. After 2009, wood pellet mills built in the southeastern U.S. received significant expansions in scale to meet rising overseas demand for wood pellet export (Bays et al. 2024). As existing supplies of mill residues were insufficient to meet the rising demand, pellet mills began to seek out raw forest materials as feedstock for pellet production (Aguilar et al. 2020; Bays et al. 2024). These materials can be harvested from southeastern forests in several forms. Conventional logging operations produce “forest residues”, or nonmerchantable tree limbs and tops, during harvesting and processing activities (Galik et al. 2009). These residues can be put into an in-woods chipper or grinder to produce wood chips for use as wood pellet feedstock (Galik et al. 2009; Barrett et al. 2014). In addition to forest residues, pulpwood-sized (or smaller) roundwood stems can be harvested directly from a site for use as wood pellet feedstock. Together, mill residues and pulpwood-sized roundwood stems have historically made up the largest proportion of feedstock consumed by wood pellet mills. This is primarily due to the relatively low price and limited processing these materials require for use as pellet feedstock (Kittler et al. 2020; Parajuli et al. 2023).

Today, wood pellet mills in the southeastern U.S. follow conventional fiber procurement strategies for the region (Conrad et al. 2011; Kittler et al. 2020). A procurement manager purchases raw forest materials from local wood dealers, logging businesses, or sometimes forest landowners directly, and coordinates with logging crews to harvest and deliver these raw materials to the mill (Conrad 2021). After harvesting, raw materials are then delivered to mills either via logging trucks or chip vans made to efficiently transport chipped feedstock material (Barrett et al. 2014; Garren et al. 2022). Upon delivery of materials to the facility, a ‘haul rate’ is paid by the mill, which is calculated per loaded ton of raw material delivered (Conrad 2021).

CONVENTIONAL AND BIOMASS LOGGING OPERATIONS IN THE SOUTHEASTERN U.S.

With the majority of forestland in the southeastern U.S. being privately owned, independent logging businesses serve as vital contributors to the southeastern wood products industry (Wear and Greis, 2013). Intensively managed, short-rotation loblolly (*Pinus taeda* L.)

and slash pine (*P. elliottii* Engelm. Var. *elliottii*) plantations are abundant in the southeastern U.S. (Hanson et al. 2010). Pine stands (*Pinus* spp.) supply the majority of the region's sawtimber and pulpwood harvests by volume (Schultz 1999). Southeastern harvesting operations utilize "whole-tree" harvesting systems, in which stems are felled within the harvest area, transported to the logging deck by skidders, and then undergo processing at the deck before being loaded for secondary transport to wood product facilities (Conrad et al. 2018). This process generally results in an accumulation of logging slash and debris piles at the landing.

Logging businesses in southeastern states such as Georgia and Florida typically employ an average of 12-14 employees, with an average business owner age of 50-60 years (Conrad et al. 2024). Typical equipment mixes for southeastern U.S. whole-tree logging operations include rubber-tired drive-to-tree feller-bunchers, grapple skidders and trailer-mounted loaders (Barrett et al. 2014; Hanzelka et al. 2016; Conrad et al. 2018; Garren et al. 2022a). About 80% of logging operations in Georgia and South Carolina have been found to use conventional feller-buncher/grapple skidder systems (Conrad et al. 2018; Conrad et al. 2024). Equipment mixes may differ slightly for bioenergy feedstock harvesting operations (Barrett et al. 2014; Garren et al. 2022a). In this context, biomass or bioenergy harvesting refers to forest operations that chip and harvest logging residues in any form for bioenergy production. Biomass logging businesses in the southeastern U.S. frequently utilize in-wood chipping or grinding units to produce feedstock for bioenergy mills (Barrett et al. 2014; Garren et al. 2022a). Biomass logging businesses commonly also use chip vans, which allow for easy loading and unloading of raw materials to efficiently transport feedstock to mills. In the southeastern U.S., pellet feedstock harvests are generally integrated into conventional harvesting operations, with both practices often occurring simultaneously (Garren et al. 2022a).

Typical bioenergy harvesting operations in the southeastern U.S. include both clearcut harvests and thinnings (Morrison and Golden 2016; Bays et al. 2024). Thinnings are a silvicultural treatment in which stems of smaller diameter or lower vigor are harvested from a stand until a desired density is achieved – allowing residual stems to grow larger and increase in value. As thinnings are typically conducted earlier in the development of a forest stand, this produces a harvest of small-diameter, pulpwood-sized roundwood stems that are suitable for use as wood pellet feedstock (Morrison and Golden 2016). Thinning represents an opportunity for forest landowners to profit from small-diameter material, increase the value of future harvests, and improve stand health by decreasing the risks of fire and pest infestation such as southern pine beetle (*Dendroctonus frontalis* Zimmermann) that may result from a high stand density (Ribe et al. 2022).

BENEFITS AND CHALLENGES OF BIOMASS HARVESTING

The profitability of biomass harvesting operations in the southeastern U.S. is a subject of frequent discussion. Several field-based observational studies have found biomass logging operation to be only marginally profitable or unprofitable altogether at market cut-and-haul rates (Conrad et al. 2013, Hanzelka et al. 2016, Garren et al. 2022b). Other studies 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). When surveyed, 50-60% of Virginia biomass harvesting businesses reported making a profit from the feedstock they delivered to bioenergy mills (Barrett et al. 2016; Garren et al. 2022a).

In addition to obstacles frequently faced by conventional logging operations in the southeastern U.S. (such as frequent mill quotas, high fuel costs, and a diminishing workforce), biomass logging businesses report unique obstacles of their own to conducting profitable feedstock harvesting operations (Barrett et al. 2014; Garren et al. 2022a; Louis et al. 2024). The cost to purchase and maintain in-woods chipping units represents a significant barrier to entry for loggers to enter the market. 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). Some types of biomass feedstock may also require more processing than conventional products such as sawtimber and pulpwood, despite being a lower-margin product (Barrett et al. 2014).

Despite these obstacles, biomass logging businesses may also receive several financial and non-financial benefits related to feedstock harvesting. As biomass harvesting can remove additional woody debris and logging residues from a harvest site, sites harvested for feedstock production are frequently considered 'cleaner-looking' and more aesthetically pleasing than conventional harvest sites (Barrett et al. 2014; Garren et al. 2022a; Louis et al. 2024). Many landowners prefer the appearance of these cleaner post-harvest sites, leading to a competitive advantage in timber sales for biomass logging businesses that can provide chipping and residue removal services. The addition of a chipper to a logging business can provide diversification and access to additional markets and sources of revenue (Barrett et al. 2014; Garren et al. 2022a).

SUSTAINABILITY OF BIOMASS FEEDSTOCK HARVESTING OPERATIONS IN THE SOUTHEASTERN U.S.

The ability of biomass harvesting operations to utilize and remove forest residues from a harvest site has led to concerns regarding the environmental sustainability of feedstock harvesting operations (Janowiak and Webster 2010; Titus et al. 2021). In the southeastern U.S., state forestry best management practices (BMPs) recommend distributing residual logging slash throughout operational features such as skid trails to prevent soil erosion (VDOF 2011, Sawyers et al. 2012; GFC 2019, Fielding et al. 2022, Hawks et al. 2022). On-site logging slash has also been found to serve as "soil armor", preventing soil compaction that would result from machine traffic (Parkhurst et al. 2018). Concerns exist that excess removal of logging slash from a harvest site during bioenergy feedstock harvests may result in a lack of slash necessary to properly implement forestry BMPs (Vance et al. 2018). This could result in adverse effects to site soil and water quality following feedstock harvests. Several studies evaluating biomass feedstock harvesting in the southeastern U.S. have found that biomass harvests tend to retain less large diameter logging slash throughout the harvest area and landings than conventional harvesting operations – though not enough to result in significant increases to soil erosion rates (Barrett et al. 2016, Garren et al. 2022a, Hawks et al. 2023, Parajuli et al. 2024). Biomass harvesting has also been theorized to have the potential for greater levels of on-site soil disturbance from machine traffic (Vance et al. 2018). As more raw material is potentially available to harvest on a site, this could lead to more skidder passes to and from the logging deck (Barrett et al. 2016).

Removal of forest residues from a harvest site could also impact the site's capacity to serve as wildlife habitat. Downed woody debris present on a harvest site provides habitat for a variety of wildlife species, including birds, mammals, herpetofauna, and macroinvertebrates (Loeb 1996; Riffel et al. 2011). It is commonly suggested that the abundance of residual woody debris on a harvest site may be correlated with a site's ability to provide lifecycle needs for wildlife (Rudolphi and Gustafsson 2007; Riffel et al. 2011). In particular, standing dead trees, or snags, are known to provide a variety of habitat and lifecycle needs for wildlife, including feeding, shelter from predators, and temperature regulation. As snags may serve as usable feedstock material for wood chip production, concerns exist that feedstock harvests in the southeastern U.S. may excessively remove snags from a site as compared to conventional forest harvests (Rudolphi and Gustafsson 2007; Riffel et al. 2011). Several studies have evaluated the effects of different levels of woody debris removal from southeastern forests on wildlife species such as winter birds, shrews, and rodents (Fritts et al. 2014; Grodsky et al. 2016; Larsen-Gray et al. 2021). Despite existing concerns, these studies generally failed to find a strong association between residual woody debris and the abundance of wildlife present on harvest sites – suggesting that the addition of a woody biomass harvesting component to logging operations in the southeastern U.S. may not result in significant adverse effects to a site's capacity to serve as wildlife habitat.

On a state policy level, concerns related to the environmental impact of feedstock harvesting operations in the southeastern U.S. are generally addressed through the application of forestry water quality BMPs (Titus et al. 2021; Bays et al. 2024). However, two states (Virginia and South Carolina) have established their own set of specific biomass harvesting guidelines (BHGs) to ensure feedstock harvests are conducted sustainably (SCFC 2021; Titus et al. 2021). BHGs for these states provide suggestions for on-site residue retention practices and advise safeguards for ensuring water quality is maintained in critical areas such as streamside management zones. While Virginia and South Carolina are currently the only two states within the southeastern U.S. implementing their own BHGs, these guidelines are more common in northern and midwestern U.S. states (Titus et al. 2021).

As international consumption of wood pellets has increased over the years, the European Union has turned to forest certification systems to ensure that wood pellet feedstock used for energy production is harvested sustainably. These systems, operated by organizations such as the Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC), and most recently the Sustainable Biomass Program (SBP), seek to monitor and evaluate the sustainability of bioenergy harvesting and production operations in forests internationally (Kittler et al. 2020; SBP 2024). Forests must be managed in accordance with a series of environmental and social policies in order to achieve certification, which assess the environmental risks provided by fiber harvesting and sourcing operations (such as forest degradation, water quality issues, and harvesting in sensitive ecosystems such as bottomland hardwood swamps). Forest certification systems also use chain-of-custody requirements to track raw forest materials as they move throughout a supply chain. This information is regularly audited by certification system personnel and can include site visits to confirm details and ensure proper implementation of state forestry BMPs on sites harvested for raw materials (Kittler et al. 2020). Compliance with forest certification systems is ultimately voluntary but provides wood pellet mills in the southeastern U.S. with greater access to European markets for bioenergy (Kittler et al. 2020; Titus et al. 2021; Bays et al. 2024).

STUDY OBJECTIVES

The purpose of this research was to:

1. Map, assess, and compare proportional areas of forest operational features between conventional and pellet feedstock harvesting operations in the southeastern U.S.

2. Evaluate postharvest ground cover and soil disturbance conditions for conventional and pellet feedstock harvesting operations in the southeastern U.S.

3. Assess and compare post-harvest wildlife metrics (frequency of standing dead trees, vegetation height and density, residual basal area) for conventional and pellet feedstock harvesting operations in the southeastern U.S.

4. Compare perspectives of wood pellet feedstock producers and consumers in the southeastern U.S. on the environmental sustainability of pellet feedstock harvesting operations.

5. Understand wood pellet feedstock and consumer attitudes on the future of the southeastern U.S. market for wood pellet production.

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CHAPTER 2

ASSESSING THE POST-HARVEST CHARACTERISTICS OF PELLET FEEDSTOCK AND CONVENTIONAL HARVEST SITES IN THE SOUTHEASTERN U.S.[1]

[1] DiGiacomo, P.M., M.C. Bolding, J.L. Conrad IV, H.L. Munro, K.M. Woosnam. Assessing the Post-Harvest Characteristics of Pellet Feedstock and Conventional Harvest Sites in the Southeastern U.S. Article currently in review by *Forest Science*.

Abstract

Environmental and site quality concerns exist regarding the effect of wood pellet feedstock harvesting on forest soil, water, and wildlife habitat, though limited information is available to characterize these harvests. We evaluated 67 recent pellet feedstock and conventional pulpwood harvests throughout the Coastal Plain of five southeastern U.S. states for operational feature size, soil disturbance, ground cover, snag density, residual basal area, and vegetation height. Sites were organized by harvest type (clearcut or first thinning) and treatment (conventional pulpwood roundwood, pellet roundwood, or pellet in-woods chipped). Pellet roundwood harvests were statistically similar to conventional pulpwood harvests across all metrics. However, in-woods clearcut harvests for chipped pellets displayed approximately 11% more of the total harvest area in bare soil ($p = 0.03$) and 5% total more area in skid trails ($p = 0.05$) than in-woods conventional pulpwood clearcuts. Pellet chipped harvests displayed less area in light slash than pellet roundwood harvests in clearcuts (4% less, $p = 0.06$) and thinnings (3% less, $p = 0.07$), though no differences were found regarding heavy slash and piles. Overall differences in post-harvest characteristics between pellet feedstock and conventional pulpwood harvests were minimal, though in-woods chipping may result in slight alterations to post-harvest ground cover.

Introduction

Over the last decade, annual production of wood biomass pellets has grown in the southeastern United States (U.S.), much of which is exported as a source of renewable energy (Aguilar et al. 2020; Camia et al. 2018; Franco 2022; Fingerman et al. 2017). A significant driver of this increase has been global interest in supplanting fossil fuel consumption with alternative sources of energy, such as renewable biofuels, to reduce emissions of carbon dioxide into the atmosphere (Camia et al. 2018; European Commission 2024; Kittler et al. 2020). The European Union’s ongoing Renewable Energy Directive (currently in its third major iteration and known as RED III) is perhaps the most prominent example of this commitment to renewable energy on a governmental scale – mandating that at least 42.5% of all energy consumed by EU member nations be produced from renewable sources by 2030 (European Commission 2024). Many EU nations, such as Belgium and Denmark, have identified wood pellets as a viable and cost-effective means of meeting the goals outlined in the RED (Aguilar et al. 2020; Camia et al 2018). As a result of this increased demand, the southeastern U.S. has developed a major market for wood pellet exports, driven in part by its highly productive planted forest stands and proximity to European seaports (Parish et al. 2018). The U.S. is currently the largest exporter of wood pellets in the world, with a current export capacity of 10.7 million tons per year in the U.S. South (US EIA 2023). Levels of European wood pellet demand and U.S. wood pellet production are projected to steadily increase in the coming years (Aguilar et al. 2020; Bays et al. 2024; Duden et al. 2017; Franco 2022).

In the southeastern U.S., pellet feedstock harvests are generally integrated into conventional harvesting operations, with both practices often occurring simultaneously (Bays et al. 2024; Garren et al. 2023). Unlike conventional sawtimber and pulpwood harvesting operations, biomass harvests can use woody debris such as tree limbs, tops, and non-merchantable stems that would otherwise be left on site (Barrett et al. 2014; Rudolphi and Gustafsson 2005). These materials are often referred to as “forest residues” or “logging slash” (Galik et al. 2009). Concerns have been raised about how these removals may affect the sustainability of southeastern pellet feedstock harvesting sites in comparison to their conventionally harvested counterparts.

One frequent concern posed regarding pellet feedstock harvesting is the effect of forest residue removal on site soil and water quality (Janowiak and Webster 2010; Titus et al. 2021). In the southeastern U.S., residual logging slash is often retained and distributed on harvest sites to stabilize operational features such as skid trails and logging decks (Cristan et al. 2016; Vinson et al. 2017). The presence of woody debris on these features reduces bare soil and slows the movement of water, leading to reduced erosion rates (Sawyers et al. 2012; Wade et al. 2012). Thus, using woody debris to stabilize skid trails is a common state-approved forestry Best Management Practice (BMP) used by logging operations in the southeastern U.S. to maintain water quality (Fielding et al. 2022; GFC 2019; Hawks et al. 2022; VDOF 2011). Biomass harvesting has also been theorized to have the potential for greater levels of on-site soil disturbance from machine traffic (Vance et al. 2018). More raw material available for harvesting on a site could lead to more skidder passes to and from the logging deck (Barrett et al. 2016). Removal of logging slash from the harvest area could also lead to greater rutting or soil compaction resulting from increased machine contact with bare soil (Parkhurst et al. 2018).

Several studies have examined the effects of biomass harvesting on woody debris retention, soil disturbance, and BMP implementation rates. Biomass harvesting in this context refers to forest operations chipping and harvesting logging residues (in any form) for bioenergy production. Multiple field studies analyzing clearcut harvests in the southeastern U.S. have found that biomass harvests tend to retain less large slash (diameter >1 in) and fewer slash piles than conventional harvesting operations (Barrett et al. 2016, Garren et al. 2022a, Hawks et al. 2023, Parajuli et al. 2024). Despite observing a reduction of large-diameter slash and wood piles present on sites harvested for bioenergy production, these studies failed to find any significant relationship between biomass harvesting treatments and rates of erosion within the harvest area of clearcutting operations. Similarly, other studies have found minimal soil disturbance due to felling and extracting small stems during biomass harvesting (Bolding et al. 2009). Findings suggest that while biomass harvesting operations do reduce slash present on a site, this effect does not necessarily lead to higher rates of erosion, provided that all requisite forestry BMPs are properly observed during and after harvesting, which was also noted by Shepard (2006).

While several studies suggest that current biomass harvesting practices are adequate to prevent elevated erosion rates on harvest sites, other concerns exist regarding removal of downed woody debris from forests within the southeastern United States. Notably, forest residues help meet a range of biological needs for a variety of common forest macro- and microfauna (Loeb 1996; Riffel et al. 2011), including feeding, shelter from predators, and temperature regulation. A prevailing idea has been that abundance of residual woody debris on a harvest site is directly related to a site's suitability as wildlife habitat (Riffel et al. 2011; Rudolphi and Gustafsson 2007). Due to this, some U.S. states (e.g., Virginia, Missouri, and Wisconsin) have developed Biomass Harvesting Guidelines (BHGs) that provide logging operations with instructions for sustainable retention of forest residues on a harvesting site (Fritts et al. 2014; Titus et al. 2021; VDOF 2024). As of 2020, over 15 U.S. states had developed their own biomass harvesting guidelines for sustainable feedstock harvests (Titus et al. 2021). Biomass harvesting operations may also follow regional harvesting guidelines required by biomass market certification schemes, such as the Sustainable Biomass Program (SBP), to gain access to international markets for biomass trade (Bays et al. 2024; Titus et al. 2021). These guidelines vary considerably by state and region, but most recommend managing for some amount of woody debris retention to conserve soil nutrient composition, maintain water quality, and promote biodiversity (Titus et al. 2021).

Snags, or standing dead trees, have been found to provide for the lifecycle needs of numerous avian, mammal, and insect species (Loeb 1996; Riffel et al. 2011). The ability of bioenergy harvests to use forest residues and large woody debris has led to concerns that these harvesting operations may lead to the on-site depletion of snags necessary to meet common lifecycle needs (Riffel et al. 2011; Rudolphi and Gustafsson 2007). As a result, several studies have evaluated the effects of coarse woody debris (CWD) and snag removal on avian, mammal, and macroinvertebrate populations under differing CWD retention levels outlined by biomass harvesting guidelines. Fritts et. al (2014)'s assessment of recent bioenergy clearcuts in Georgia and North Carolina found no significant association between the abundance of forest residues and shrew abundance, but rather an association between vegetative cover and shrew abundance. Two subsequent studies using the same treatment methodology (Fritts et al. 2016; Grodsky et al. 2016) failed to establish any connection between levels of CWD retention and the abundance of both herpetofauna and migratory winter birds. A 10-year study by Larsen-Gray et al. (2021) also found no strong relationship between abundance of common rodent species and CWD across a series of managed pine and hardwood stands in South Carolina. These studies suggested that the addition of a woody biomass harvest to most conventional logging operations may not result in any significant effects to multiple taxa of wildlife present on-site, regardless of biomass harvesting guidelines observed.

Though effects of conventional biomass harvesting operations on forests in the southeastern U.S. have been evaluated by multiple studies, no studies have isolated the effects of specifically harvesting for wood pellet feedstock on sustainability of southeastern forests. Many types of biomass feedstock products exist, including wood chips, grindings, and shavings (Aguilar et al. 2020; Galik et al. 2009; Kittler et al. 2020). As such, it is possible that operational specifics involved in pellet feedstock harvesting operations may result in unique effects regarding slash retention, soil disturbance, and wildlife habitat. Additionally, current field studies have primarily evaluated biomass harvesting conducted using clearcutting (e.g. Barrett et al. 2016; Garren et al. 2022a; Hawks et al. 2023; Parajuli et al. 2024). While clearcut harvesting operations serve as a common source of wood pellet feedstock to southeastern pellet mills, several other sources of raw feedstock material are also often relied upon for pellet production (Bays et al. 2024). Sawdust and wood shaving byproducts from forest products mills, known as "mill residues", are a common feedstock used in wood pellet production (Aguilar et al. 2020; Bays et al. 2024). Wood pellet feedstock is also frequently obtained from silvicultural thinning operations, where small-diameter or low-quality stems (e.g. pulpwood) are removed from a stand to increase accessibility and timber value for a later planned harvest (Buchholz et al. 2021). Clearcut and thinning operations may differ in terms of the machines and product specifications used to harvest merchantable raw materials for pellet production. Harvesting treatments that use in-woods chippers to produce wood chips from forest residues may harvest and use residues differently than treatments that focus on harvesting pulpwood-sized stems as roundwood for pellet production – leading to different post-harvest site characteristics for each (Kline et al.

2021; Spinelli et al. 2019). These alternative harvesting treatments represent novel environments in which to examine effects of pellet feedstock harvesting on site quality and habitat.

To better understand the environmental effects of pellet feedstock harvesting on planted forest stands, we evaluated post-harvest site characteristics between pellet feedstock and conventional pulpwood harvests throughout the Coastal Plain of the southeastern United States. Study objectives included: (1) map, assess, and compare proportional areas of forest operational features (skid trails, decks, streamside management zones (SMZs) harvest area, roads) between conventional and pellet feedstock harvesting operations, (2) evaluate postharvest ground cover and soil disturbance for conventional and pellet feedstock harvesting operations, and (3) assess and compare post-harvest wildlife metrics (frequency of standing dead trees, vegetation height and density, residual basal area) for conventional and pellet feedstock harvesting operations.

Methods

Site Selection and Treatments

Study sites were distributed across the Coastal Plain regions of five states within the southeastern United States: Alabama, Florida, Georgia, Louisiana, and Mississippi (Figure 2.1). Site identification and access was facilitated through cooperation with local wood pellet producing-businesses and a forest real estate investment trust. Sites were primarily planted loblolly pine (*Pinus taeda* L.) stands that were harvested within six months or less of site observation. Harvest study sites were typical of harvesting operations in the southeastern U.S., consisting of clearcuts and first thinnings. Harvests were conducted with rubber-tired drive-to-tree feller-bunchers, grapple skidders, trailer-mounted loaders, and in-woods chippers for two pellet production treatment categories (Conrad et al. 2018; Hanzelka et al. 2016). Each site was a predominantly pulpwood harvest (>50% of material removed was pulpwood sized, i.e., <9 in DBH), as indicated by our wood-consuming cooperators, and was of typical operational size (i.e., 20-200 acres) (Fielding et al. 2022; Horton et al. 2023) for the area.

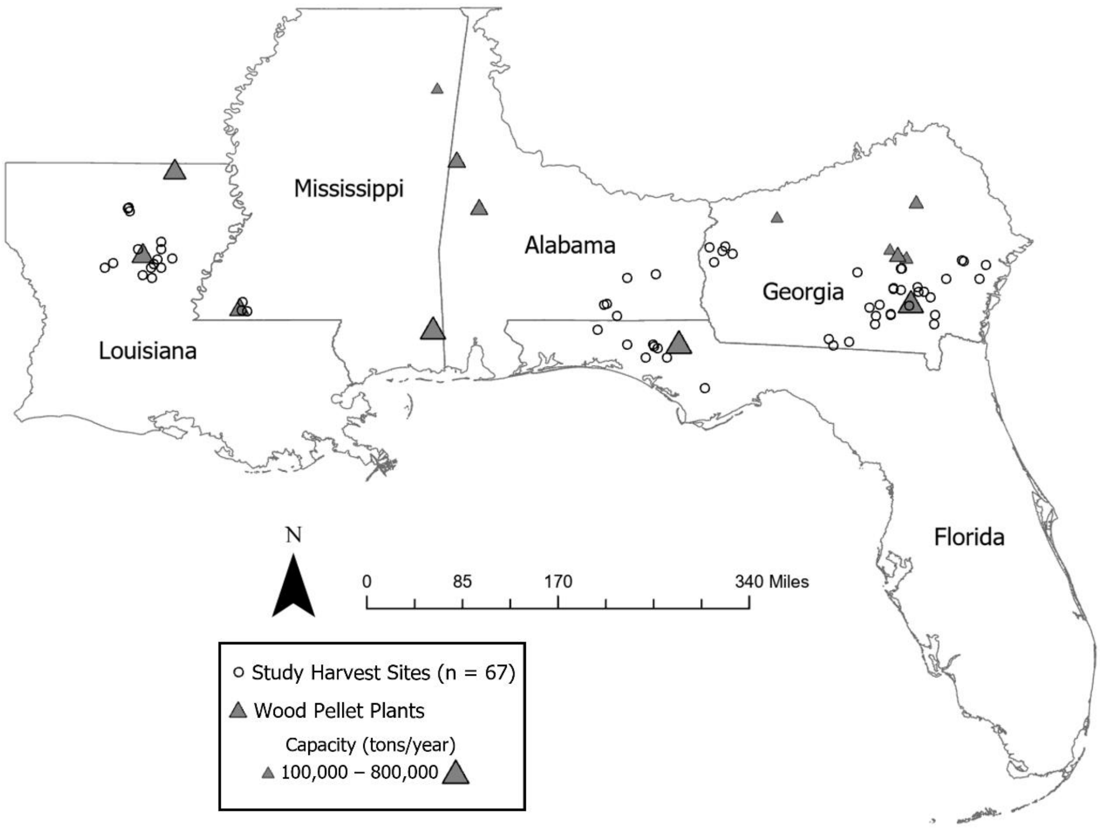

Figure 2.1. Geographic distribution of southeastern harvest sites evaluated by this study across the Coastal Plain physiographic region of the southeastern United States.

We evaluated 67 recent harvest sites from June 2023 to July 2024, including 31 clearcuts and 36 first thinnings. First thinning typically removed every fourth row with machine operator selection between rows. All accessible identified harvest sites that met the above study criteria (recent clearcuts or thinnings in the southeastern U.S.) and fit into one of the following treatment categories were evaluated by the study.

The 67 sites were grouped using the following six treatment categories:

1. Pulpwood roundwood clearcut (8): Clearcut harvest where pulpwood-sized and smaller roundwood material was removed. No material was delivered to pellet production facilities.
2. Pellet roundwood clearcut (12): Clearcut harvest where pulpwood-sized and smaller roundwood material was removed to deliver to wood pellet production facilities.
3. Pellet chipped clearcut (11): Clearcut harvest using an in-woods chipper to produce wood chips from pulpwood-sized and smaller roundwood stems and logging residuals to deliver to pellet production facilities.
4. Pulpwood roundwood thinning (14): Thinning harvest where pulpwood-sized and smaller roundwood material was removed. No material was delivered to pellet production facilities.
5. Pellet roundwood thinning (11): Thinning harvest where pulpwood-sized and smaller roundwood material was removed to deliver to wood pellet production facilities.
6. Pellet chipped thinning (11): Thinning harvest using an in-woods chipper to produce wood chips from pulpwood-sized and smaller roundwood stems and logging residuals to deliver to pellet production facilities.

Operational Feature Mapping

On each site, six operational features (harvest area, skid trails, stream crossings, landings, haul roads, and SMZs) were identified, adapted from classifications used in Christopher and Visser (2007), Hawks et. al (2023), and Horton et al. (2022).

- Harvest area: Areas where timber harvesting was conducted, and that did not belong to any other operational feature class.
- Skid trails: Temporary paths created by repeated skidder traffic through the site for primary transport of stems to the landing.
- Stream crossings: Temporary or permanent stabilized points of access constructed for vehicles to cross active stream features.
- Landings: Central locations for skidders to deliver raw material for processing and loading for secondary transport to wood product facilities.
- Haul roads: Roads used for accessing the harvest site and secondary transport of processed raw material to wood product facilities. Only areas of haul road located within or adjacent to the harvest site boundary were included in the total operational area for a site.
- Streamside management zones (SMZs): Areas located within the harvest boundary with standing stems surrounding streams with widths and stem retention consistent with state best management practices. Common SMZ widths range from 35 to over 50 feet, depending on state BMPs and stream type (VDOF 2011; GFC 2019).

Operational features were identified, traversed, and mapped using a Trimble Nautiz X8 GPS receiver (Trimble 2024). For skid trails and haul roads, width was measured using a 100-ft tape. Harvest site boundaries were obtained from harvest plan maps or aerial imagery, if available, or alternatively by walking harvest boundaries. From GPS data, shapefiles were created for each operational feature, then processed in ArcGIS Pro version 3.2.0 (Esri 2024) to produce a map of operational features within the site's boundaries. Area of each operational feature class (in acres) was then calculated from the shapefiles and width estimates.

Soil Disturbance and Ground Cover

Post-harvest ground cover and soil disturbance categories were visually assessed using sample plots distributed throughout the harvest area of each site. Ground cover and soil disturbance categories were adapted from Eisenbies et al. (2007) and Hawks et al. (2023). The seven ground cover categories included bare soil, forest litter, vegetation, light slash (woody debris <1 inch in diameter), heavy slash (woody debris >1 inch in diameter), slash piles (woody debris stacked to a height of 1 ft or greater), and exposed rock. Four soil disturbance categories were evaluated: undisturbed soils (no visible machine traffic), trafficked soils (soils with visible traffic but without gouges or ruts), lightly disturbed soils (soils containing gouges or ruts <1 ft in depth), and rutted soils (soils containing ruts ≥1 ft in depth). At each sample plot center, the observer visually estimated the proportion of ground area within each of the seven ground cover categories (total of 100%), then repeated this process for the four soil disturbance categories (total of 100%). Ten to fifteen 200-ft^2 sample plots were distributed across the harvest area of each tract, providing a representative sample of each site related to size and terrain variability (Hawks et al. 2023). Each sample plot was established using two 100-ft measuring tapes intersecting perpendicularly, which created four 50 ft^2 square quadrants within each sample plot, each of which were evaluated individually by the observer.

Vegetation Height and Density Sampling

Vegetation height and density sampling was conducted using the visual obstruction method outlined in Robel et al. (1970). A Robel pole was used to measure vegetation height within each existing soil disturbance and ground cover sample plot, with the cover pole placed 50 ft from the plot center (using the azimuth of the first drawn measuring tape) to avoid trampling vegetation prior to measurement. An observer standing 13 ft from the pole recorded the lowest marked band not completely obscured by vegetation, viewing the pole at a consistent height of 39 in from the bottom of the pole. Three additional measurements were recorded at each plot, with additional measurements taken at 90-degree increments from the initial reading.

Basal Area and Snag Sampling

In thinning treatments, a 20-Basal Area Factor (BAF) prism was used to sample post-thinning basal area (ft^2/ac) at the center of each existing soil disturbance and ground cover sampling plot. Snag density (snags/ac) was estimated on each harvest site. Snags were defined as standing dead trees with a diameter at breast height (dbh) of >4 in (Kilgo and Vukovich, 2014; Zarnoch et al. 2013). For clearcuts, each snag within the harvest site boundary was tallied. For thinnings, a 10% stratified strip sample was conducted using 100-ft-wide strips. Strip samples were arranged between consecutive soil disturbance and ground cover plots for efficiency of sampling and to obtain a representative sample of each site.

Data Analysis

Soil disturbance, ground cover, operational feature area proportions, vegetation height (in), basal area (ft^2/ac), and snag density were averaged by site, then organized by harvest type (clearcut or thinning) and treatment (pulpwood roundwood, pellet roundwood, or pellet chipped). Data normality was evaluated using the Shapiro-Wilk Goodness of Fit test and data found to follow a normal distribution were then assessed using a one-way ANOVA test to identify significant differences among harvest treatment categories. The Tukey's HSD test was used to evaluate differences among group means for parametric data. Non-normal datasets were assessed using the non-parametric Kruskal-Wallis test, with the Steel-Dwass multiple comparison test used to determine differences in group medians. All data analyses were performed using JMP statistical software version 17.0 (SAS Institute, Inc. 2024) at $\alpha = 0.1$, as recommended for operational data (Stephano, 2001).

Results and Discussion

Operational Area Features

The mean size of clearcut harvests evaluated by this study was 85.8 acres, similar to Parajuli et al. (2024)'s reported average of 85-100 acres for clearcut harvests in the Coastal Plain of the southeastern United States. The average size of pellet chipped clearcuts (53.8 acres) was significantly smaller than that of both pellet roundwood clearcuts (93.1 acres) and pulpwood roundwood clearcuts (114.7 acres) ($p = 0.01$) (Figure 2.2). These findings suggest that smaller harvest tracts (which may be unsuitable for roundwood harvesting operations) may be more viable for pellet chip harvesting operations. Garren et al. (2022) and Parajuli et al. (2024) also observed smaller tract sizes for southeastern bioenergy harvests as compared to conventional harvests, but did not differentiate between roundwood-only and in-woods chipping bioenergy harvest treatments. The average size of thinning harvest tracts was found to be 69.9 acres, with no significant differences in area between harvest treatment types ($p = 0.43$) (Figure 2.3). Landings in clearcut harvests were larger in size than landings in thinnings ($p < 0.01$), with the average clearcut landing being 0.75 acres and average thinning landing being 0.35 acres. The size of individual landings did not differ by clearcut treatment ($p = 0.14$), or by thinning treatment ($p = 0.27$).

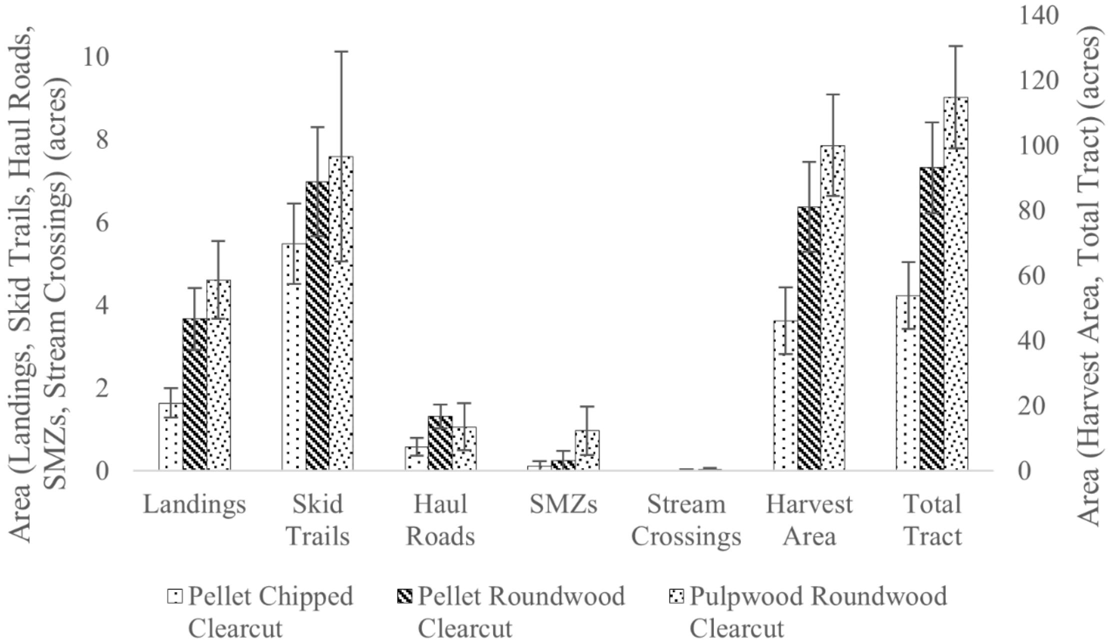

Figure 2.2. Mean areas of clearcut operational features by harvest treatment (in acres). Mean areas of harvest areas and tract areas are plotted on the right axis; mean areas of landings, skid trails, haul roads, SMZs, and stream crossings are plotted on the left axis.

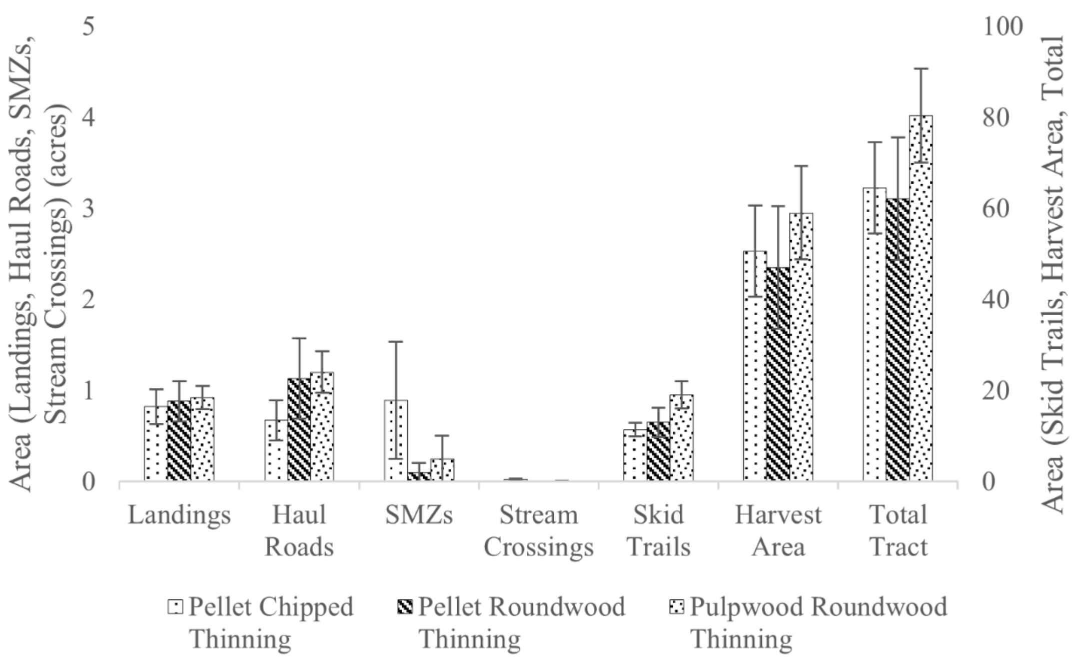

Figure 2.3. Mean areas of thinning operational features by harvest treatment (in acres). Mean areas of skid trails, harvest areas, and tract areas are plotted on the right axis; mean areas of landings, haul roads, SMZs, and stream crossings are plotted on the left axis.

There were no differences in the average proportion of harvest tract area contained in landings ($p = 0.47$), haul roads ($p = 0.55$), stream crossings ($p = 0.13$) or SMZs ($p = 0.28$) among clearcut treatments (Table 2.1). No significant differences were observed in the number of individual landings present per clearcut harvest tract ($p = 0.15$), with the average number of landings per site being 2.5. The average percentage of harvest tract in skid trails was found to be significantly higher in pellet chipped clearcuts than in roundwood pulpwood clearcuts ($p = 0.05$), with pellet chipped clearcuts having approximately 5% more area in skid trail than roundwood pulpwood clearcuts (Table 2.1). The mean percentage of tract area allocated to access features was also found to be higher in pellet chipped clearcuts than conventional roundwood pulpwood clearcuts ($p = 0.07$) – potentially due to the smaller overall size of pellet chipped clearcuts. Among the three observed clearcut harvest treatments, the average percentage of tract allocated to access features was 14%, slightly higher than the 10% found by Horton et al. (2023)'s evaluation of clearcut harvests across the southeastern U.S., and comparable to the 13% observed by Hawks et al. (2023)'s evaluation of clearcuts in the Virginia Coastal Plain.

Table 2.1. Mean and median (in parentheses) percentages of clearcut site area in each operational feature class by harvest treatment.

	Pellet chipped clearcut		Pellet roundwood clearcut		Pulpwood roundwood clearcut			Overall (all treatments)
Operational feature	%	SE	%	SE	%	SE	p	%
Harvest area	84.31^{a} (83.95)	1.21	85.92^{ab} (85.71)	1.47	87.25^{b} (90.22)	1.87	0.07	86.04 (87.02)
SMZ*	0.44 (0.00^{a})	0.44	0.61 (0.00^{a})	0.62	0.88 (0.00^{a})	0.44	0.28	<0.10 (0.00)
All operational	15.70^{a} (16.06)	1.21	14.08^{ab} (14.28)	1.47	12.75^{b} (9.79)	1.87	0.07	14.00 (12.98)
Landing	3.20^{a} (2.89)	0.39	4.00^{a} (3.55)	0.60	4.13^{a} (3.73)	0.58	0.47	3.77 (3.22)
Skid trail	11.40^{a} (11.28)	1.43	8.67^{ab} (8.56)	1.46	6.88^{b} (5.40)	1.71	0.05	9.1 (8.16)
Haul road*	1.10 (0.99^{a})	0.39	1.47 (1.25^{a})	0.40	0.95 (0.64^{a})	0.31	0.28	1.13 (1.02)
Stream crossings*	<0.10 (0.00^{a})	0.00	<0.10 (0.00^{a})	0.00	<0.10 (0.00^{a})	0.00	0.13	<0.10 (0.00)

^{a,b} Denotes statistical differences ($\alpha = 0.1$) between row means or medians that do not share letters.

* Denotes nonparametric data evaluated using the Kruskal-Wallis test

Note: SE = standard error. Standard error of the mean is used for all parametric data, with standard error of the median used for nonparametric data.

There was no evidence to support that pellet feedstock clearcutting operations have a higher percentage of site access features than conventional clearcutting operations – only that pellet chipped clearcuts have larger percentages of site access features than conventional pulpwood clearcuts. Previous studies (Barrett et al. 2016; Vance et al. 2018) have discussed concerns that biomass harvesting treatments may require larger landings or areas of skid trail compared to conventional harvesting operations due to the need for additional skidder passes to harvest on-site forest residues. A higher proportion of site area in access features could be associated with higher rates of soil disturbance, compaction, and erosion resulting from vehicle traffic, which could lead to sedimentation into nearby water features (Barrett et al, 2016; Garren et al. 2022a; Hawks et al. 2023). As such, in-woods chipped clearcuts could be at greater risk of negative effects to site soil and water quality. Overall, pellet chipped clearcuts were found to have about 3% more site area in access features than pulpwood roundwood clearcuts (Table 2.1), differing only about 2-5% from the averages for access features on southeastern harvests found by Hawks et al. (2023) and Horton et al. (2023) respectively.

For thinnings, no differences in the percentage of site in landings, haul roads, stream crossings, or SMZs. were found (Table 2.2). No differences were observed in the number of individual landings present per thinning harvest tract ($p = 0.15$), with the average number of landings per site also being 2.5, similar to clearcut harvests. Conversely to clearcut harvests, the average percentage of harvest tract in skid trails was found to be significantly higher in conventional roundwood pulpwood thinnings as compared to pellet chipped thinnings ($p < 0.01$) (Table 2.2). Roundwood pulpwood thinnings were also found to have a higher percentage of area in access features compared to pellet chipped thinnings ($p = 0.07$). These differences in skid trail and operational feature area may be related to characteristics of sites selected for in-woods chipping operations. As in-woods chipping allows logging operations to merchandise material removed from a stand during pre-commercial thinning operations, it is possible that dense, low-quality forest stands may be more viable for in-woods chipping thinnings than for other types of thinning operations (Hanzelka et al. 2016). Machine traffic through these stands may be more difficult and less tightly organized than those in planted stands, leading to a reduced area present in total skid trails. The average percentage of harvest tract area allocated to access features was found to be approximately 23% for all thinning treatments (Table 2.2).

Table 2.2. Mean and median (in parentheses) percentages of thinning site area in each operational feature class by harvest treatment.

	Pellet chipped thinning		Pellet roundwood thinning		Pulpwood roundwood thinning			Overall (all treatments)
Operational feature	%	SE	%	SE	%	SE	p	%
Harvest area	80.28[a] (74.28)	1.42	76.09[ab] (69.73)	1.74	74.00[b] (68.33)	1.01	0.07	76.56 (70.50)
SMZ*	1.27 (0.00[a])	1.23	0.27 (0.00[a])	0.27	0.16 (0.00[a])	0.16	0.15	0.54 (0.00)
All operational	19.72[a] (19.69)	1.42	23.91[ab] (24.52)	1.74	26.00[b] (25.06)	1.01	0.07	23.44 (23.80)
Landing	1.26[a] (1.09)	0.33	1.27[a] (0.00)	0.14	1.14[a] (1.15)	0.10	0.77	1.22 (1.14)
Skid trail	17.36[a] (18.64)	1.27	20.90[ab] (21.78)	1.50	23.29[b] (22.30)	0.95	<0.01	20.75 (20.47)
Haul road*	0.72 (0.42[a])	0.27	1.54 (1.47[a])	0.51	1.5 (1.19[a])	0.25	0.36	1.28 (1.19)
Stream crossings*	<0.10 (0.00[a])	<0.10	<0.10 (0.00[a])	<0.10	<0.10 (0.00[a])	<0.10	0.19	<0.10 (0.00)

[a,b] Denotes statistical differences ($\alpha = 0.1$) between row means or medians that do not share letters.
* Denotes nonparametric data evaluated using the Kruskal-Wallis test
Note: SE = standard error. Standard error of the mean is used for all parametric data, with standard error of the median used for nonparametric data.

Soil Disturbance and Ground Cover

For clearcuts, the average percentage of bare soil present within harvest areas was 11% higher on pellet chipped clearcuts than both pellet roundwood clearcuts and pulpwood roundwood clearcuts ($p = 0.03$) (Table 2.3). Pellet chipped clearcuts averaged approximately 21% of the site in bare soil, while pellet roundwood clearcuts averaged 10%. Pellet roundwood clearcuts had 4% more of the harvest area in light slash (<1 inch) than pellet chipped clearcuts ($p = 0.06$). No significant differences were observed among treatments in the proportion of harvest area covered in litter, heavy slash, slash piles, or vegetation. These findings differ from recent studies by Hawks et al. (2023) and Parajuli et al. (2024), which observed that biomass clearcut harvests had a smaller proportion of site ground cover in light slash, heavy slash, and slash piles. This study observed significant differences in the proportions of light slash left behind after harvest, but only between pellet chipped and pellet roundwood clearcuts. This suggests that using an in-woods chipper during harvesting may be more of a crucial influence in the amount of light slash remaining post-harvest than whether a site was harvested for bioenergy feedstock.

As the absence of post-harvest logging slash and forest residues on harvest sites has been correlated with increased rates of erosion (Garren et al. 2022a; Hawks et al. 2023; Parajuli et al. 2024), these findings support the notion that pellet feedstock clearcut harvests using an in-woods chipper may be at risk of having more bare soil present on the site. Overall, increased levels of bare soil observed by this study present a low risk for negative site effects. Hawks et al. (2023) and Parajuli et al. (2024) observed similar levels of residual on-site logging slash and litter (over 10% ground covered by slash) and concluded this was sufficient to keep erosion rates to an acceptable level, as they failed to observe differences in erosion rates between biomass and conventional clearcut operations. As pellet roundwood clearcut harvests were not found to be significantly different from conventional roundwood pulpwood clearcuts in any of the measured ground cover metrics, we find that any differences in post-harvest ground cover are likely the result of in-woods chipping operations rather than the process of harvesting for feedstock production itself.

No differences were observed among thinning treatments for average proportion of bare soil, litter, slash piles, or vegetation covering the ground of the harvest area (Table 2.4). Like clearcut harvests, pellet roundwood thinnings had more light slash remaining within the harvest area than pellet chipped thinnings ($p = 0.07$). However, pellet chipped thinnings had a higher amount of heavy slash (>1 inch) left within the harvest area than both pellet roundwood and pulpwood roundwood thinning harvests ($p = 0.04$).

Table 2.3. Mean and median (in parentheses) percentages of clearcut harvest area in each ground cover class by harvest treatment.

Ground cover class	Pellet chipped clearcut %	Pellet chipped clearcut SE	Pellet roundwood clearcut %	Pellet roundwood clearcut SE	Pulpwood roundwood clearcut %	Pulpwood roundwood clearcut SE	p	Overall (all treatments) %
Bare soil*	21.04 (20.36[a])	4.12	11.51 (7.12[ab])	2.57	10.08 (9.07[b])	1.63	0.03	14.31 (11.36)
Litter	27.17[a] (22.6)	6.93	25.40[a] (27.97)	3.74	17.91[a] (15.76)	4.89	0.32	23.99 (23.91)
Light slash*	8.55 (8.87[a])	0.95	12.59 (11.79[b])	1.35	9.42 (10.28[ab])	0.93	0.06	10.40 (10.32)
Heavy slash*	9.10 (9.18[a])	1.35	10.18 (9.36[a])	1.32	9.42 (9.81[a])	2.02	0.81	9.90 (9.47)
Piles*	2.39 (0.41[a])	1.20	1.74 (0.89[a])	0.62	1.74 (1.95[a])	1.32	0.47	2.31 (0.91)
Vegetation	31.60[a] (34.53)	5.61	38.64[a] (41.75)	4.50	49.07[a] (52.49)	7.41	0.14	39.00 (42.42)

[a,b] Denotes statistical differences ($\alpha = 0.1$) between row means or medians that do not share letters.

* Denotes nonparametric data evaluated using the Kruskal-Wallis test

Note: SE = standard error. Standard error of the mean is used for all parametric data, with standard error of the median used for nonparametric data.

Table 2.4. Mean and median (in parentheses) percentages of thinning harvest area in each ground cover class by harvest treatment.

Ground cover class	Pellet chipped thinning %	Pellet chipped thinning SE	Pellet roundwood thinning %	Pellet roundwood thinning SE	Pulpwood roundwood thinning %	Pulpwood roundwood thinning SE	p	Overall (all treatments) %
Bare soil*	3.92^{a} (1.67)	2.16	2.86^{a} (3.14)	0.53	2.76^{a} (2.06)	0.78	0.60	3.14 (2.12)
Litter	35.92^{a} (35.02)	3.86	60.00^{a} (50.37)	5.15	49.43^{a} (54.78)	6.36	0.12	45.79 (47.35)
Light slash*	10.65^{a} (9.32)	1.18	7.54^{b} (7.71)	0.64	8.42^{ab} (7.47)	0.84	0.07	8.83 (8.32)
Heavy slash*	8.71^{a} (8.93)	1.20	4.64^{b} (4.71)	0.97	5.10^{ab} (4.30)	0.90	0.04	6.07 (6.09)
Piles*	0.84 (0.00^{a})	0.82	1.9 (0.03^{a})	1.10	1.69 (0.29^{a})	1.00	0.39	1.49 (0.18)
Vegetation	37.09^{a} (35.67)	2.60	30.64^{a} (29.79)	6.39	31.60^{a} (29.81)	5.14	0.42	32.99 (34.54)

^{a,b} Denotes statistical differences ($\alpha = 0.1$) between row means or medians that do not share letters.

* Denotes nonparametric data evaluated using the Kruskal-Wallis test

Note: SE = standard error. Standard error of the mean is used for all parametric data, with standard error of the median used for nonparametric data.

No differences were observed among harvest treatments in any of the evaluated soil disturbance categories (Table 2.5, Table 2.6) for clearcut and thinning harvests. This finding suggests that, regardless of effects on post-harvest ground cover, pellet feedstock harvests do not result in undue rutting or soil disturbance as compared to conventional roundwood pulpwood harvests in the Coastal Plain. Similar results were observed by Hawks et al. (2023), who found no significant differences in soil disturbance between biomass and conventional harvests in Virginia. We did, however, find that over 90%, on average, of ground within the harvest area of clearcut operations received some level of machine traffic (Table 2.5). This elevated level of traffic could be a result of the relatively flat terrain encountered on Coastal Plain harvest sites, which may incentivize skidder operators to travel more freely throughout a harvest site rather than adhering to designated skid trails. This estimate is also higher than Hawks et al. (2023)'s estimates of 65 – 70% of disturbed ground for Virginia Coastal Plain harvest areas. In contrast to clearcuts, we found the average percentage of undisturbed ground for thinning harvests to be approximately 64%, with only approximately 36% of the harvest area falling into the trafficked, lightly disturbed, or rutted categories (Table 2.6).

Table 2.5. Mean and median (in parentheses) percentages of clearcut harvest area in each soil disturbance class by harvest treatment type.

	Pellet chipped clearcut		Pellet roundwood clearcut		Pulpwood roundwood clearcut			Overall (all treatments)
Soil disturbance class	%	SE	%	SE	%	SE	p	%
Undisturbed*	8.76 (9.47[a])	2.56	10.93 (6.61[a])	3.37	16.18 (8.55[a])	6.90	0.97	11.61 (8.92)
Trafficked	62.65[a] (66.2)	8.32	71.78[a] (73.82)	6.04	60.28[a] (61.905)	4.12	0.46	65.67 (66.32)
Lightly disturbed*	23.41 (14.31[a])	8.65	16.13 (12.05[a])	3.86	16.13 (19.00[a])	4.48	0.61	20.12 (17.86)
Rutted*	5.13 (2.06[a])	2.80	2.64 (0.57[a])	1.32	2.64 (0.59[a])	0.87	0.60	3.20 (0.77)

[a,b] Denotes statistical differences ($\alpha = 0.1$) between row means or medians that do not share letters.
* Denotes nonparametric data evaluated using the Kruskal-Wallis test
Note: SE = standard error. Standard error of the mean is used for all parametric data, with standard error of the median used for nonparametric data.

Table 2.6. Mean and median (in parentheses) percentages of thinning harvest area in each soil disturbance class by harvest treatment type.

	Pellet chipped thinning		Pellet roundwood thinning		Pulpwood roundwood thinning			Overall (all treatments)
Soil disturbance class	%	SE	%	SE	%	SE	p	%
Undisturbed*	63.58[a] (63.37)	4.07	66.03[a] (65.53)	2.83	62.78[a] (62.96)	1.80	0.97	64.02 (63.58)
Trafficked	26.55[a] (20.09)	3.55	26.12[a] (27.55)	2.40	31.76[a] (30.85)	1.45	0.46	28.44 (28.65)
Lightly disturbed*	5.03[a] (4.70)	1.13	5.81[a] (5.80)	0.81	3.95[a] (3.79)	0.67	0.61	4.85 (4.60)
Rutted*	0.79 (0.78[a])	0.22	0.58 (0.23[a])	0.29	0.41 (0.20[a])	0.15	0.60	0.58 (0.26)

[a,b] Denotes statistical differences ($\alpha = 0.1$) between row means or medians that do not share letters.
[*] Denotes nonparametric data evaluated using the Kruskal-Wallis test
Note: SE = standard error. Standard error of the mean is used for all parametric data, with standard error of the median used for nonparametric data.

Wildlife and Habitat Metrics

We found no differences in the average density of snags among harvest treatments for both clearcut ($p = 0.47$) and thinning harvests ($p = 0.24$). The average density of snags was 0.20 snags per acre on pellet chipped clearcuts, 0.08 snags per acre on pellet roundwood clearcuts, and 0.06 snags per acre on pulpwood roundwood thinnings, with a mean of 0.11 snags per acre among all clearcut treatments. As expected, snag abundance was much higher on thinnings than clearcuts. The average density of snags was found to be approximately 1.4 snags per acre on pellet chipped thinnings, 1.13 snags per acre on pellet roundwood thinnings, and 0.78 snags per acre on roundwood pulpwood thinnings, with a mean of 1.05 snags per acre among all thinnings. These findings support the notion that pellet feedstock harvests do not increase the removal of snags from a harvest site as compared to conventional pulpwood roundwood harvests, despite their ability to use forest residues.

Excess removal of basal area from a stand undergoing a thinning could alter canopy conditions and thus influence habitat for various species. There were no differences in residual basal area among thinning treatments ($p = 0.68$), indicating that pellet feedstock harvests do not remove stems in a manner differently than conventional pulpwood harvests. The average residual basal area of thinning harvests was found to be 99 ft^2 ac^{-1} for pellet chipped thinnings, 88 ft^2 ac^{-1} for pellet roundwood thinnings, and 97 ft^2 ac^{-1} for roundwood pulpwood thinnings, with the mean basal area amongst all treatments being 95 ft^2 ac^{-1}. There were also no differences between harvest treatments in terms of dominant vegetation height for both clearcuts ($p = 0.38$) and thinning harvests ($p = 0.64$). Average height of dominant vegetation was 7.2 in on pellet chipped clearcuts, 6.5 in on pellet roundwood clearcuts, and 9.7 in on roundwood pulpwood clearcuts, with a mean of 7.6 in among all clearcut treatments. Vegetation heights for thinnings were not significantly different than those for clearcuts ($p = 0.50$), though mean heights were slightly greater than on clearcuts. The average height of dominant vegetation was 8.8 inches in pellet chipped thinnings, 8.8 inches in pellet roundwood thinnings, and 7.9 inches in pulpwood roundwood thinnings. The mean height of dominant vegetation among all thinning treatments was 8.0 inches. Grodsky et al. (2016)'s evaluation of bioenergy clearcuts for winter bird habitat encountered similar results, failing to find significant differences in vegetation structure between bioenergy and conventional clearcuts in North Carolina under a variety of woody debris removal regimes. Findings from Grodsky et al. (2016) suggest that winter bird perch selection may be more influenced by perch height rather than type (woody debris vs. vegetation). As such, average vegetation height being homogenous among all harvest treatments further supports the notion that bioenergy harvesting operations do not significantly alter a forest stand's quality as habitat as compared to conventional harvests.

Conclusion

Post-harvest characteristics of harvesting operations for conventional roundwood pulpwood and pellet feedstock (both roundwood and in-woods chips) were evaluated for both clearcut and thinning harvests throughout the Coastal Plain of the southeastern United States. Overall, findings from this study did not support concerns that wood pellet feedstock harvests inherently differ from conventional pulpwood harvests regarding the percentage of site in operational and access features, site ground cover, soil disturbance, and wildlife habitat conditions post-harvest.

Clearcut pellet feedstock harvests using an in-woods chipper were, however, found to differ from both conventional pulpwood roundwood clearcut harvests and pellet roundwood clearcut harvests in several metrics – including the proportions of bare soil, light slash, heavy slash, proportional area of skid trails, and total operational features within the site harvest boundaries. The fact that pellet chipped clearcuts were found to have more bare soil than roundwood pulpwood harvests (2x) and less light slash than pellet roundwood clearcuts represents a potential area of further investigation regarding post-harvest soil and water quality. Chipped pellet clearcuts also exhibited significantly higher proportions of area in skid trail as compared to pulpwood roundwood clearcuts, which is generally associated with higher risks of soil disturbance and disruption.

Despite having higher proportions of bare soil, pellet chipped clearcuts had high proportions of litter, vegetation, heavy slash, and slash piles relative to the other two clearcut treatments. This suggests that while pellet feedstock harvesting treatments have an additional source of harvestable materials present in forest residues, they may not adversely affect the proportion of logging slash present on site compared to conventional pulpwood harvests, which may be important for properly stabilizing access features in accordance with state BMPs. Results of the soil disturbance evaluation found no significant differences between harvest treatments for both clearcut and thinning harvests, supporting the idea that pellet feedstock harvests are not excessively disruptive to soil in terms of machine traffic compared to conventional pulpwood harvests. Additionally, no differences were observed among treatments regarding any of the evaluated habitat metrics (snag density, residual basal area, vegetation height), suggesting equivalent post-harvest habitat quality between pellet feedstock and conventional harvests.

In conclusion, this study found that pellet feedstock and conventional harvest clearcut and thinning treatments throughout the Coastal Plain of the southeastern U.S. do not differ significantly from one another regarding important metrics such as ground cover, soil disturbance, wildlife habitat, and access feature prevalence. There was no evidence to support the notion that roundwood pellet feedstock harvests degrade planted forest stands more than conventional roundwood pulpwood harvests. Clearcut harvesting operations that use in-woods chipping may alter post-harvest ground cover conditions in a manner that would advise vigilance in safeguarding against soil erosion and disturbance. As always, it is critical for timber harvesting crews to implement state forestry BMPs before, during, and after harvesting. Future research to better understand why and how in-woods chipping operations can alter post-harvest forest stand conditions may prove beneficial to forest landowners and logging operations throughout the southeastern United States.

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CHAPTER 3

OPERATIONAL CHARACTERISTICS AND BUSINESS PERSPECTIVES OF WOOD PELLET PRODUCERS AND FEEDSTOCK SUPPLIERS IN THE SOUTHEASTERN U.S.[2]

[2] DiGiacomo, P.M., Conrad J.L IV, Bolding M.C., Woosnam K.M., Munro H.L. Operational Characteristics and Business Perspectives of Wood Pellet Producers and Feedstock Suppliers in the Southeastern U.S. To be sent to the *Forest Products Journal*.

Abstract

As the wood pellet market grows and sourcing strategies evolve in response to changing European energy goals, it is crucial to understand the characteristics and perspectives of wood pellet producers and feedstock suppliers in the southeastern United States (U.S). This study developed a pair of mixed-methods surveys to be sent to wood pellet producers and feedstock suppliers throughout the southeastern U.S. (Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, and Louisiana). Feedstock suppliers were active logging businesses in the southeastern U.S. that harvested raw forest materials (wood chips, roundwood, forest residues) to deliver to wood pellet mills. Procurement managers represented active southeastern U.S. wood pellet mills that utilized raw forest materials for pellet production. We sought to better understand the operational characteristics of these groups and their perspectives on pellet feedstock markets and harvesting practice sustainability. Pellet feedstock suppliers cited business diversification and increased competitiveness when purchasing timber sales as reasons to enter the market. Pellet producers and feedstock suppliers alike agreed that feedstock harvesting does not differ from conventional harvesting in terms of impacts to soil quality, water quality, or ease of forestry best management practice (BMP) implementation. Procurement managers and logging business owners viewed each other as being concerned with proper BMP implementation. Most procurement managers (70%) believed that pellet mills throughout the southeastern U.S. would use more raw forest materials in the near future. Responses from logging business owners suggested that delivering raw materials to pellet mills can strengthen their businesses, provided associated challenges are overcome.

Introduction

During the past decade, heightened concern related to climate change and the 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) (November 2023), has outlined significant targets for the proportion of renewable energy consumed by its member nations, requiring a minimum of 42.5% of all consumed energy to be from renewable sources by 2030 (European Union, 2024). 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 (U.S) is currently the largest exporter of wood pellets to the European Union, with the majority of its wood pellet exports sourced from the southeastern U.S. (Aguilar et al. 2020, Bays et al. 2024). Several significant factors, including the southeastern U.S.'s highly productive forests, 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 U.S. exported over 9.6 million tons of wood pellets, with exports having steadily increased each year for the past decade (Aguilar et al. 2020, EIA 2024). 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 pellet production facilities, forest landowners, and logging businesses (Parish et al. 2018).

Wood pellet feedstock, or the raw material utilized 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, wood pellet mills in the southeastern U.S. primarily utilized mill residues, or excess fibers sourced from primary wood product mills (such as sawdust and shavings) for wood pellet production (Aguilar et al. 2020). The implementation of the RED and subsequent increase in international demand for wood pellets led to greater demand for wood pellet feedstock in the U.S. – resulting in pellet mills beginning to procure 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 processed into in-woods chips or grindings (Lündback et al. 2021, Kline et al. 2021). Currently, pulpwood-sized roundwood and mill residuals make up the majority of feedstock consumed by pellet mills in the U.S., with approximately 7 million green tons of roundwood consumed by southeastern pellet mills in 2015 (Brandeis and Abt 2019, Kittler et al. 2020).

In the southeastern U.S., the majority of forestland is privately owned, with independent logging contractors serving as key contributors to the region's supply of wood fiber (Wear and Greis 2013). Harvests of intensively managed loblolly (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. Var. *elliottii*) planted forests are common, and represent a significant amount of the region's produced wood fiber (Schultz, 1999). The typical logging business owner in the southeastern U.S. is about 50-60 years old, and employs an average of 12-14 employees at their business (Conrad et al. 2024). "Whole-tree" harvesting systems are prevalent throughout the southeastern U.S., where stems are felled within the harvest area, transported to the logging deck by skidders, and then undergo processing at the deck before being loaded for secondary 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). Once the harvested material is delivered to a wood product facility, the facility pays their supplier a 'haul rate' calculated per loaded ton of raw material delivered (Conrad 2021).

When biomass harvesting occurs in the southeastern U.S., 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 in any form 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, Diniz 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).

As typical of bioenergy harvesting operations, wood pellet feedstock harvests can utilize smaller or lower-quality woody material (such as tree limbs and tops) that would otherwise be left on site by a conventional harvest (Barrett et al. 2014, Fritts et al. 2014). These materials are often referred to as "forest residues" and represent an additional source of revenue for both forest landowners and logging crews (Galik et al. 2009, Barrett et al. 2014, Garren et al. 2022a). The ability of pellet feedstock harvests to utilize this otherwise nonmerchantable material has led to concerns regarding the environmental sustainability of feedstock harvests, however (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 post-harvest soil erosion as a component of state forestry Best Management Practices (BMPs) (VDOF 2011, GFC 2019, Fielding et al. 2022, Hawks et al. 2023). It has been suggested that high levels of forest residue harvesting by bioenergy logging could leave harvest sites with insufficient levels of slash necessary to implement forestry BMPs (Vance et al. 2018). Recent studies evaluating post-harvest biomass harvest site conditions have found no evidence to support these claims, however (Garren et al. 2022a, Hawks et al. 2023, Parajuli et al. 2023). Alongside BMPs, the southeastern states of Virginia and South Carolina have implemented biomass harvesting guidelines (BHGs) which 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 feedstock harvesting is a relatively new component to the southeastern U.S. market for wood fiber, it is crucial to further understand how feedstock harvesting may result in different environmental effects on a forest stand than conventional harvesting operations.

Concerns related to the environmental sustainability of bioenergy harvesting operations are also addressed using certification schemes such as the Sustainable Biomass Program (SBP) (Bays et al. 2024, Sustainable Biomass Program 2019). 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 sourced 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 has been studied frequently over the last decade. Several field-based time and motion studies have evaluated the per-unit costs of biomass harvesting activities in the southeastern U.S. 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 are often lower than 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). Feedstock hauling distance has been found to be a major factor related to the profitability of biomass harvesting operations, with increased hauling distances resulting in reduced economic viability of harvesting operations (Conrad et al. 2013, North and Pienaar 2021, Louis et al. 2024). Another frequently reported obstacle to biomass harvesting businesses has been 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 forest harvests - 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 the characteristics of bioenergy operations in the southeastern U.S. 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), evaluating these characteristics may prove valuable to better understanding bioenergy harvesting operations across the region. Understanding the perspectives of logging businesses regarding the environmental sustainability of their operations may also allow for more effective 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 the characteristics of biomass logging businesses but not those of the production facilities they deliver raw materials to. Many of the obstacles to profitable bioenergy feedstock harvesting (such as delivered price for raw material and having reliable markets for feedstock products) are heavily influenced by interactions between wood pellet feedstock suppliers and feedstock-consuming bioenergy mills. As such, understanding the perspectives of both pellet feedstock logging businesses in the southeastern U.S. and the mills they provide material to may help provide greater insight into these obstacles to profitable feedstock harvesting operations and how they may be resolved. Objectives of this study included evaluating: (1) operational characteristics of southeastern wood pellet feedstock suppliers and pellet producers, (2) perspectives of wood pellet feedstock suppliers and pellet producers regarding the environmental sustainability of pellet feedstock harvesting, and (3) wood pellet feedstock supplier and pellet producer attitudes on the future of the southeastern market for wood pellet production.

Materials and Methods

This study evaluated characteristics of wood pellet feedstock suppliers and pellet producers across the southeastern U.S. (Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, and Louisiana) using two individual but related survey instruments. For the purposes of this study, "wood pellet feedstock suppliers" were active logging businesses in the southeastern U.S. that harvested raw forest materials (in any form) to deliver to wood pellet mills. "Pellet producers" were represented by procurement managers that sourced raw forest materials such as wood chips, roundwood, and forest residues for active wood pellet mills in the southeastern U.S. with an annual production capacity of 100,000 tons/year of pellets or greater. Procurement managers for pellet facilities that did not utilize raw forest materials (i.e., facilities that only utilized mill residuals for pellet production) were excluded from the survey. Logging businesses that were pellet feedstock suppliers were identified with the help of information provided by regional wood pellet production companies. Initial supplier contacts from these companies were filtered as thoroughly as possible to contact only active logging businesses.

We used a mixed-methods approach of online and mail surveys to evaluate operational characteristics and perspectives regarding the sustainability of pellet feedstock harvesting practices for both wood pellet feedstock suppliers and pellet producers. Survey question design was adapted from Barrett et al. (2014) and Garren et al. (2022a). The pellet feedstock supplier questionnaire contained 25 questions, including categorical and continuous questions regarding business operational characteristics and a series of 5-point Likert scale questions concerning feedstock harvesting business and sustainability perspectives. Three open-ended questions regarding advantages and disadvantages of pellet feedstock harvesting were also included. The pellet producer survey questionnaire contained 18 questions (categorical/continuous, 5-point Likert scale, and open-ended) regarding pellet mill production characteristics and pellet harvesting sustainability perspectives. Eleven Likert-scale questions were common in both questionnaires to compare logging business owner and pellet mill procurement manager perspectives on several subjects. Both survey instruments 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 non-merchantable materials produced by conventional roundwood timber harvests”. Online survey development and distribution was conducted using Qualtrics software (Qualtrics 2024). Each survey instrument was evaluated by the University of Georgia’s Institutional Review Board (IRB) in December of 2023 and deemed exempt from a full human subjects research review.

Online survey distribution of the supplier survey questionnaires began in mid-February 2024, with emailed invitations to participate sent to feedstock logging businesses once per week for five weeks. To obtain additional responses, a round of physical mail surveys was sent in April 2024 to all feedstock logging businesses that had not already responded to the online survey. The final contact list for the supplier survey (online and physical mail) contained a total of 218 potential pellet feedstock logging business owner respondents. This contact list included all in-woods logging business suppliers for the two largest wood pellet production companies in the southeastern U.S. and represents a majority of suppliers to all pellet mills that used raw forest materials within the region. For the pellet producer survey, survey distribution similarly occurred via email. Pellet producer survey questionnaire distribution began in late April 2024, with emailed invitations to participate sent to 12 pellet mill procurement managers once per week for five weeks. While only 12 procurement managers were contacted by this study, this number represents the entirety of the pellet producer study's identified target population – procurement managers for wood pellet mills in the southeastern U.S. with a production capacity of 100,000 tons/year or greater that used raw forest materials for pellet production. Due to the smaller overall population size, the pellet producer survey was conducted as online-only, with no physical mail survey distribution.

Data analysis

For all 5-point Likert scale questions, the nonparametric Wilcoxon signed-rank test was used to analyze differences between responses, testing the null hypothesis that the mean response was equal to 3 (neutral response). 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 questionnaire answers from early and late respondents. Nonrespondents to the initial email survey were mailed physical copies of the survey. Responses received this way were considered 'late respondents' and compared to responses received by email from 'early respondents' (Armstrong and Overton 1977). 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. All analyses were performed using JMP statistical software version 17.0 (SAS Institute, Inc. 2024) at $\alpha = 0.05$.

Results

A total of 218 supplier businesses were sent invitations (by email or physical mail) to participate in the feedstock supplier survey. Of these 218 businesses, 25 responses were received from feedstock supplying businesses, 33 responses were received from suppliers outside the target population, and nine surveys were undeliverable. Seventeen of these twenty-five responses were received by email – seven were received by physical mail. This resulted in an adjusted final response rate of 14.2% for the feedstock supplier survey.

The most common state in which respondents harvested timber was North Carolina (listed by seven respondents), followed by Virginia (six respondents), Georgia (four respondents), Florida and South Carolina (three respondents each), Mississippi (two respondents), and Alabama and Louisiana (one respondent each). Analysis of survey responses revealed that respondents to the physical mail survey had owned their logging businesses for longer than online respondents ($p = 0.02$), with a mean of 49 years of ownership compared to a mean of 27 years of ownership for online respondents. Respondents to the physical mail survey were also less likely to utilize forest residues for feedstock production ($p = 0.04$) than online respondents, with 67% of online respondents and 17% 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 U.S., or to logging businesses that do not utilize forest residues for feedstock production.

Operational and business characteristics

The mean duration of ownership for logging businesses was 33 years (Table 3.1). Logging businesses operated an average of 3.5 crews, with an average of 7.9 in-woods workers per crew. Fifty-six percent of feedstock logging businesses operated two or fewer crews, with twelve percent of businesses operating only one crew. Feedstock logging 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). A mean of 747 tons of roundwood were produced per crew per week by all respondents. Feedstock logging operations that produced wood chips produced a mean of 112 tons wk^{-1} $crew^{-1}$ of chips. The volume of roundwood and wood chips delivered to wood pellet mills was similar among businesses, with 54% of raw material delivered to pellet mills by feedstock logging crews as roundwood and the remaining 45% being as in-woods chips. The average reported haul distance for feedstock to wood pellet mills was 43 miles. Feedstock logging businesses delivered raw materials to an average of 1.4 pellet mills, with slightly over half (58%) delivering to a single pellet mill. Most (68.8%) respondents owned at least one whole-tree chipper, with a median of two chippers per operation and an average age of six years per chipper. No respondent reported owning a horizontal or tub grinder for feedstock processing. Sixty-two percent of respondents reported owning one or more chip vans, with a median of five chip vans per company and an average age of nine years per van.

Table 3.1 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/week) [24]	2,481 (1,800)	3,415.7
Roundwood delivered to mills per crew (tons/week) [24]	747 (770)	486.4
Wood chips delivered to mills (tons/week) [13]	270 (5)	524.7
Wood chips delivered to mills per crew (tons/week) [13]	112 (18)	207.2
Total production of roundwood and wood chips (tons/week) [24]	2,751 (1,810)	3694.4
Total production of roundwood and wood chips per crew (tons/week) [24]	782 (825)	549.0

Eight businesses (32% of respondents) reported delivering only roundwood to pellet mills, and three (12%) reported delivering only wood chips to pellet mills. Approximately half (52%) of all respondents indicated they harvested forest residues (tops, limbs, bark, and foliage) during operations, while 48% indicated that they did not. All respondents that harvested forest residues reported running an integrated operation, with roundwood and forest residue harvesting occurring simultaneously. Approximately 80% of logging business owners reported frequently leaving marketable residues on site to ensure proper forestry BMP implementation. Twenty percent of businesses reported not choosing to leave marketable residues behind on any harvest sites, while 33% percent of businesses reported leaving marketable residues behind on 100% of harvest sites for BMP implementation. Logging business owners were found to harvest wood pellet feedstock on an average of 69% of all harvest tracts. Tracts harvested for wood pellet feedstock had an average area of 61 acres, with about two-thirds (69%) of these feedstock harvests being clearcuts, and one-third (31%) of feedstock harvests being thinnings. Fifty-eight percent of all feedstock harvests were reported to occur within predominantly pine stands, with an average of 33% taking place within mixed stands, and 21% in predominantly hardwood stands.

Wood pellet feedstock supplier perspectives

Pellet feedstock logging business owners were asked questions regarding their initial motivations for deciding to harvest raw forest materials to deliver to wood pellet mills (Table 3.2). Most respondents (79%) began delivering raw materials to wood pellet mills to diversify their business ($p < 0.01$). Logging business owners predominantly 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 statistically 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 logging business owners reported a positive view of their ongoing 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 ($p = 0.04$). When evaluating their feedstock logging operations in retrospect, 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 predominantly disagreed that they had plans to begin or increase their levels of forest residue harvesting (as opposed to pulpwood-sized roundwood harvesting) in the near future ($p = 0.04$) however. This statement had the lowest overall rate of agreement from respondents, with only 18.2% 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 3.3). On most questions, about half of all respondents (~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, the amount of merchantable material present on a site, and the price for delivered feedstock material were all frequent considerations ($p < 0.01$). Mill distance was the most reported factor of influence (87% of respondents), followed by mill delivered price (83% of respondents), and then amount of merchantable raw forest materials present (65% of respondents).

Table 3.2 Responses from pellet feedstock logging business owners on their reasons to begin and continue harvesting wood pellet feedstock.

Statement	Mean	p-value	% agree or strongly agree
Perspectives on feedstock harvesting			
Delivering raw material to pellet mills makes my overall business stronger.	4.09 a	<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	<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	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	0.29	57
On most sites, I make a profit on the raw material I deliver to pellet mills.	3.36 ab	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	0.23	50
I expect to increase my levels of forest residue harvesting (tree limbs, tops) in the near future.	2.54 b	0.04	18
Reasons to begin pellet feedstock harvesting			
I began delivering raw material to pellet mills to diversify my business.	4.04 a	<0.01	79
I began delivering raw material to pellet mills to satisfy landowners that wanted logging residues chipped.	3.50 ab	0.11	59
I began delivering raw material to pellet mills to increase my total profit.	3.28 ab	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	0.17	48
I began delivering raw material to pellet mills so that I could contribute to renewable energy production.	3.13 ab	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	0.04	30

Rated on a 5-point Likert scale: 1=strongly disagree, 5=strongly agree. Mean responses that do not share letters within groups are significantly different ($\alpha = 0.05$). p-values <0.05 indicate a significant difference from a neutral mean response of 3 (evaluated using the nonparametric Wilcoxon signed-rank test).

Table 3.3 Feedstock logging business owners' perspectives on the cost of conducting feedstock harvesting activities.

Statement	Mean	p-value	% agree or strongly agree
Pellet feedstock processing operations cost more to conduct than conventional operations.	3.59 a	0.04	59
Pellet feedstock skidding operations cost more to conduct than conventional operations.	3.59 a	<0.01	50
Pellet feedstock loading operations cost more to conduct than conventional operations.	3.59 a	<0.01	50
Pellet feedstock felling operations cost more to conduct than conventional operations.	3.41 a	0.02	41
Pellet feedstock hauling operations cost more to conduct than conventional operations.	3.39 a	0.02	31

Rated on a 5-point Likert scale: 1=strongly disagree, 5=strongly agree. Mean responses that do not share letters are significantly different ($\alpha = 0.05$). p-values <0.05 indicate a significant difference from a neutral mean response of 3 (evaluated using the nonparametric Wilcoxon signed-rank test).

Respondents strongly disagreed that harvesting wood pellet feedstock from a site made it more difficult to follow forestry BMPs (75% disagreement, $p < 0.01$). Respondents also disagreed that pellet feedstock harvesting had a greater negative impact on water quality (62% disagreement, $p < 0.01$), or had a greater negative impact on soil quality than conventional operations (59% disagreement, $p < 0.01$). Business owners 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 post-harvest site than conventional harvests, though this agreement was not significantly different from neutral ($p = 0.40$).

Wood pellet feedstock supplier interactions with wood pellet mills

Logging business owners overwhelmingly agreed that the wood pellet mills they supplied with raw materials were concerned about BMP implementation during feedstock harvesting

(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 turn 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, $p < 0.01$). Feedstock logging operations reported being placed on a restrictive quota by sawmills an average of 45.5% of the year, pulp mills an average of 64.8% of the year, and pellet mills an average of 61.1% of the year. No significant differences were found between the percent of the year businesses were placed on quota by mill type ($p = 0.07$).

Advantages and challenges related to pellet feedstock harvesting

Nineteen respondents provided answers to questions regarding their perspectives on the advantages and disadvantages of delivering raw forest materials to wood pellet mills. The most common responses for the greatest advantages of pellet feedstock harvesting were greater utilization of raw material and improved aesthetics (49% of respondents provided a response related to either topic) (Table 3.4), with approximately half of all answers related to one of those categories. Other 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 3.4). 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.

Table 3.4 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%, as respondents were able to provide more than one answer per question.

Wood pellet producers

Of the twelve procurement managers for wood pellet mills who were sent an invitation to the online survey, ten submitted a response. This yielded an overall response rate of 83.3%. Wood pellet mills represented by procurement manager respondents had been in operation for an average of 11 years (Table 3.5). 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 105,000 tons and a maximum of 2 million tons per year. Procurement manager respondents reported an average of 48 suppliers per facility, and an average size of 100 acres for feedstock-supplying harvests.

Approximately 57% of these harvests were clearcuts, and 43% were thinnings. The average pellet facility procurement radius was 75 miles, with the average haul distance of suppliers to the facility being 49 miles. Mill residues were the most common feedstock utilized by wood pellet mills (Figure 1), comprising an average of 39% of all feedstock types consumed. Pulpwood-sized roundwood was the next most common feedstock type (32%), followed by in-woods chips (29%). Only one facility utilized any proportion of in-woods clean chips (i.e., chips containing no bark content).

Table 3.5 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/year)	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

Procurement manager perspectives

Producer survey participants were asked questions regarding their perspectives on the current state of the southeastern market for wood pellets, including questions related to the logging businesses that supply their facilities with raw forest materials (Table 3.6). Most procurement manager responses were neutral related to whether their own facility would increase its utilization of raw forest materials going forward (40% agreement, $p = 0.12$). However, most procurement managers also believed that the majority of other southeastern wood pellet production facilities would utilize more raw forest materials in the near future (70% agreement, p

< 0.01). 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 reported having strong relationships with their logging business suppliers (providing a neutral response), and all procurement managers stated that their feedstock suppliers did a good job implementing forestry water quality BMPs during harvesting operations.

Table 3.6 Perspectives of wood pellet mill procurement managers regarding the current pellet market and their pellet feedstock suppliers in the southeastern U.S.

Statement	Mean	p-value	% 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	<0.01	100
This facility has strong relationships with the logging businesses that supply it with raw forest materials.	4.4	<0.01	90
This facility's logging and hauling rates for raw forest materials allow suppliers to make a profit.	4	<0.01	90
This facility prioritizes trained logging businesses as its suppliers of raw forest material.	4.5	<0.01	90
Harvesting raw forest materials to deliver to pellet mills makes a logging business more competitive.	4.1	<0.01	80
I expect all southeastern pellet facilities' utilization of raw forest materials to increase over the next five years.	4.0	<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	<0.01	70
I expect this facility's utilization of raw forest materials to increase over the next five years.	3.5	0.12	40
On average, this facility places its logging business suppliers on quota less frequently than conventional wood product mills.	3.0	0.5	40
Raw forest materials are the most economical type of wood pellet feedstock for this facility.	2.5	0.88	20

Rated on a 5-point Likert scale: 1=strongly disagree, 5=strongly agree. p-values <0.05 indicate a significant difference from a neutral mean response of 3 (evaluated using the nonparametric Wilcoxon signed-rank test).

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. All procurement managers disagreed that pellet feedstock harvesting makes it more difficult to follow forestry water quality BMPs ($p < 0.01$), has a greater negative impact on water quality than conventional harvesting operations ($p < 0.01$) or has a greater negative impact on soil quality than conventional harvesting operations ($p < 0.01$). All but one procurement manager disagreed that pellet feedstock harvesting negatively impacts post-harvest 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 ($p < 0.01$). Procurement manager responses to these sustainability questions were compared to those received from the feedstock supplier survey using the Kruskal-Wallis test. Pellet producer and feedstock 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 observed statistical differences in responses related to water quality and aesthetics, both procurement manager and logging business owner responses still showed significant agreement that feedstock harvesting does not negatively impact 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 were followed to an extent that ultimately restricted raw material supply to mills by preventing harvesting in certain forest types (e.g. hardwood swamps, stands containing longleaf pine (*Pinus palustris*)). Three other respondents mentioned pellet production operations 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 placed on suppliers. 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 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 for southeastern wood product producers in the near future. Two respondents also 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

Results of the wood pellet feedstock supplier survey revealed similarities in the operational characteristics of southeastern pellet feedstock producers and those of other logging operations throughout the southeastern U.S. The mean production level reported by pellet feedstock logging suppliers in this study (2,722 tons/week) was consistent with the median production level of 2,495 tons/week for biomass logging crews in Virginia's Coastal Plain (Garren et al. 2022a). This level of productivity is also consistent with the production levels for all logging businesses in Georgia (2,619 tons/week) and Florida (1,956 tons/week) (Conrad et al. 2024). This suggests that pellet feedstock logging businesses have similar productivity to other biomass or conventional logging operations in the southeastern U.S. Pellet feedstock logging business 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 Plain of Georgia and Florida (Conrad et al. 2024. The majority of pellet feedstock logging businesses owned at least one in-woods chipper, similar to findings reported by Barrett et al. (2014) and Garren et al. (2022a). The mean age of in-woods chippers owned by pellet feedstock logging operations (approximately 6 years) was similar to Garren et al. (2022a)'s average of seven 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. This difference in chipper age may suggest that chipping operations are more frequently conducted in the Coastal Plain region of the southeastern U.S. compared to the Piedmont.

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, Parajuli et al. 2023, Louis et al. 2024). Most feedstock logging business owners reported deciding to deliver raw materials to pellet mills as a way to diversify their business. Responses to Likert-scale and open-ended questions revealed that pellet feedstock suppliers view the aesthetic benefits of pellet feedstock harvesting as a benefit desired by landowners that gives them a competitive advantage for purchasing timber sales. These responses, along with mixed agreement from survey respondents on the overall profitability of pellet feedstock to mills, suggest that benefits such as business diversification, competitiveness in timber sales, and greater wood utilization may be stronger drivers for logging businesses to begin delivering pellet feedstock to mills than a desire to increase profits alone. Overall, the percentage of logging business owners who reported making a profit on delivered wood pellet feedstock (55%) was similar to the 50-60% statistics for bioenergy logging businesses reported by Barrett et al. (2014) and Garren et al. (2022a). This suggests that feedstock logging businesses are similarly profitable to other types of biomass harvesting operations throughout the southeastern U.S. In 2022, around 26% of percent of logging businesses in Georgia and 50% of logging businesses in Florida reported the profitability of their operations as "good" or "excellent", with the remainder reporting break-even or worse profitability (Conrad et al. 2024). The results of this study suggest that, on average, pellet feedstock logging business owners report higher perceptions of profitability from 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 for chippers, inconsistent mill orders, quotas for feedstock, and rising hauling and labor costs have been observed by numerous other studies (Conrad et al. 2011, Saunders et al. 2012, Barrett et al. 2014, Hanzelka et al. 2016, Conrad et al. 2018b, Garren et al. 2022a, Conrad et al. 2024, Louis et al. 2024) and also serve as significant issues for pellet feedstock logging businesses. Responses from the 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 are able to 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 U.S.

The majority of respondents from the feedstock supplier survey reported similar costs between their conventional and feedstock harvesting activities – though all respondents who did not, reported feedstock harvesting activities being more expensive than conventional operations. Previous studies support this notion, as biomass chips and grindings require a greater amount of 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 the distance of skidder drags and number of cycles required by the increased utilization of wood represented a significant challenge to their profitable feedstock harvesting operations. Situations where fuel prices are high and mill delivered prices for raw forest materials are low may further exacerbate this issue and reduce the viability of harvesting low-margin forest residues.

Utilization of roundwood

Roundwood has historically been known to make up a large portion of feedstock consumed for pellet production in the southeastern U.S. (Brandeis and Abt, 2019; Kittler et al. 2020). Roundwood was found to be 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%

of all feedstock consumed. The 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 U.S., 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 intent to increase or expand their utilization of forest residues in the near future - 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 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, slightly higher than the 64% and 73% statistics reported by Barrett et al. (2014) and Garren et al. (2022a), respectively. All ten procurement managers reported prioritizing trained logging operations (i.e., Sustainable Forestry Initiative log training programs) as suppliers of wood pellet feedstock. Feedstock suppliers themselves were also found to agree overwhelmingly with the statement that mills they supplied were concerned about proper BMP implementation. As adherence to state forestry BMPs is a requirement for participation in certification schemes such as the Sustainable Biomass Program (and is verified by these schemes 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.

Conclusions

Overall, wood pellet feedstock suppliers in the southeastern U.S. 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 significant obstacles to profitability for pellet feedstock logging operations, along with inconsistent markets for raw material and rising costs of fuel and labor. Despite these challenges, pellet feedstock suppliers in the southeastern U.S. look positively on their decision to deliver raw material to pellet mills – citing benefits such as landowner satisfaction and access to additional markets as reasons to continue pellet feedstock harvesting operations. While only about 50% of respondents indicated making a profit on the material they deliver to pellet mills, this statistic remains consistent with previous studies on the profitability of bioenergy logging operations throughout the southeastern U.S.

Logging business owners and pellet mill procurement managers alike overwhelmingly disagreed that feedstock harvesting negatively affects harvest site environmental quality compared to conventional 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 they supplied material to were concerned with proper BMP implementation. In conclusion, we find that the current southeastern market system for wood pellets holds both benefits and challenges for wood pellet feedstock suppliers. Delivering raw forest materials to wood pellet mills provides logging businesses with opportunities for business diversification, competitiveness, and greater utilization of raw material, provided business owners can accommodate the associated costs of harvesting, processing, and hauling feedstock to pellet mills. Both wood pellet feedstock suppliers and pellet mill procurement managers presented a positive outlook in terms of the sustainability of pellet feedstock harvesting operations - with no outstanding concerns brought to attention by either group. Future research evaluating the environmental impacts of pellet feedstock harvesting on southeastern forest sites may be beneficial to provide evidence for these perspectives - especially in the context of existing biomass harvesting guidelines (or the lack thereof) throughout the southeastern U.S.

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CHAPTER 4

CONCLUSION

Pellet Feedstock Harvest Sites

The environmental sustainability of wood pellet feedstock harvesting in the southeastern U.S. may have significant effects on regional levels of feedstock harvesting and consumption. The field study described in chapter two aimed to characterize wood pellet feedstock harvest sites and determine whether pellet feedstock harvesting activities were degrading the environmental quality of southeastern U.S. forests. Unlike previous studies evaluating biomass harvests in the southeastern U.S., this study specifically distinguished between multiple types of feedstock harvests (for roundwood and in-woods chips) and evaluated post-harvest conditions of thinnings in addition to clearcuts.

Results of the field study suggest that both pellet feedstock and conventional pulpwood harvests for roundwood material produce similar post-harvest site conditions. No statistically significant differences in any site characteristic (soil disturbance, ground cover, access features, wildlife metrics) were observed between pulpwood roundwood and pellet roundwood feedstock harvests. Notably, the proportion of light and heavy slash distributed through the harvest area and landings were similar between these treatments. This supports the notion that while pellet feedstock harvesting operations are potentially able to utilize a greater proportion of woody debris present on a site than conventional operations, they may not necessarily choose to do so. Kittler et al. (2020) found that pulpwood-sized roundwood is often consumed by pellet mills wishing to produce a higher grade of product. As such, feedstock logging operations may be incentivized to bring higher-quality pulpwood-sized roundwood to pellet mills instead of forest residues – ultimately resulting in harvesting treatments similar to those of conventional pulpwood harvests.

Clearcut harvests that utilized an in-woods chipper, however, differed from conventional pulpwood roundwood harvesting treatments by having significantly smaller site acreages and greater percentages (5% more) of site in access features. Pellet chipped clearcuts also had more bare soil (10% more) on average within the harvest area than conventional harvests for roundwood-sized pulpwood. While having smaller acreages and larger proportions of sites in access features may simply be a result of chipping treatments being more financially viable on smaller sites, having more onsite bare soil could represent issues for local water quality. Results of previous biomass post-harvest site evaluations suggest that similar rates of onsite bare soil may not be a cause for significant concern, provided that state forestry BMPs are properly implemented (Hawks et al. 2023; Parajuli et al. 2023).

This study was also the first to utilize an evaluation of wildlife habitat metrics alongside the post-harvest soil disturbance and ground cover metrics developed by Eisenbies (2005). No significant differences in post-harvest vegetation height, basal area, or snag density were observed among harvesting treatments. Altogether, the results of this field study present a positive outlook regarding the sustainability of pellet feedstock harvests. Pellet feedstock and conventional pulpwood harvests sharing a majority of similar site characteristics suggests that as long as forestry BMPs are followed, feedstock harvests may not require additional harvesting guidelines or management practices associated with their usage to prevent environmental impacts.

Feedstock Logging Business Suppliers and Pellet Mill Procurement Managers

The study described in chapter three was the first survey to have a target population of logging businesses that supplied raw forest materials to wood pellet mills in the southeastern United States. Results of the supplier survey revealed that feedstock logging businesses in the southeastern U.S. shared similar characteristics with other conventional and biomass logging operations within the region, such as crew sizes, equipment mixes, and overall levels of production (Barrett et al. 2014; Garren et al. 2022a; Conrad et al. 2024). Approximately half (55%) of business owners reported making a profit on the raw material they delivered to pellet mills, consistent with the 50-60% statistics found by surveys of Virginia Piedmont and Coastal Plain biomass logging businesses (Barrett et al. 2014; Garren et al. 2022a).

Overall, business owners viewed their decision to begin harvesting wood pellet feedstock as a positive outcome for their business. Business diversification was the leading reason for logging business owners to begin delivering raw material to pellet mills. Common advantages and challenges relating to wood pellet feedstock harvesting were consistent with results from other surveys of biomass logging operations (Barrett et al. 2014; Garren et al. 2022a; Louis et al. 2024). Advantages included cleaner-looking post-harvest conditions, increased landowner satisfaction, and better utilization of raw materials on site. Challenges included high equipment and fuel costs, low mill delivered prices for raw materials, and inconsistency of orders or frequent mill quotas. Responses to open-ended questions suggested that logging business owners continue to harvest pellet feedstock for benefits other than a direct increase in profit – though these benefits likely serve to strengthen these businesses by increasing their competitiveness on timber sales.

Results of the pellet producer survey found that feedstock consumption at procurement manager respondents' facilities was consistent with results of previous studies (Brandeis et al. 2019; Kittler et al. 2020). Mill residues and pulpwood-sized roundwood were the most common feedstock types consumed, likely due to the low cost and ready availability of these materials. Seventy percent of procurement managers agreed that most pellet mills in the southeastern U.S. would increase their utilization of raw forest materials over the next several years. Procurement managers perceived rising costs of equipment, fuel, and labor, as well as limited access to markets for pulpwood-sized material as being significant obstacles for pellet feedstock logging operations in the region.

Sustainability of Pellet Feedstock Harvesting Operations

Procurement managers and feedstock suppliers alike held positive perceptions on the sustainability of wood pellet feedstock harvesting in the southeastern United States. Both groups strongly disagreed that pellet feedstock harvests degraded site soil or water quality compared to conventional harvesting operations. Pellet feedstock logging business owners reported that feedstock harvesting activities did not increase the difficulty of implementing forestry BMPs. Logging business owners overwhelmingly viewed pellet mill procurement managers as being concerned with the proper implementation of forestry BMPs during harvests. Similarly, pellet mill procurement managers overwhelmingly agreed that the loggers supplying their facilities with raw materials did a good job of implementing forestry BMPs during harvesting. Procurement managers also failed to report any significant issues with conducting sustainable pellet production operations at their facility. Several respondents stated that existing certification system requirements frequently limited access to raw materials near areas deemed ecologically sensitive, such as bottomland hardwood forests or longleaf pine (*Pinus palustris*) stands.

While chapter two's field study did not specifically evaluate the water quality or BMP implementation rates of pellet feedstock harvests in the southeastern U.S., the study's findings serve to support perspectives of wood pellet procurement managers and feedstock logging businesses in several aspects. As no differences were observed in the proportion of light and heavy slash between pellet feedstock and conventional harvests, this would suggest that pellet feedstock harvests contain enough logging slash to properly implement forestry BMPs. Similarly, despite observing elevated levels of bare soil within in-woods chipped pellet feedstock harvests, this observation may not represent issues for site water quality if BMPs are implemented. Regardless of the type of harvesting conducted, it is vital that logging businesses in the southeastern U.S. follow forestry best management practices in order to preserve site soil and water quality and ensure sustainable harvesting of raw forest materials.

Implications for Future Research

As the only significant differences in harvest site characteristics observed by this study were between in-woods chipping and roundwood harvests, future research further evaluating in-woods chipping operations in the southeastern U.S. may be beneficial. Understanding how and why in-woods chipping harvests can contribute to a greater proportion of bare soil on site may allow for the development of strategies to mitigate this effect. Further research evaluating BMP implementation rates on wood pellet feedstock harvests in the southeastern U.S. may help evaluate the on-site environmental sustainability of pellet feedstock harvesting.

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APPENDICES

Appendix A: Wood Pellet Logging Business Survey

UNIVERSITY OF GEORGIA
INVITATION TO PARTICIPATE IN A RESEARCH STUDY
Evaluating Characteristics of Southeastern Wood Pellet Producers and Feedstock Logging Crews

Hello!
My name is Paul DiGiacomo and I am a Master's student in the Warnell School of Forestry and Natural Resources at the University of Georgia, under the supervision of Dr. Chad Bolding and Dr. Joseph Conrad. I am inviting you to participate in a research study.

I am conducting research on southeastern logging companies that deliver raw material (wood chips, roundwood, etc.) to wood pellet mills. This research is done in cooperation with the wood pellet producers Enviva Biomass and Drax Global. This research seeks to understand logging business owner decisions for delivering raw material to pellet mills, as well as logger perspectives on the environmental impacts of harvesting raw material from southeastern forests.

I am looking for business owners of logging companies that currently deliver raw material (wood chips, roundwood, etc.) to one or more pellet mills in the southeastern United States to participate in this study.

Included in this letter is a brief logging survey. The survey will ask you questions about your reasons for harvesting raw material to deliver to pellet mills, and your thoughts on the environmental impact of these harvesting practices. You may also be asked for information about your logging business and the harvesting operations you conduct. **We are interested to hear your perspectives on the current state of the southeastern wood pellet market!**

While answering the survey, you are free to skip over any question you do not want to answer.

Your responses will help us understand the reasons why southeastern loggers choose to deliver raw material to wood pellet mills. Your responses may also help us understand how loggers view the environmental impacts of harvesting for wood pellet production compared to the impacts of conventional harvesting operations.

Individual survey responses will be anonymous and will be seen only by the researchers. Individual survey responses will not be used or distributed for future research without additional consent.

Please keep this document for your records.

Sincerely,

Paul DiGiacomo, M.S. Student

Warnell School of Forestry
& Natural Resources
UNIVERSITY OF GEORGIA

Wood Pellet Logging Business Survey

1. I represent a logging business **that supplies raw material** (in-woods products such as wood chips, roundwood, and forest residues) **to wood pellet mills**. (Circle one)

   Yes No (If no, you may skip the rest of this survey)

i. Company & Operational Information

2. In which three counties do you most often harvest timber? *(Please include the state of each county)*

   ____________________________ ____________________________ ____________________________

3. How long have you operated your logging business? _____ **years**

4. How many in-woods crews does your company normally operate? ____ **crews**

5. Please indicate the number of people your company employs by their PRIMARY job category.

   _____ **woods workers** _____ **foreman/supervisors** _____ **timber cruisers**

   _____ **mechanics** _____ **truck drivers** _____ **office & clerical**

   _____ **owners/managers** _____ ***total number of employees***

6. What is your average weekly production of the following (total of all crews): Give the answer in tons **OR** number of loads.
   - Roundwood (pulpwood & logs, sent to any type of mill)
     __________ **Tons OR** _________ **Loads**
   - Wood Chips (clean or dirty chips, sent to any type of mill)
     ___________ **Tons OR** _________ **Loads**

Raw material: *Products such as wood chips, roundwood, and forest residues that are delivered to pellet mills for the production of wood pellets.*

7. How long have you been harvesting raw material to deliver to pellet mills? ____ **years**

8. To how many pellet mills do you supply raw material? What is your average haul distance to these pellet mills?
   _________ **mills** **average distance to pellet mills (miles)** _______

9. What percentage of sites do you harvest raw material to deliver to pellet mills? What is the average size of these harvests?
   _____**% of sites** _____ **acres**

Roundwood: *Pulpwood, logs, or other products sold without being processed by chipping or grinding.*

10. What percentage of the raw material you deliver to pellet mills is made up of roundwood, and what percentage is made of in-wood chips?

    _____**% roundwood** _______**% chips** _______**% other** **(Should total 100%)**

11. About what percentage of sites upon which you harvest raw material to deliver to pellet mills is clearcuts, and what percentage is thinnings?

    _____**% clearcuts** _______**% thinnings/partial harvests** **(Should total 100%)**

12. About what percentage of sites upon which you harvest raw material to deliver to pellet mills is hardwood stands, and what percentage is pine stands?

_____% hardwood **_______ % pine** **(Should total 100%)**

Forest residues*: Tops, limbs, bark, foliage, and other non-merchantable materials produced by conventional roundwood timber harvests.*

13. On what percentage of sites do you harvest forest residues? (If you do not harvest forest residues, write 0%). **_____% of sites**

14. Which of the following best describes your business in terms of forest residue harvesting practices? **(Circle one)**
    a. Residue harvesting is integrated into normal operations (Residues and roundwood harvested at the same time, with roundwood going to any type of mill).
    b. Residue harvesting occurs separately from normal operations
    c. No residue harvesting occurs

15. On what percentage of sites do you typically choose to leave some amount of harvestable forest residues on site to meet BMP standards? (If you do not typically leave marketable residues behind, write 0%). **____% of sites**

Market, Profit, and Environmental Factors

Pellet harvesting: Harvesting any type of raw material (wood chips, roundwood, and forest residues) from a site to deliver to a wood pellet mill.

16. Please rate the following categories based on your perception of the costs of conducting pellet harvesting operations.
(Check one box per row)

Compared to the same type of operation for a conventional harvest, my pellet harvesting operations…	Cost **significantly less (1)**	Cost **somewhat less (2)**	Cost **the same (3)**	Cost **somewhat more (4)**	Cost **significantly more (5)**
Felling operations					
Skidding operations					
Processing operations *(delimbing, topping, bucking, chipping)*					
Loading operations					
Hauling operations					

17. The following statements relate to your decision to begin harvesting raw material to deliver to pellet mills. Please rate each statement based on the following scale: **(Check one box per row)**

I began delivering raw material to pellet mills…	**Strongly disagree (1)**	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
… to diversify my business.					
… to be competitive on timber sales that require forest residues to be chipped.					
… to increase my total profit.					
…to satisfy landowners that wanted logging residues chipped.					
…because a mill that I do business with encouraged me to do it.					
…so that I could contribute to renewable energy production.					

18. The following statements relate to the outcomes of your decision to begin harvesting raw materials to deliver to pellet mills. Please rate each statement based on the following scale: **(Check one box per row)**

	Strongly disagree (1)	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
On most sites, I make a profit on the raw material I deliver to pellet mills.					
I must be able to produce raw materials from logging residues for my business to remain competitive in purchasing timber sales.					
Delivering raw material to pellet mills makes my overall business **stronger**.					
I have never harvested raw material to deliver to pellet mills at a financial loss in order to satisfy a landowner.					
Given the overall impacts to my operation, deciding to harvest raw materials to deliver to pellet mills was a good decision.					
I expect to begin or increase my levels of **forest residue** *(limbs, tops, etc.)* harvesting in the near future.					
Pellet harvesting would continue to be economically feasible **even if** a clean site was not a priority for landowners.					

19. The following statements relate to your perception of the current markets for wood pellets, and the pellet mills that you deliver raw material to. Please rate each statement based on the following scale: **(Check one box per row)**

	Strongly disagree (1)	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
There are reliable markets/buyers for raw materials in my operating region.					
Pellet mills I deliver raw materials to are concerned about BMP implementation during harvesting.					
My company has stronger relationships with the procurement staff at pellet mills than the procurement staff at other types of mills.					
Wood pellet markets are growing faster than conventional timber markets in my area.					
Wood orders from wood pellet mills are more consistent than wood orders from other types of mills.					
Turn times at wood pellet mills are longer than turn times at other types of mills.					

20. How frequently do the following factors influence your decision to harvest for raw material to deliver to pellet mills on a site? Please rate each factor based on the following scale: **(Check one box per row)**

	Very infrequently (1)	**Infrequently (2)**	**Neutral (3)**	**Somewhat Frequently (4)**	**Very frequently (5)**
Distance to pellet mills					
Amount of suitable material present on site					
Price for raw material					
Terrain features/site operability					

21. On what percentage of the year are you typically placed on quota by… *(leave space blank if you do not deliver to that mill type)*

- Pulpmills? _______**% of the year**
- Sawmills? _______**% of the year**
- Pellet mills? _______**% of the year**
- Other mills? (please describe) ___________________ _______**% of the year**

22. The following statements relate to your perception of the environmental impacts of pellet harvesting. Please rate each statement based on the following scale: **(Check one box per row)**

	Strongly disagree (1)	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
Compared to conventional harvesting, it is more difficult to follow forestry BMPs during pellet harvesting.					
Pellet harvesting results in greater impacts to water quality than conventional harvesting operations.					
Pellet harvesting results in greater impacts to site soil and erosion rates than conventional harvesting operations.					
Sites where pellet harvesting was conducted are more aesthetically pleasing than sites where only conventional harvesting occurred.					
Harvesting raw materials for pellet mills provides a way to contribute to renewable energy production without degrading harvest site quality.					

23. What do you believe is the greatest advantage of harvesting raw material to deliver to pellet mills?

____

____

24. What is your greatest challenge to conducting profitable operations for providing raw material to pellet mills?

____

____

25. Is there anything more that you would like to add?

____

____

____

Equipment Information

26. **Please list the number and average age (years) of each type of equipment you use. Do NOT count spare equipment not kept in the woods. If you own multiple pieces of particular equipment, separate their ages by commas.**

Ex. Grapple skidders: Number =2, Average age = 3

Felling	Number	Average age (years)
Rubber-tired feller-bunchers		
Tracked feller-bunchers		
Cut-to length Harvesters (NOT processors)		

Loading & Hauling	Number	Average Age (years)
Trailer-mounted loaders		
Tracked loaders		
Extra log trailers		
Tractor-trailers		
Chip vans		

Processing	Number	Average age (years)
Pull-through delimber		
Cut-to-length processor		
Chain-flail delimber		
Whole-tree chipper		
Horizontal/tub grinder		

Skidding	Number	Average age (years)
Cable skidders		
Forwarders		

Appendix B: Wood Pellet Producer Survey

UNIVERSITY OF GEORGIA
INVITATION TO PARTICIPATE IN A RESEARCH STUDY
Evaluating Characteristics of Southeastern Wood Pellet Producers and Feedstock Logging Crews

Hello!

My name is Paul DiGiacomo and I am a student in the Warnell School of Forestry and Natural Resources at the University of Georgia under the supervision of Dr. Chad Bolding. I am inviting you to take part in a research study.

I am conducting research on southeastern wood pellet mills that utilize raw forest materials for pellet production. This research seeks to understand mill decisions for utilizing raw forest materials, as well as procurement manager perspectives on the environmental impacts of harvesting raw material from southeastern forests.

I am looking for procurement managers for wood pellet mills that utilize raw forest materials in the southeastern United States to participate in this study.

If you agree to take part in this study, you will be asked to take a short online survey. This survey will ask you questions about your reasons for utilizing raw forest materials in your facility, and your thoughts on the environmental impact of this practices. You may also be asked information about your facility's pellet production and raw material consumption rates. The survey itself is expected to take 6-8 minutes to complete.

Participation is voluntary. You can refuse to take part or stop at any time without penalty. While answering the survey, you are free to skip over any question you do not want to answer.

Your responses may help us understand the reasons why southeastern loggers choose to deliver raw material to wood pellet mills. Your responses may also help us understand how loggers view the environmental impacts of harvesting for wood pellet production compared to the impacts of conventional harvesting operations.

No direct identifying information (personal or business names) will be collected by this study. Individual survey responses will be anonymous, and will be seen only by the researchers working on this study. Individual survey responses also will not be used or distributed for future research without additional consent.

Please keep this letter for your records.

Sincerely,

Paul DiGiacomo, M.S. Student

Warnell School of Forestry & Natural Resources
UNIVERSITY OF GEORGIA

UGA Warnell Wood Pellet Producer Survey

Note:

For procurement managers who source raw materials **to more than one mill facility**: Please choose **the facility that you source the most raw materials for** to answer on behalf of for the following survey questions.

If you do not know the answer to a question, feel free to skip over it.

ii. Company & Operational Information

1.) Which of the following best describes your position at this facility? *(Please select the best one)*

- o Procurement forester
- o Procurement manager
- o Mill manager
- o Owner
- o Other (please specify)______________________

2.) For how many years has this facility been producing wood pellets? **____ years**

Raw forest material: Products such as wood chips, roundwood, and forest residues that are delivered to pellet mills for the production of wood pellets.

Roundwood: Pulpwood, logs, or other products sold without being processed by chipping or grinding.

3.) What percentage of wood pellet feedstock in this facility comes from each of the following categories?

____% mill residues

____% roundwood (any type)

____% in-woods clean chips (contains no bark)

____% in-woods dirty chips (contains wood and bark)

____% other (please describe) _______________

(Should total to 100%)

4.) Approximately how many tons of *raw forest materials* does this facility *consume* annually?
____ tons

5.) Approximately how many tons of *wood pellets* does this facility *produce* annually?
____ tons

6.) How many individual logging businesses currently supply raw forest materials to this facility?
____ logging businesses

7.) On average, what percentage of the year does your facility place the logging businesses that supply raw forest materials to your facility on quota?

_____ % of the year

8.) What is this facility's *procurement radius* (radius from which this facility purchases 90% of its raw *forest* material)? **____ miles**

9.) What is the average *haul distance* for raw forest materials delivered to this facility? **____ miles**

10.) What percentage of the harvests this facility procures raw materials from are clearcuts vs. thinnings? If known, what is the average size (in acres) of these clearcuts? Of these thinnings?

____% clearcuts ____% thinnings/partial cuts (should equal 100%)

Average clearcut size ____ acres

Average thinning size ____ acres

Forest residues: Tops, limbs, bark, foliage, and other generally non-merchantable materials produced in the woods.

11.) Does this facility utilize forest residues for wood pellet production? **Y/N**

iii.	**<u>Markets, Profit, and Suppliers</u>**

12.) **Please rate your agreement to each of the following statements based on the following scale *(check one box per row):***

	Strongly disagree (1)	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
I expect this facility's utilization of raw forest materials to increase over the next five years.					
I expect *all* southeastern pellet facilities' utilization of raw forest materials to increase over the next five years.					
This facility has strong relationships with the logging businesses that supply it with raw forest materials.					
On average, this facility places its logging business suppliers on quota less frequently than conventional wood product mills.					
Raw forest materials are the most economical type of wood pellet feedstock for pellet production for this facility.					
Harvesting raw forest materials to deliver to pellet mills makes a logging business more competitive.					
Harvesting raw forest materials to deliver to pellet mills would be profitable to logging businesses even if a clean site *was not* a priority for landowners.					
This facility's logging and hauling rates for raw forest materials allow suppliers to make a profit.					
The logging businesses that supply this facility with raw forest materials do a good job of implementing forestry Best Management Practices.					
This facility prioritizes certified logging businesses as its suppliers of raw forest material.					

iv. Impacts of Pellet Harvesting

13.) **Please rate each statement based on the following scale (*check one box per row):***

Compared to conventional harvesting operations, harvesting raw forest materials (in any form) for pellet production…	**Strongly disagree (1)**	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly agree (5)**
…. has a greater negative impact on site *water quality*.					
…. has a greater negative impact on site *aesthetics*.					
…. has a greater negative impact on *soil quality*.					
…. has a greater negative impact on site *productivity*.					
…. makes it more difficult to implement forestry Best Management Practices.					
… is a way to contribute to renewable energy production without degrading overall harvest site quality.					

14.) What is **this facility's biggest barrier** to conducting sustainable wood pellet production operations?

____

____

____

15.) What do you believe is the **biggest barrier for logging businesses** to conduct profitable wood pellet feedstock harvesting operations?

____

____

____

16.) Is there anything more that you would like to add?