Economic Feasibility of Utilizing Precommercially Thinned Southern Pine as a Woody Biomass Energy Source

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Abstract

The use of woody biomass as a feedstock for wood-burning energy facilities and pellet mills has increased across the southern United States in recent years. Feedstock for these facilities comes in a variety of forms, including roundwood, logging residues, and mill residues. Precommercial thinning (PCT) of pine stands is sometimes used to mitigate southern pine beetle (*Dendroctonus frontalis*) risk that traditionally incurs added cost to landowners. Utilization of biomass from PCT for biomass energy production may provide an opportunity to reduce the costs of southern pine beetle risk mitigation practices. Potential use of PCT biomass has been suggested in previous studies, but little effort has focused on quantifying amounts available for utilization. Using a list of nonindustrial, private forests enrolled in the Virginia Department of Forestry Pine Bark Beetle Prevention Program, we conducted inventories of pine stands scheduled to undergo PCT to estimate potentially harvestable biomass. Inventories of stands in the 5- to 7-year-old and the 8- to 12-year-old age groups showed average volumes of 14.47 and 39.63 green tons per acre of biomass, respectively. Results suggest that PCT stands in the 8- to 12-year-old age group may contain sufficient volumes for economically feasible harvests based on removal estimations, thinning costs, and regional biomass prices. The feasibility of such harvests will largely depend on the degree to which harvesting costs are affected by utilizing the small-diameter stems typically found in PCT stands and local demand for biomass.

The use of woody biomass energy as an alternative to fossil fuels has gained significant interest within the United States over the last several decades. Announced and operating wood-consuming bioenergy projects in the United States are expected to increase to a total use of 84,000,000 green tons (gt) per year by 2023, of which 45,000,000 gt/yr is attributed to the southern United States (Forisk Consulting 2015). Several wood-fired energy plants have been created or retrofitted from existing energy-producing facilities to utilize biomass as an alternative energy source, with US biomass energy nameplate capacity totaling 6,850 MW (Biomass Magazine 2015). Compared with other states, Virginia ranks fifth in biomass energy plant total nameplate capacity. Seven biomass energy facilities of 50 MW or greater have been constructed in Virginia, for a combined nameplate capacity of over 400 MW utilizing a variety of feedstock sources, including municipal solid waste, forest residues, and wood waste. Using a ‘‘rule of thumb’’ of 12,000 gt/yr of biomass needed to create 1 MW of energy (Georgia Forestry Commission 2009), more than 4,800,000 gt/yr is currently needed to fuel these energy plants in Virginia.

Construction of wood pellet–producing mills has also increased throughout the United States in response to greater demands for alternative energy sources. The maximum production capacity of pellet mills in the United States totaled 9,422,500 tons in 2014, with eight pellet mills

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in Virginia producing pellets for both domestic and export markets (Biomass Magazine 2014). A large proportion of pellet demand can be attributed to the European Union's 2020 climate and energy package to reduce energy dependence on fossil fuels and increase utilization of renewable energy sources by the year 2020 (Guo et al. 2013, European Commission 2014). Fiber needed for pellet production previously consisted of predominantly mill residues, with a small proportion sourced from pulpwood and logging residues (Spelter and Toth 2009). However, recent increased global demand for wood pellets has led to increased use of primary forest products, like pulpwood, for producing pellets for export from the southeastern United States (Hoefnagels et al. 2014).

A potential feedstock for biomass energy facilities that has not been explored extensively is the biomass left on the ground in young pine stands as a result of precommercial thinning (PCT). PCT is an intermediate stand treatment used to increase individual tree diameter and reduce stand susceptibility to southern pine beetle (*Dendroctonus frontalis*) outbreak (Burkhart et al. 1986, Nowak et al. 2008). Dense southern pine stands often pose a greater risk for southern pine beetle infestation, and diameter growth is often limited in such stands. PCT treatments are typically net cost treatments that do not produce revenue and therefore equate to management investments or added expenses to landowners with the expectation of increased future returns, although some states offer cost-share programs to encourage PCT. The Virginia Department of Forestry Pine Bark Beetle Prevention Program (VDOF PBBPP) offers a 60 percent cost-share to nonindustrial private forest landowners who wish to conduct PCT and meet program criteria (Watson et al. 2013). Pine stands enrolled in the VDOF PBBPP must be at least 5 acres in size, with trees no older than 15 years and an average stem diameter at breast height (DBH) not exceeding 4 inches (VDOF 2014). Additionally, pretreatment density of stands must be at least 800 stems per acre, and posttreatment residual density must be from 300 to 500 stems per acre.

Traditionally, conventional PCT treatments are completed manually with brush saws and leave small-diameter thinned stems on site, which remain unused for any type of wood or energy production (Perlack and Stokes 2011). Previous interest in alternatives to fossil fuel energy during the 1970s and 1980s led to attempts at mechanically harvesting precommercial stems (e.g., Koch and McKenzie 1976, Watson and Stokes 1989), but reductions in fossil fuel prices soon dissipated interest in harvesting small-diameter biomass. As woody biomass energy markets have since become more viable, utilizing PCT biomass may become economically feasible. More recently, the potential use of PCT biomass for energy has been suggested by the US Department of Agriculture Forest Service (Staudhammer et al. 2011) and the US Department of Energy (Perlack and Stokes 2011). However, considering the relatively low commercial value of stems less than 4 inches DBH, little work has been directed toward estimating realistic biomass quantities available for harvest in young, small-diameter southern pine stands. Since PCT treatments normally incur an added cost to the landowner, utilizing PCT biomass for energy may reduce this cost, cover harvesting expenses, or even produce a profit if the removed biomass quantities are substantial enough and the harvesting costs are low enough.

The purpose of this study was to estimate potentially harvestable biomass in PCT stands and examine the costs associated with harvesting PCT biomass versus the costs of conducting a conventional PCT treatment. Specific goals were to (1) inventory biomass abundance in PCT stands before thinning and examine stand characteristics and (2) estimate PCT biomass removals and harvesting costs and explore the economic feasibility of PCT biomass harvests. Below, we describe methods used to inventory stands slated for PCT treatment in the Virginia Piedmont and Coastal Plain regions, report on inventory results and potential stumpage values of PCT biomass, and summarize and discuss the implications and limitations of our work.

Methods

Considering the lack of information regarding biomass quantities available for harvest in small-diameter pine stands, an inventory was conducted to assess the economic feasibility of harvesting PCT biomass for energy. Stands selected for measurement were from among those enrolled in the VDOF PBBPP, because the enrolled stands in this program are required to possess conditions justifying a PCT. Plots were established and measured within 18 stands located across Virginia to estimate woody biomass volume (green tons per acre). Stands were selected for measurement using a variety of criteria, including age, location, availability for measurement before thinning, and landowner permission. Plots were systematically distributed within stands to measure no more than one plot per acre. Selected stands had been planted or naturally regenerated with loblolly pine (*Pinus taeda*), as determined by the VDOF forester responsible for the stand, and they usually contained a large number of loblolly pine "volunteers" or natural regeneration, with a few stands containing large numbers of Virginia pine (*Pinus virginiana*) volunteers. Although hardwood species were present in some stands, only pine species were measured.

Stands were measured using a total of 241 fixed-radius, 1/250th of an acre circular plots. Though relatively small, the plot size was practical for this application, because stands that traditionally undergo PCT possess a high stem density. Past PCT studies have examined treatments on stands with average densities exceeding 5,000 stems per acre (Mann and Lohrey 1974, Lohrey 1977), and another study observed a 7-year-old pine stand with an average density of 25,300 pine stems per acre in southern Arkansas (Grano 1969).

The minimum size of measured stem diameters was 1.0 inch DBH, and stems were recorded in 1-inch-diameter classes. Stem heights in each plot were obtained by measuring three randomly selected stems, to the nearest 1 foot, in each 1-inch-diameter class and then averaging the values to determine the representative height for the corresponding diameter class. Emphasis was placed on measuring stands older than 5 years. Considering first commercial thinnings of southern pine stands do not typically occur until age 10 (Demers et al. 2010), younger stands were not anticipated to have a high potential for containing volumes of woody biomass sufficient for mechanical recovery. Stands were located within the following nine counties in Virginia: Accomack, Albermarle, Brunswick, Chesterfield, Dinwiddie, Essex, Lunenburg, Middlesex, and Southampton (Fig. 1). Additional information regarding the use of herbicides and the type of regeneration within the stand (i.e., natural or planted) was

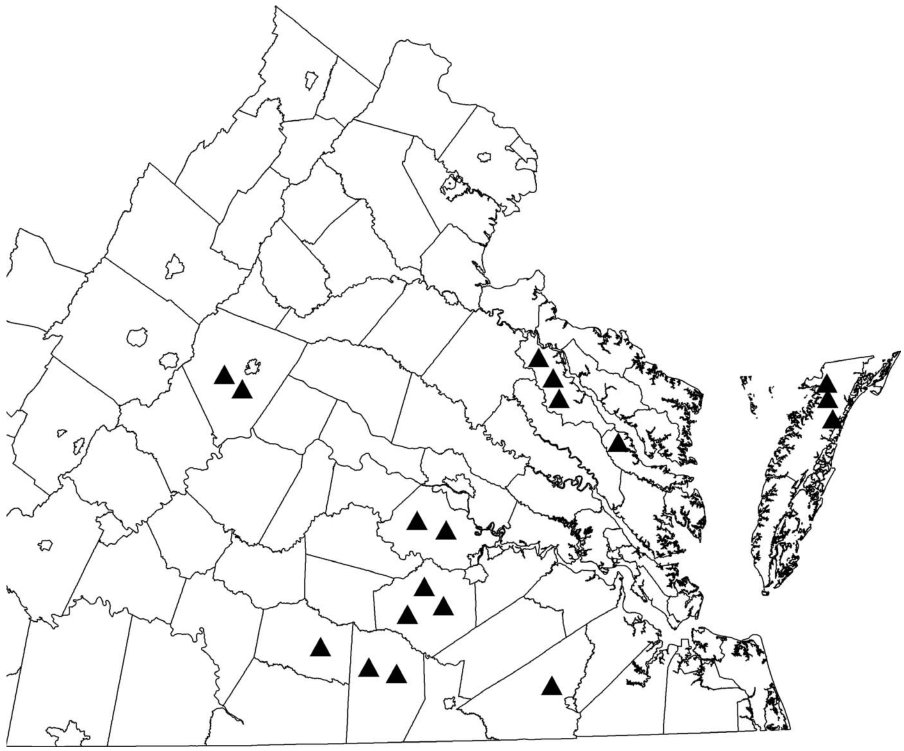

Figure 1.—Precommercial thinning stand inventory locations in Virginia, measured between August 2013 and July 2014.

obtained from the VDOF forester responsible for each stand's cost-share program application. Two different stand age groups were formed (5 to 7 years and 8 to 12 years), each with approximately the same number of sample plots, based on statistical tests that showed differences in key attributes, including density, diameter, and volume. The Tukey-Kramer Honestly Significant Difference test (SAS Institute Inc. 2015), with $\alpha = 0.05$, was used to test means among our sampled plots.

Volumes were calculated from plot-level data using a combination of biomass equations (Clark and Saucier 1990, Bullock and Burkhart 2003). The biomass equation of Clark and Saucier was developed from southern pine trees in Alabama, Georgia, South Carolina, and Florida. Of the Natural Coastal Plain southern pine trees measured in their study, a relatively small proportion were less than 5 inches DBH, with an overall range of 1.1 to 24.0 inches. The equation of Bullock and Burkhart was developed from loblolly pine trees in the Georgia Piedmont, eastern Texas, and the Coastal Plain and Piedmont regions of Virginia, with a size range of 0.8 to 12.3 inches DBH. When the Bullock and Burkhart equation is applied to 1-inch-DBH stems, a negative value for volume results. Hence, we used Bullock and Burkhart's equation for all trees greater than 1 inch DBH, given that their equation is based on trees sampled from sites similar to those in our study. For all 1-inch-DBH trees in our analysis, the equation of Clark and Saucier for Natural Coastal Plain southern pine was used, as we believe it produces a more realistic volume estimate for stems in this diameter class. Although the size range and density of the trees in our dataset may be outside the intended use of these equations, we believed this combination of equations provides the best possible estimate of PCT stand volume.

Results and Discussion

Inventory findings

Pine density of sampled plots ranged from 250 to 11,000 stems per acre, with the majority containing from 600 to 1,000 stems per acre (Fig. 2). Planting was the more common source of regeneration for our stands, with only 33 percent of the stands being regenerated naturally. The use of herbicides also was common, with 72 percent of the stands having received herbicide treatment. Stand density of pine for naturally regenerated stands was higher than that for planted stands ($P = 0.049$), with a mean of 4,273 stems per acre compared with 3,544 stems per acre, and the 8- to 12-year-old age group exhibited a higher mean density than the 5- to 7-year-old age group ($P < 0.001$), with 4,419 stems per acre compared with 3,117 stems per acre (Table 1). Although planted pine stands exhibited a lower average density than naturally regenerated pine stands, the use of planting is not itself a guarantee of avoiding costly treatment expenses, such as PCT.

The average DBH for all measured plots was 2.47 inches (Table 1). Plots in stands that were sprayed with herbicides showed a significantly higher DBH than nonsprayed plots ($P = 0.006$), likely a result of lower stand density. The diameter distribution for all measured stems nearly resembles a reverse-J curve (Fig. 3). The majority of all plots measured had an average DBH of less than 5 inches, with most plots falling into the 2-inch-DBH class (Fig. 4). Although older stands would typically be expected to have higher mean DBH than younger stands, the 8- to 12-year-old age group did not show a statistically higher DBH than the 5- to 7-year-old age group. This nonsignificant difference may have been a function of the higher stem density observed in the 8- to 12-year-old age group.

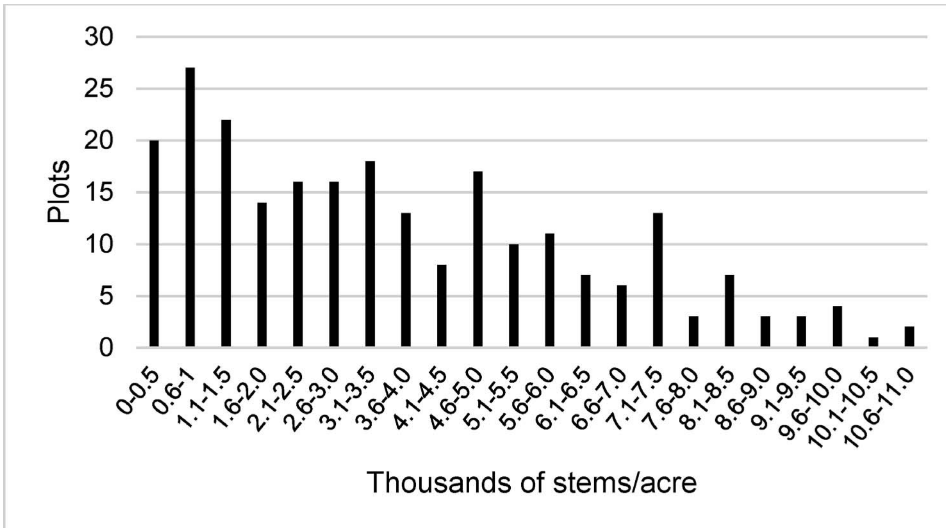

Figure 2.—Plot distribution by stand density of pine species on inventoried precommercial thinning stands in Virginia.

Estimated current and removed volumes

Results from the inventory were used to estimate current and potentially removable volumes of PCT stands. An overall average pine volume of 27.10 gt/acre (Table 1) was estimated using the sample plot data and the biomass equations of Clark and Saucier (1990) and Bullock and Burkhart (2003). Plots in natural stands showed a significantly higher volume than planted stands ($P < 0.001$), with a mean of 34.66 gt/acre compared with 23.68 gt/acre, respectively, which could be attributed to the higher density of natural stands. Plots in stands that were treated with herbicides showed a significantly higher volume than nonsprayed stands ($P < 0.001$), with 30.08 gt/acre compared with 14.82 gt/acre, which was expected because most herbicide applications are meant to deter the growth of hardwoods and encourage pine growth. Furthermore, the greater DBH of sprayed stands could have a positive effect on volume as well. Average volume for plots in the 8- to 12-year-old age group was significantly higher than that for plots in the 5- to 7-year-old age group ($P < 0.001$), with a mean of 39.63 gt/acre compared with 14.47 gt/acre. This higher volume in the 8- to 12-year-old age group could be attributed to the higher stand density of this age group.

When estimating potentially removable volumes, for our starting point we used target residual stand densities obtained from the VDOF forester responsible for each PCT stand, as reported on PCT cost-share applications. These prescribed densities ranged from 350 to 484 stems per acre for the 198 plots measured where a target stand density value was recorded, and a target density of 400 stems/acre was assumed for the remaining 43 plots in which target densities were not identified. Subtracting the target density from the initial density for each plot produced an estimated removable density that was multiplied by the calculated tons per stem to determine an estimate of removable PCT biomass volume.

Using the calculation described above, potential removable volumes for the 5- to 7-year-old and 8- to 12-year-old age groups averaged 11.41 and 33.31 gt/acre, respectively. This estimated removable volume per acre of the 8- to 12-year-old age group compares favorably with the minimum commercial harvest volume guideline of 30 gt/acre suggested for the southern United States (Baker et. 2012), although this minimum volume is based on roundwood (stems $\geq$4 in. DBH) and not precommercial stems ($<$4 in. DBH). Actual removed volumes from a biomass harvest

Table 1.—Characteristics within plots on inventoried precommerical thinning stands in Virginia.[a]

Factor	*n*	Pine density (stems/acre)	DBH (in.)	Vol (gt/acre)
Overall	241	3,771 (171.87)	2.47 (0.07)	27.10 (1.45)
Age (yr)				
5–7	120	3,117 A (209.83)	2.39 A (0.09)	14.47 A (0.77)
8–12	121	4,419 B (259.48)	2.56 A (0.10)	39.63 B (2.28)
Regeneration type				
Natural	75	4,273 C (296.08)	2.44 C (0.14)	34.66 C (3.47)
Planted	166	3,544 D (208.84)	2.49 C (0.08)	23.68 D (1.34)
Herbicide use				
Nonsprayed	48	3,676 E (354.20)	2.10 E (0.15)	14.82 E (1.47)
Sprayed	193	3,794 E (195.90)	2.56 F (0.07)	30.08 F (1.71)

[a] Values are means (standard errors). Means with the same letter are not significantly different ($\alpha = 0.05$) between age groups (A and B), between regeneration types (C and D), and between herbicide use (E and F). DBH = diameter at breast height; gt = green tons.

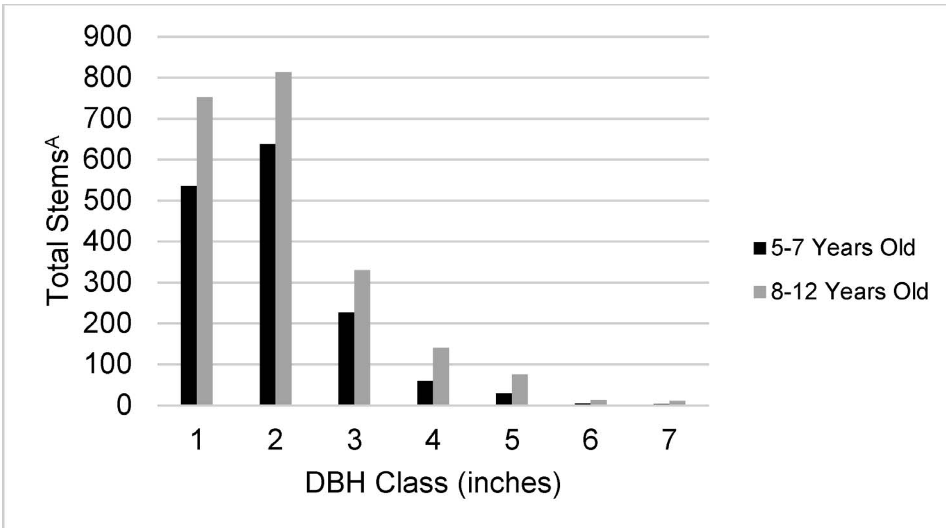

Figure 3.—Diameter distribution of measured stems on inventoried precommercial thinning stands in Virginia. [A] *Stems less than 1.0 inch were not measured.*

may be less than our calculated numbers, depending on the harvest selection method. Our calculation is based on an assumption of a random selection of small- and large-diameter stems, whereas the actual proportion of small-diameter stems harvested would likely be much greater than large-diameter stems in order to maximize the value of residual stems. Also, our calculated volumes only reflect the removal of pine stems; therefore, a small additional component of hardwood volume could potentially be expected.

Potential stumpage value of PCT biomass

The stumpage value of PCT biomass was represented by the difference between the revenue from delivered biomass and the cost of harvesting and transporting the biomass to facilities. Of the potential products derived from harvesting PCT biomass, we believe in-woods whole-tree pine chips to be the most likely product, because in-woods chips are commonly produced from biomass chipping operations (Barrett et al. 2014). Using this assumption, we base our revenue calculations on reported Timber Mart-South regional average prices for delivered in-woods pine biomass chips from plantation thinnings in the southeastern US Coastal Plain (Timber Mart-South 2014). Combined with our calculated volumes, we estimated average delivered revenue from a PCT biomass harvest. PCT biomass stumpage value was then estimated by deducting anticipated logging and hauling costs from these mill-gate revenues.

To estimate potential harvesting costs, actual PCT treatment costs for inventoried stands were obtained from the VDOF. Conventional, manual nonremoval thinning costs for stands inventoried in the 5- to 7-year old and 8- to 12-year-old age groups averaged $142.57 and $138.75 per acre, respectively (Table 2). Typically, harvesting costs incurred by loggers in Virginia are expressed in units of dollars per green ton rather than dollars per acre. Therefore,

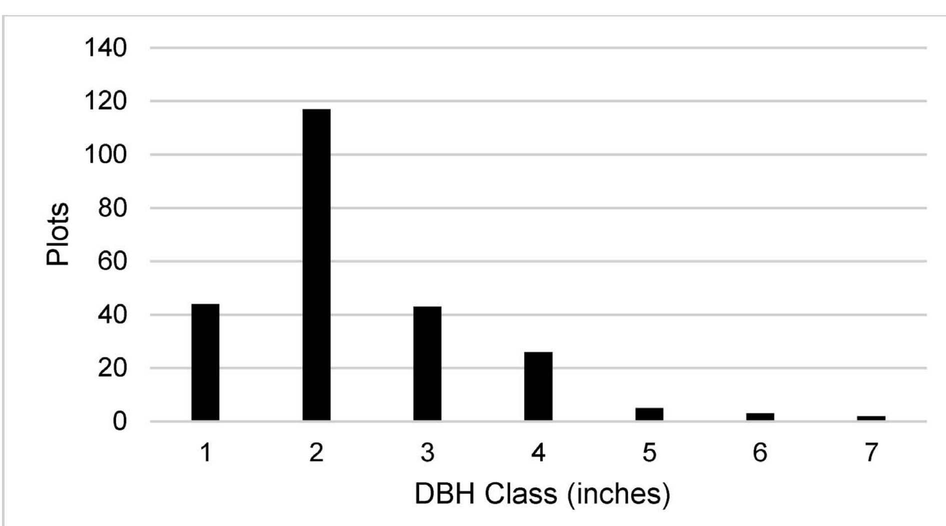

Figure 4.—Plot distribution by diameter at breast height (DBH) class on inventoried precommercial thinning stands in Virginia.

Table 2.—*Thinning costs to landowner on inventoried precommercial thinning stands in Virginia.*

	Actual ($/acre)		Estimated ($/green ton)	
Age (yr)	Without cost-share	With 60% cost-share	Without cost-share	With 60% cost-share
5–7	142.57	85.54	12.90	7.74
8–12	138.75	83.25	4.17	2.50

to compare the cost of conventional treatment to the cost of mechanically harvesting PCT biomass, we used the actual PCT treatment costs to calculate the thinning cost in units of dollars per green ton. The per-acre cost from the VDOF was divided by the estimated removed PCT biomass volume for each age group. These estimated costs per ton for the 5- to 7-year-old and 8- to 12-year-old age groups were $12.90/gt and $4.17/gt, respectively. When including the current 60 percent cost-share from the VDOF, these costs to the landowner drop to $7.74/gt and $2.50/gt, respectively, for the two age groups.

As in-woods chips are normally made from logging residues that have already been transported from the woods to the landing (including ''tops, limbs, limited bole material, and otherwise pre-commercial material,'' according to the Timber Mart-South product definition), we assumed higher harvesting costs associated with utilizing PCT biomass because stems would have to be cut and transported from the woods to the landing and then chipped. Furthermore, we assumed that over-the-road transportation costs would be the same, whether hauling logging residues or PCT biomass to market. Decreased productivity rates associated with the lower per-stem volumes of nonmerchantable–PCT biomass could further lead to higher harvesting costs (Bolding and Lanford 2005, Bolding et al. 2009) and, consequently, lower stumpage values. In studies analyzing the harvesting costs of utilizing both merchantable and nonmerchantable stems for biomass, total cut-and-load costs were $9.18/gt (Mitchell and Gallagher 2007), $14.58/gt (Pan et al. 2008), and $39.83/gt (Bolding et al. 2009). A forest-fire fuel reduction study estimated a cost of harvesting nonmerchantable stems at $25.70/gt (Bolding and Lanford 2005). The harvesting machine configurations, productivities, stem diameters, and initial stand densities varied widely among these studies. Of the studies that were completed in the southeastern United States (Bolding and Lanford 2005, Mitchell and Gallagher 2007), stand conditions differed greatly from those of typical PCT stands, in which average stem diameters are lower and average per-acre stand densities are much greater. Therefore, further information regarding machine productivity and costs in conditions more representative of typical PCT stands would provide better insight regarding harvesting costs associated with PCT biomass.

Understanding the likelihood of higher harvesting costs associated with PCT biomass, we estimated stumpage values at varying levels of costs, anticipating that harvests are likely to be unprofitable in most cases. Using regional average prices for delivered in-woods pine biomass chips and average cut-and-load rates, haul rates, and haul distances for plantation thinnings in the southeastern US Coastal Plain (Timber Mart-South 2014), the stumpage value (dollars per green ton) was estimated at percentage-based levels of higher cut-and-load costs compared with the published baseline values (Fig. 5).

With cost increases over baseline values ranging from 0 to 120 percent, our calculated stumpage values for harvesting PCT biomass vary from $0.11/gt to –$16.52/gt. The one positive stumpage value ($0.11/gt) reflects a net profit for the landowner, and the negative values reflect a net cost where the landowner would need to pay the logger.

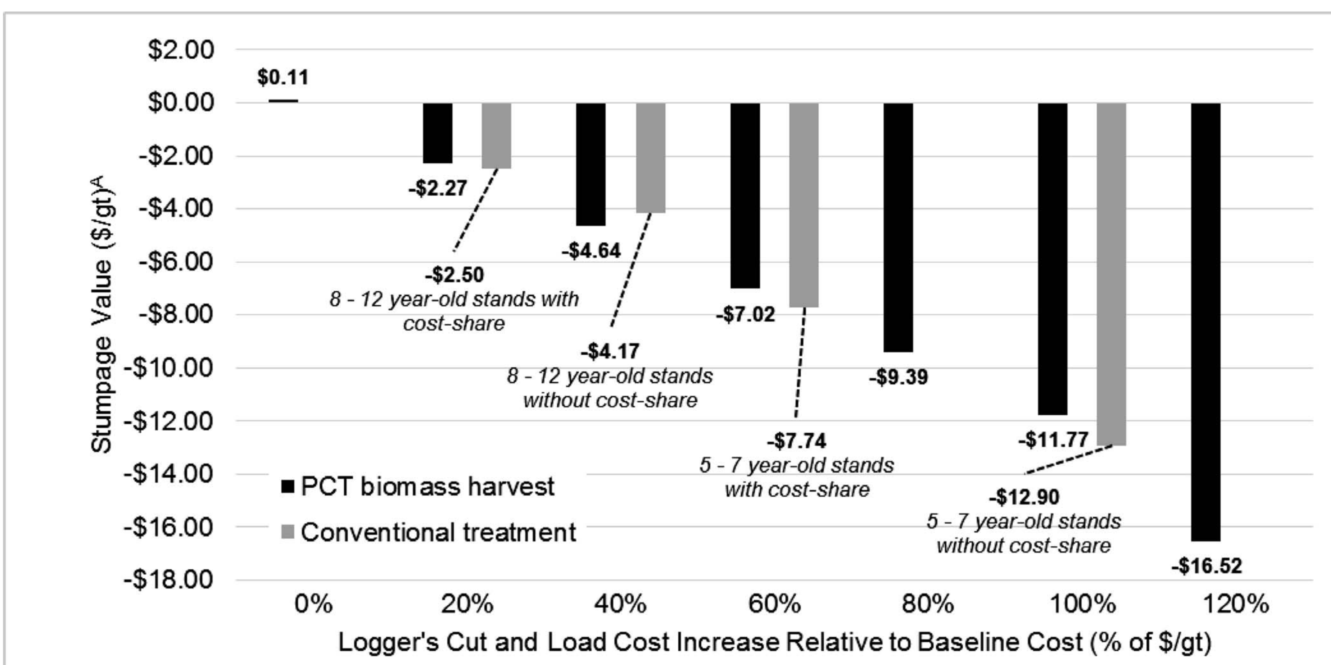

Figure 5.—Stumpage value (dollars per green ton [gt]) at varying levels of cut-and-load cost to a logger compared with baseline values and conventional treatment costs. [A] *Assumes in-woods pine price of $18.62/gt, cut-and-load rate of $11.88/gt, haul rate of $0.13/gt per loaded mile, and one-way haul distance of 51 miles (Timber Mart-South 2014).*

Considering the estimated cost per green ton of the conventional PCT treatment for the 5- to 7-year-old and 8- to 12-year-old age groups, our stumpage value estimates indicate that in some circumstances, landowners may have an opportunity to reduce the cost of treating their overstocked stands by harvesting PCT biomass rather than choosing the conventional treatment. In the absence of the cost-share program provided by the VDOF, cut-and-load costs for harvesting PCT biomass from the 5- to 7-year-old age group could be as much as 100 percent higher than baseline costs ($11.77/gt) and still cost less than conventional PCT treatment ($12.90/gt). However, if cut-and-load costs exceeded 40 percent of the baseline costs for the 8- to 12-year-old age group, harvesting biomass would be more expensive than conventional treatment. If the current cost-share incentive (in which 60 percent of costs are reimbursed) were available, landowners would be better off financially paying a logger to harvest biomass even if cut-and-load costs are up to 60 percent higher than baseline costs ($7.02/gt) for the 5- to 7-year-old age group and up to 20 percent higher than baseline costs ($2.27/gt) for the 8- to 12-year-old age group.

Summary and Conclusions

A total of 241 plots across 18 southern pine stands enrolled in the VDOF PBBPP were measured to estimate harvestable biomass from a PCT treatment in stands between 5 and 12 years old. Total stand density averaged 3,771 stems per acre, with the majority of measured stems falling into the 2-inch-DBH class. Inventory measurements were separated by age group, 5 to 7 years old and 8 to 12 years old, to determine mean standing biomass quantities of 14.47 and 39.63 gt/acre respectively.

Estimated PCT biomass quantities and stumpage values suggest that landowners may have an opportunity to reduce the cost of conventional PCT treatment through harvesting and utilizing PCT biomass, depending on the degree to which harvesting costs are affected by utilizing small-diameter PCT stems. Previous studies have assessed the harvesting costs of nonmerchantable stems, but the stand conditions in these studies vary widely and are not very representative of typical PCT stands. If the total cut-and-haul cost of harvesting PCT biomass is less than the cost of the conventional treatment, landowners would be better off financially with a PCT biomass harvest. Of course, if the additional costs of extracting, chipping, and transporting PCT biomass create a total cut-and-haul cost greater than the cost of conventional treatment, landowners should not consider harvesting PCT biomass as a means of reducing treatment costs. If it is determined that a PCT treatment is necessary, landowners should consider offers from both loggers and conventional treatment contractors to determine the cheapest treatment option. Regardless of treatment option, enrollment in available cost-share program(s) will help to minimize treatment costs.

As woody biomass energy use remains popular in the southeastern United States, biomass from PCT may be a viable resource for energy production. The estimated biomass removals and thinning costs in this study provide some initial insight regarding the economic feasibility of harvesting PCT biomass. Additional work is needed to improve the accuracy of these estimates. Current biomass equations need to be improved to include more stems sampled from smaller (<4 in.) DBH classes to produce more accurate estimates of the woody biomass present. More accurate estimates of actual removed volumes from small-diameter stands are also needed, as the volumes in this study were based on target residual densities that were not confirmed following the completion of PCT in each stand. Finally, better information is needed regarding machine productivity and costs of equipment operating in small-diameter southern pine stands to develop accurate estimates of PCT biomass harvesting costs.

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