Quantification of Biomass Potential from Timber Stand Improvement (TSI) Operations in Hardwood Stands in North Carolina

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Abstract

Across North Carolina, forest species composition has changed substantially over the past 35 years. Oak species have declined while other species, especially red maple and sweetgum have proliferated. This general trend is seen across the state of North Carolina, though each of the four physiographic regions of the state has different factors that contribute to the specie composition changes. Within oak stands, competition in the understory and midstory can significantly reduce oak regeneration. Mitigating competition with oak species through TSI can generate biomass for energy. This project explores potential connections between oak regeneration through conservation forestry and timber stand improvement operations that target red maple and sweetgum removals for biomass energy. This project quantifies small-diameter biomass of red maple and sweetgum trees in oak dominated stands across North Carolina.

Biomass supply estimates typically focus on available residues from forest harvests or from overstocked stands. This report is the first to focus on biomass available from restoration activities in hardwood stands. The standing stock of small diameter red maple and sweetgum is approximately 18,000,000 tons in North Carolina, or 725,000 green tons on an annual basis. However, because harvesting biomass in stand improvement operations is expensive and because of the distributed nature of the resource, limited quantities of biomass will be utilized by our current biomass energy infrastructure. A supply model of the biomass facilities in the state shows that only 87,000 green tons could be utilized. The four facilities modeled in the scenario could produce 53,000 MWh of electricity from the available biomass. Utilization of all biomass in high efficiency thermal applications could yield 1,500,000 MWh-equivalent of thermal energy. A distributed network of biomass energy utilization, focusing on high efficiency thermal applications appears necessary to realize the full potential of North Carolina's biomass resources.

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Background

Forest trends

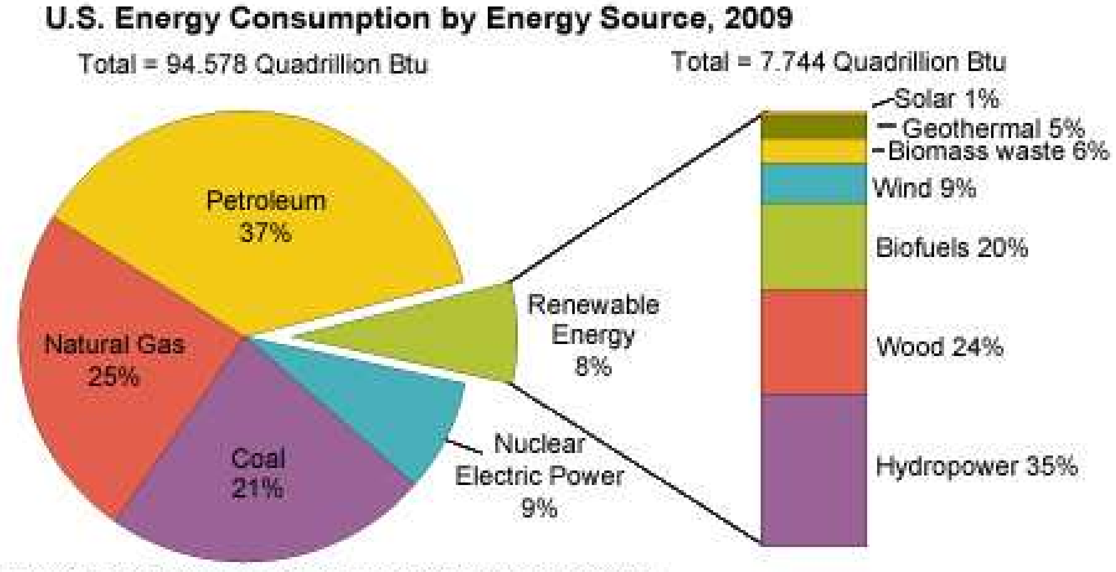
Total acreage of forestland in the five southeastern states has remained roughly constant over the past century after several centuries of decline. The North has actually seen an increase in forest land as farms have been abandoned and the land returns to forest once more. In the Southeast, increase in forest land from reforestation of abandoned farm land has been largely balanced by existing forests being converted to other uses for a largely stable forest land are over the past 100 years (FIA, 2002). However, the composition of hardwood stands in the Southeast region has changed significantly over the same time period, especially with regard to advanced regeneration, or small diameter trees. The typical equilibrium vegetation in eastern forests was oak-hickory or mixed oak-pine. However, oaks (*Quercus spp*.) have declined in many stands for many reasons, both in hardwood and mixed pine-hardwood forests. Other species have risen to prominence in these stands including red maple (*Acer rubrum*), but also tulip poplar (*Liriodendron tulipifera*) and sweetgum (*Liquidambar styraciflua*) (McDonald et al, 2002).

Red maple populations have exploded over the past century, and they have become sizeable components of many forest types within their range, replacing the dominant oaks in both the understory and midstory. Part of this increase may be attributed to the ability of red maple to survive over a wide variety of site conditions (Abrams, 1998). Red maple is also shade tolerant, which allows it to survive under to canopy of other species, while shading out advanced regeneration from oak species. A large increase in white-tailed deer over the past several decades and increased deer browse may have contributed to reduced oak regeneration. Deer prefer oak mast and oak foliage over that of red maple (Abrams, 1998). Another factor for the decline of oaks and increase in red maple may be the suppression of fire, for which red maple is not particularly well adapted (McDonald et al, 2003; Brose et al, 2001). In particular, low intensity ground fires allow greater regeneration of oak saplings by removing other species from competition. Prescribed fire may play a critical role in reducing the prevalence of red maple regeneration, but red maple is already well established in many hardwood forest stands. In addition, prescribed fire may be difficult to bring back to many forested areas. Using prescribed fire is costly and it is often difficult to manage smoke in a fragmented landscape. In addition, air quality concerns can limit the ability of forest managers to use prescribed fire in many communities in the state.

The increased prevalence of red maple and other less desirable species may concern forest managers for two different reasons. The trees may be marginal in merchantable size for conventional timber products and may also prevent oak regeneration. While many individual specimens of red maple may be small, they nevertheless can represent a large amount of woody material in many hardwood stands. This biomass could hypothetically be harvested for energy production while helping to promote oak regeneration in managed hardwood stands.

Energy from biomass

Biomass is an alternative source of energy that can reduce greenhouse gas emissions and provide a reliable supply of energy. Several developed nations in Europe get substantial amounts of their total energy from biomass, including Finland, which obtains 20% of its energy from wood (Hakkila, 2006), and Austria, which obtains 12% of its total energy from biomass (BTEC, 2010). Currently, biomass is the largest renewable energy source in the U.S. after hydro power. Figure 1 shows the contribution from biomass for the U.S. energy supply. Most of this capacity comes from installed generation from the wood products industries, especially pulp and paper. The pulp and paper industry has used waste wood to fuel their operations for decades, lowering their electricity costs and making use of a waste product. It is important to note that Figure 1 displays total energy consumption, rather than simply electricity consumption. Wood fuels are still used for heating in many areas of the U.S., including the Northeast and the Great Lakes states. Wood fuels have also increased in popularity in recent years as the prices of fuel oil have spiked, natural gas has remained volatile, and environmental concerns over climate change have become more prominent.



Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Annual Energy Review 2009*, Table 1.3, Primary Energy Consumption by Energy Source, 1949-2009 (August 2010).

Figure 1 shows U.S. energy consumption in 2009. Biomass waste and wood combined make up one third of total renewable energy production. Biofuels is primarily composed of corn ethanol and soy biodiesel. Source: EIA.

A major driver of renewable energy installations in the U.S. are renewable portfolio standards (RPS) enacted by various states. An RPS forces utilities to obtain a certain percentage of their electricity production from qualifying renewable sources over a certain time frame. North Carolina instituted a Renewable Energy and Energy Efficiency Portfolio Standard in August of 2007, which mandates 12.5% of energy used in the state come from new renewable sources or be offset through efficiency measures by 2021 (2007 N.C. Sess. Law 2007-397). Figure 2 investigates the current energy production in North Carolina as of 2009. It is important to note that the current biomass energy is dominated by captive plants producing energy for the pulp and paper industry.

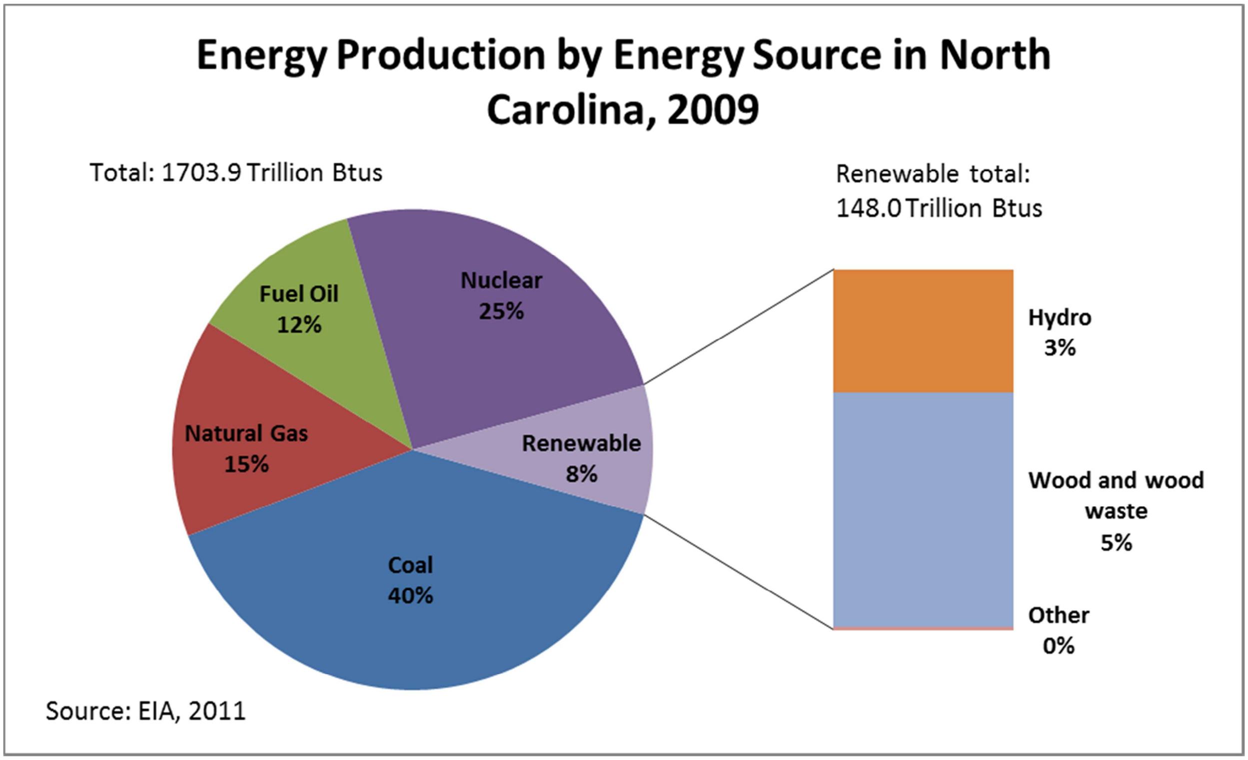


Figure 2 shows energy production in North Carolina in 2009. The primary source of wood energy is the pulp and paper industry.

In the southeastern U.S., it is projected that the major renewable energy source will be from biomass resources. The southeast does not have strong onshore wind potential and has limited solar potential due to cloud cover. Many environmental groups have expressed concern over the large increase in biomass energy that is projected for the state of North Carolina and for the Southeast as a whole. The definition of renewable energy included in NC Session Law 2007-397 indicates that “wood waste” qualifies as a renewable biomass resource. However, the NC Court of Appeals ruled in the summer of 2011 that whole trees qualify as renewable energy sources in a case that pitted the Environmental Defense Fund against Duke Energy. Duke Energy sought to use whole tree of pulpwood size to co-fire in several coal fired power plants. Biomass has potential to be co-fired in coal plants at ratios up to 10% without substantial changes in the boiler systems. This is seen by utilities in the southeast as a way to meet pollution standards, in addition to the REPS in North Carolina, at the lowest cost. Another option is to build standalone biomass facilities to produce electricity exclusively from the combustion of wood or other biomass resources, though standalone facilities typically have a lower efficiency of combustion.

Carbon and biomass

While many groups currently advocate for biomass as a carbon neutral energy source, including forestry associations and energy trade groups, there has been debate within the scientific community over how carbon emissions from biomass burning should be treated. The traditional view of biomass energy is that it is “carbon neutral.” The carbon released by burning trees is part of the active carbon cycle and would be released eventually anyway, with the death of the tree. In contrast, fossil fuels represent carbon that have been removed from the carbon cycle and effectively stored for millennia. However, it is important to consider the full implications of biomass burning for energy. Harvesting biomass systemically reduces the amount of carbon stored in the forest, with a resulting increase in atmospheric carbon. Much greater amounts of carbon are added to the atmosphere when producing energy from wood at low efficiencies.

Biomass energy depletes carbon stocks in forests, adding that carbon to the atmosphere. This carbon is taken up again by regenerating forests, but the result is a temporary increase in atmospheric CO_2 concentrations (Johnson, 2009). Therefore, biomass energy can increase emissions in the short term, before forests regenerate fully and accumulate the carbon released during energy generation. The state of Massachusetts commissioned a study that concluded that electricity from biomass would increase CO_2 emissions over the short term (Manomet, 2010). The study found that biomass combustion releases 60% more CO_2 per unit of energy produced than coal combustion. While the study was particular to the state of Massachusetts, it does show that carbon accounting of biomass must be done carefully. Biomass, and especially biofuels, can also cause indirect carbon emissions through land conversion (Searchinger et al, 2008). As agricultural land is used to grow biofuel crops, trees, or energy crops, new land must be found for food crops, which results in the conversion of virgin forests. The impact from indirect land use change can be a significant factor in the overall carbon footprint of biomass energy (Searchinger et al, 2008). Table 1 illustrates the differences in emissions from producing 1 MWh of energy using a variety of fuels. The coal and natural gas emissions rates are averages from all plants in the country.

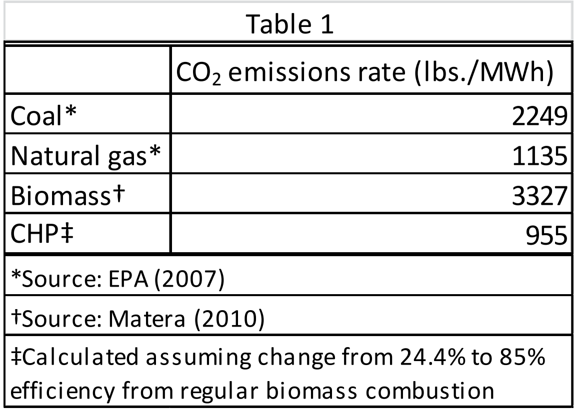


Table 1

	CO_2 emissions rate (lbs./MWh)
Coal*	2249
Natural gas*	1135
Biomass†	3327
CHP‡	955

*Source: EPA (2007)

†Source: Matera (2010)

‡Calculated assuming change from 24.4% to 85% efficiency from regular biomass combustion

The increase in carbon emissions from biomass energy that produces electrical power contains many complexities. Biomass energy releases nearly double the CO_2 per MWh of electricity produced as coal and four times that of natural gas. Therefore, the reference fuel to which biomass is compared is important. In many analyses, biomass energy is assumed to supplant coal, but this may not be accurate for all areas and all markets. For example, in the Northeast, natural gas is the dominant electricity generation source and heating oil is the dominant heating source. Both may be the source of energy replaced by additional biomass generation. The carbon implications of adding biomass energy versus a business-as-usual scenario therefore depend on the technology to be replaced in each region.

Carbon emissions from biomass energy are also inherently different than that from fossil fuels. Carbon present in biomass is part of the active carbon cycle and is being continuously cycled between the biosphere and atmosphere. Release of this carbon through biomass burning only speeds the transition back to the atmosphere. Use of fossil fuels, on the other hand, releases carbon that had been previously removed from the active carbon cycle and sequestered in geologic formations. Thus, ancient carbon is released, adding significantly to atmospheric concentrations of carbon dioxide. However, while biomass while increase atmospheric carbon, a steady state can be reached where continued energy production does not increase atmospheric emissions.

The biomass technology and its related conversion efficiency also determine the carbon emissions of biomass energy. Combustion of biomass in a conventional boiler has an average efficiency of 24.4%. Thermal technologies, such as the Advanced Wood Combustion (AWC) used in much of Europe, and combined heat and power (CHP) can have efficiencies that reach 90% (Richter et al. 2009). Thus, for a given amount of energy produced, there are far fewer carbon emissions. Finally, the source of biomass also factors into determining the cumulative CO_2 emissions. Using waste wood or logging slash from harvesting operations results in no net CO_2 emissions, because these wood sources would have decomposed anyway in a relatively short time period (Manomet, 2010). All of these factors, the biomass source, the combustion technology, the displaced energy generation, and the inherent difference between active and fossilized carbon are important to consider when calculating the CO_2 emissions of biomass energy.

Sustainability

Sustainability of biomass harvesting for energy has also raised concerns. Slash and other low-value wood, collectively termed logging residues, which are left on site, perform many valuable ecosystem services. Logging residues retain nutrients, especially in the foliage, which are recycled into the soil upon decomposition of the residues. Nitrogen is especially recycled in this way. Residues also perform other important benefits, such as reducing erosion on a harvested site, and protecting water quality. Residues, especially coarse woody debris, also provide habitat for small animals and insects, which are important to ecosystem functions. The Forest Guild has proposed sustainability guidelines for many biomass harvesting operations for different regions of the country, to prevent the depletion of ecosystem services after biomass harvests.

In May of 2011, the EPA proposed to defer regulation of greenhouse gas emissions from biomass plants for three years. The proposed deferral was opened to public comment, with many environmental groups opposed to the deferral, while many forestry groups supported the decision by the EPA. Some of the comments are instructive as to the role of small-diameter trees, conservation forestry, and ecosystem restoration in biomass energy. The Director of U.S. Government Relations at the Nature Conservancy and the Vice President of Public Policy at the National Audubon Society commented that “In carrying our conservation work, we conduct or support many habitat restoration projects that may stand to benefit from new biomass energy markets. For instance, some projects remove small trees and other biomass from forest landscapes to reduce catastrophic fire risks. In other locations, our organizations are restoring degraded agricultural lands by planting perennial grasses. If the biomass materials produced and harvested through these activities could be sold to bioenergy facilities for conversion to low carbon energy, additional resources would be available to carry out these conservation projects", (Bendick and Daulton, 2011). From these comments, it is clear that a large landowner, like the Nature Conservancy, is considering selling small-diameter trees as biomass in order to off-set some of the costs of land maintenance and restoration.

The removal of small-diameter trees for use as biomass may also be preferable from a carbon perspective, as well. Small trees currently have no market. Thus, when they are removed to promote regeneration or to restore the native ecosystem, they are typically left in the forest to decompose. Diverting this resource to a biomass energy facility would release the carbon, but only slightly faster than if left to decompose naturally. One concern is that with a market for small-diameter trees, removal would increase greatly. However, these removals are used to promote regeneration and growth of high-value species, and may actually increase the carbon uptake of the forest, in response to forest thinning. At the present time, the amount of biomass available from restoration practices is unknown.

Objective

There have been several biomass estimates that have included the forested lands in North Carolina. The first major study was conducted by the USDA and the DOE to investigate the potential contribution to total biomass availability for all feedstocks across the country (Perlack et al, 2005). The billion-ton study was not as much a biomass inventory but a study of the feasibility of producing a billion tons of biomass a year. Forest biomass estimates were aggregated for the entire country and were composed of residues from traditional forest harvesting operations and a small percentage of saplings deemed to be overstocked (Perlack et al, 2005). Additional studies have focused more narrowly on Southeastern states, including North Carolina. A recent estimate of current biomass availability in North Carolina found 2.8 million dry tons available for energy production (Galik et al, 2009). However, this analysis estimated only forest residues of on-going harvesting operations. Biomass potential of less desirable species in hardwood stands, particularly of non-merchantable trees has not been investigated.

This project will attempt to understand the change in hardwood forest composition over the past 60 years on the state level, using forest inventory information for North Carolina. This information may be valuable to landowners and forest managers throughout the state. The in-depth analysis in North Carolina will also allow for general comparison to other states in the Southeast that have similar physiographic provinces. By understanding the changing composition of hardwood stands, it will be possible to analyze the amount of biomass currently composed of low value species, which may be restricting oak and hickory regeneration. This project will provide an estimate of available biomass for energy production using only low value hardwood species that can be obtained from stand thinning and improvement operations in mixed hardwood stands. The project incorporates the idea of conservation forestry and managing forests for multiple uses. Removal of low value species, such as red maple and sweetgum, provides biomass but can also improve the regeneration and growth of high value species within the stand. For example, oak mast is typically considered more conducive to wildlife. Oak is also a high value timber product. Therefore, oak regeneration is important when managing a forest for wildlife or timber or managing for multiple uses. Ultimately, this project will provide an estimate of total available biomass, while providing forest managers with information on a possible market for low value wood that can be removed in Timber Stand Improvement (TSI) practices.

Methods

Forest Inventory and Analysis (FIA)

The US Forest Service undertakes the Forest Inventory and Analysis (FIA) which is a continuous inventory of the nation's forests. The FIA began in 1936, providing constant data on the composition of North Carolina forests over the last 80 years. The FIA program uses forest plots scattered through public and private lands throughout the state to analyze changes in the forest structure and species composition. Both forested and non-forested lands are sampled, though tree data is only available for plots that are greater than 25% forested. Up until the 1990s, a statewide survey was conducted about every 10 years. In 1999, the FIA shifted from a periodic state by state survey to an annual inventory of each state, providing increasing fine temporal resolution to the data. The annual survey looks at a sampling of sites across the state in each year, with all sites being surveyed in a ten year period. This method is preferred because it can give greater temporal detail on changes in the forest. FIA gathers information in four distinct regions in North Carolina that correspond roughly to physiographic provinces: the mountains, the piedmont, and the northern and southern coastal plain. The data is then broken down by county estimates, but this spatial resolution of the data does not match the resolution in which it was collected. Therefore, the project focused on North Carolina as a whole, broken down by region rather than county. Long term trends in species composition within North

Carolina’s forests are important to couple with the history of forest management to determine the cause of changing forest composition.

The FIA sampling method begins with satellite remote sensing. Land use and land cover classification is used to determine areas with similar land cover. The different forest classifications are used in developing the second phase of sampling using ground plots. Ground plots, or Phase 2 plots, are designed to cover a 1-acre sample area. Current inventories use a standard fixed radius plot and subplot layout for the sampling process, which is standard across the country. Older inventories used a combination of fixed radius and prism plots for tree selection, though the current method has been in place since the mid-1990s. Each sampling location consists of four plots, each consisting of three different size nested plots, referred to as macroplots, subplots, and microplots. Figure 1 gives a description of a standard FIA sampling plot with the locations and diameters of each plot. The three different size plots all measure trees in different size classes. The microplots measure all trees between 1 inch and 5 inches in diameter, while the subplots measure all trees above 5 inches in diameter. The macroplots measure larger trees, though the size cutoff varies among plot locations and forest types.

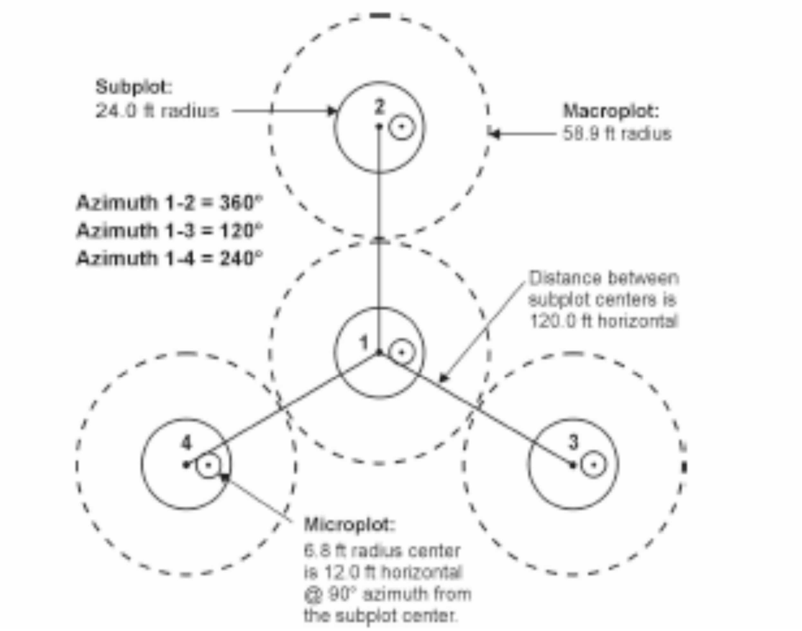


Figure 3. The subplot layout of a standard FIA Phase 2 sampling location. Source: FIA Database User Manual, v. 4.0 (2010).

The division of data into four physiographic provinces is also important for the analysis of changing species composition. Oaks, and in general the oak-hickory forest, dominated in the Piedmont region. The mountains historically were dominated by oaks as well, though other species, such as sugar maple and white pine were also present. Each province has a different historic species composition. The primary hardwood forests in the state were throughout the Piedmont and mountains, though the species of hardwoods also differed between these two regions. Therefore the greatest decline in oaks and the largest increase in low value species are expected in the piedmont and mountain provinces of the inventory data.

The northern and southern coastal plain were historically dominated by pine forests and mixed oak-pine forests. Today, pine plantations are common in the coastal plain and mixed hardwood forests are much rarer. Pine plantations will also make reduce the usefulness of small-diameter trees as a source of biomass. In hardwood forests, these small diameter trees can be removed as part of stand improvement operations. However, pine plantations typically have short rotations and regenerating species may not have time to grow to sufficient size to be worth harvesting. In addition, there is no reason to remove the small-diameter biomass before a final harvest. However, the biomass from small diameter trees could contribute to the total biomass removed from a site, such as tops and limbs, if a biomass harvest was added to a more traditional sawtimber or pulpwood harvest.

Data from the Forest Service's FIA was obtained from the online database. The FIA "TREE" database contains all individual records for sampled trees. In North Carolina, this information is available from the 1974, 1984, 1990, and 2002 periodic inventories, as well as the recent annual inventories that have taken place from 2003-2010 (FIA, 2008). The data three periodic surveys undertaken in North Carolina before 1974 have been lost. Several publications were written on the periodic survey data of 1936, 1945, and 1954 by the Forest Service and were obtained from the Forest Service archives to supplement the existing data. This data is only useful in evaluating trends in the overall species composition.

FIA data contains information on the sampling site and plot locations, and includes tree species, diameter (DBH), height, stem biomass, top biomass, stump biomass, and belowground biomass. Diameter and height are reported for every tree, though biomass is not calculated for every tree. For small diameter trees (<5 inches DBH), sampled in each FIA microplot, biomass values are constant and based solely upon diameter. These missing values could be filled in based on the diameter of the tree in each record. The biomass of pulpwood size trees between 5 and 8 inches in diameter was calculated in order to inform the economic analysis of stand improvement operations. Therefore, it was necessary to determine a relationship between DBH and biomass for the two species of interest, red maple and sweetgum.

For pulpwood-sized trees, between 5 inches and 8 inches in diameter, the FIA uses a series of twelve equations sourced from the academic literature to determine total biomass in each tree (FIADB, 2010). However, the relationship between a combination variable of DBH and height and biomass were strong. Tree records for both species that included both DBH and a calculation of biomass were aggregated and regressed to find the equation for this relationship. For each species, all tree records that contained DBH, height, and biomass in the Annual surveys, which represent the most recent data and methodologies, were used in the regression to identify the relationship. The regression found the relationship between a combination variable (diameter * height) and the total aboveground biomass (stem biomass + top biomass). The Appendix contains a further explanation of the regressions and shows the plot of the regressions for each species and region.

Estimates of current biomass supply from small-diameter trees will necessarily use the most recent data. Therefore, only this data is appropriate to use in determining the relationship between diameter and height, and biomass. A different regression was performed for each of the four sampling regions in North Carolina simply because of how the data were aggregated. It is possible that regional variations exist between diameter, height, and their relationship to biomass. FIA biomass calculations, however, use consistent equations across the country, so no regional differences were expected. The regression equations resulting from the analyses were used to populate the missing pulpwood biomass values for red maple and sweetgum in each region.

After calculating biomass values for individual trees sampled, it was necessary to scale up to the biomass available in each acre. FIA calculates a factor TPA_UNADJ that allows individual tree data to be scaled up to an acre. The factor is calculated using Equation 1:

$$TPA = 1/(N*A) \qquad (1)$$

where N is the number of subplots, and A is the area of each subplot. The biomass from each tree record is multiplied by the factor TPA_UNADJ to scale up to the estimated biomass available on an acre. The amount of biomass on each acre is then sorted by forest type, which must be obtained from the COND table from the FIA. A filter was applied to retain only the estimates of biomass for hardwood stands, specifically oak dominated stands. The total biomass available from small-diameter red maple and sweetgum trees was scaled up to the region level. The FIA uses one sample plot for approximately every 5936 acres. The sample plots are distributed by so that each forest type meets this relationship between total acres and number of sample plots. Therefore, the amount of biomass from both tree species was summed for each region, both in total and only including oak stands, and was multiplied by 5936 to scale the plot level data up to the regional level. FIA biomass estimates are in dry pounds, which were converted to tons to enable a comparison with traditional biomass estimates. The results are displayed in both dry and green tons in order to facilitate such a comparison.

The statewide stock of biomass also needed to be converted to a sustainable rate, where biomass could be removed every year. FIA data does not included age with individual tree records. Age can be obtained for selected trees of several species for each inventory year. Red maple did not have any age related data, and sweetgum ages were charted from the last 5 annual inventories. A relationship between diameter and age at diameter height was regressed. The age at diameter height is several years lower than the true age. 2.5 years were added to find the average age necessary for a sweetgum tree to reach 5 inches in diameter, which is the limit for our low-value biomass estimate. The total amount of available biomass was divided by the average time needed for a sweetgum tree to reach the maximum diameter to arrive at a sustainable harvest rate. No data for red maple was available so the same rate was used for both species.

Energy analysis

Standalone biomass facilities within the state were identified as Craven County Wood Energy and Green Power Kenansville (ORNL, 2011), while there is a plant currently on hold in Hertford County. In addition, Duke Energy recently test-fired biomass with coal at a rate of 10% in the Buck Steam Station in Rowan County, North Carolina. These four facilities were used to conduct an analysis of biomass demand from current facilities in North Carolina and the potential for low-value biomass from TSI operations to be utilized. Two of these facilities are not currently producing power, the proposed Hertford plant and the Duke co-firing operation, but could produce energy from biomass in the future. These plants are currently the only standalone facilities using biomass in the state. The pulp and paper industry has large biomass capacity, but these plants are considered captive plants. The biomass produces large amounts of steam for industrial processes and electricity generation, but nearly all is consumed by the facilities themselves.

ArcGIS was used to create a map of the four biomass plants. The plants were isolated using Google Earth to find the exact location for each plant. A shapefile was created to include the locations of the biomass plants within the state. Shapefiles of the counties of North Carolina and all major roads in North Carolina were obtained from NC OneMap. The road layer was used to create a road network that covered the state of North Carolina. The network layer was necessary to determine biomass source areas around each individual plant. Typically, biomass must be sourced from within 50 miles of a facility to be economical (source). However, this is not a straight-line distance, but a haul distance. Transportation is the largest component of the total cost of delivered biomass (Galik et al. 2009). Therefore, a 50 mile road network must be established to determine the area within economical haul distance. Aggregate area within haul distance was found for 5 mile distances up to 50 miles for all four facilities. Overlapping wood supply sheds for different facilities were taken into account by including their area only once, while all out of state area was excluded. The road area within the 50 mile road network buffer is displayed in Figure 3.

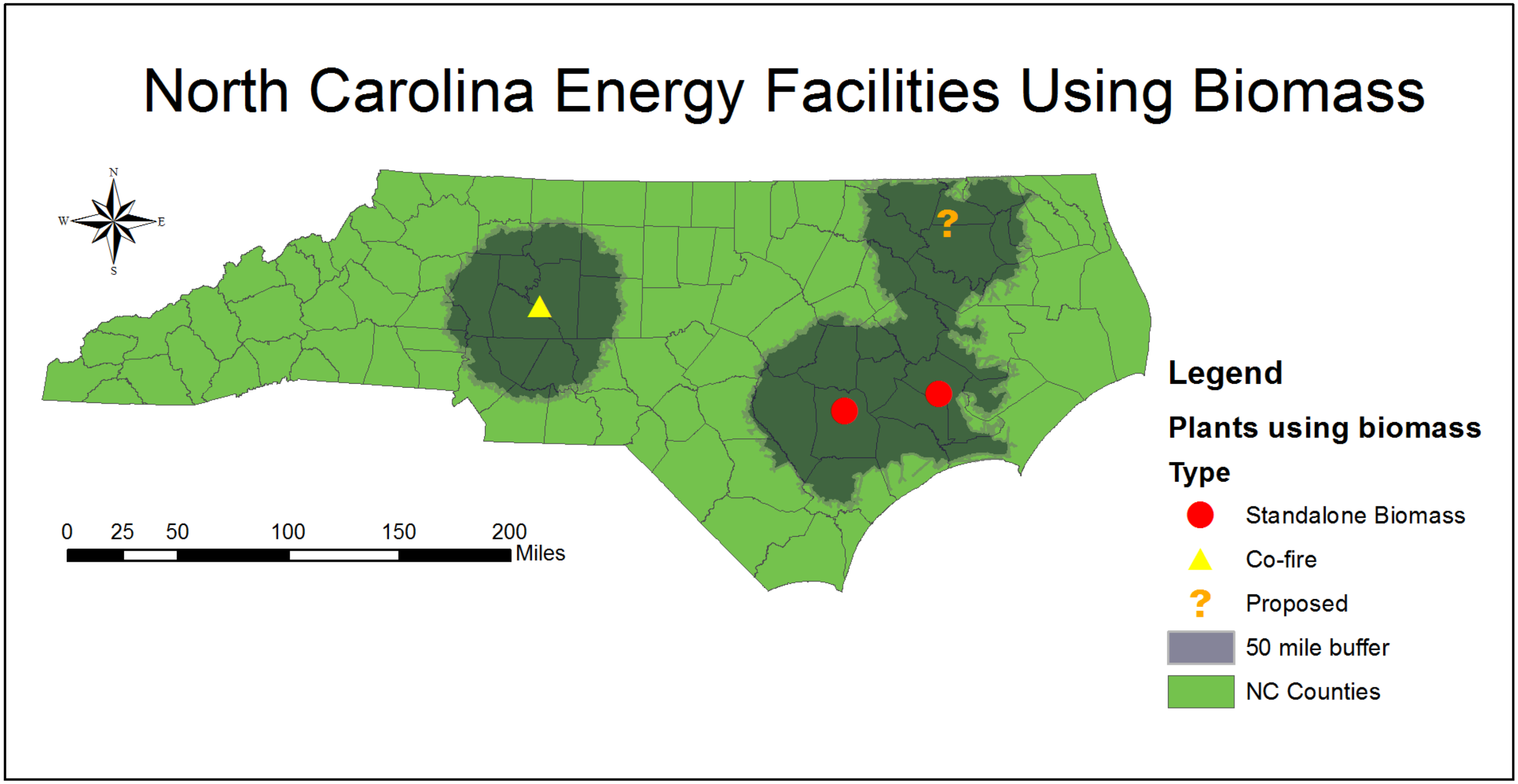


Figure 4 displays four biomass facilities in the state of North Carolina. Two are standalone biomass facilities that produce electricity. One is a coal fired power plant that Duke Energy used to co-fire biomass, but is currently operating solely on coal. The fourth is a proposed biomass facility to produce electricity that has been put on hold.

Total available biomass inside each component of the supply shed was estimated. Total biomass included that available from TSI operations and from forest residues after typical forest harvests, which were obtained from Connor and Johnson (2011). The spatial distribution of low-value biomass from hardwood TSI operations was not available. Each FIA plot has general location information associated with it. However, each plot represents 5936 acres of the same forest type in the same region. Spatial data was also not available with the forest residues total. Therefore, an even distribution of residues across the state was assumed for the sake of the biomass aggregation. While there is spatial heterogeneity in the availability of these biomass residues, the supply sheds for the biomass facilities are large, making an average value an appropriate estimate of actual biomass supply.

Supply curves were generated using the amount of low-value biomass, residues, and aggregate biomass available to the four facilities at particular prices. The delivered price per green ton was assumed to start at $17.25 for residues and increase $0.16 per ton-mile (Galik et al. 2009). Biomass from low-value trees from TSI operations are more expensive to harvest, typically costing twice as much to harvest as forest residues (EPA, 2008). Therefore, the starting price for low-value wood from thinnings started at $18.93 per green ton. The total biomass needed by the facilities was also graphed to show where supply met demand, assuming all demand is met with these two biomass resources. The energy generated from these four facilities was calculated using the total amount of biomass used by each plant. The amount of biomass needed each year per MW of capacity is approximately 10,000 green tons (Wiltsee, 2000). Conversion rates of 4250 Btu/green lb. and 14000 Btu/kWh, (Wiltsee, 2000) corresponding to 24.4% thermal efficiency) were used to calculate total energy production from these four plants.

The total energy available from the wood from a distributed network of high efficiency thermal applications was also calculated for comparison.

Results

Species composition trends

FIA data shows a clear trend in the composition of forests in North Carolina from 1974 to the present, especially in the Piedmont and Mountains regions. The proportion of total stems comprised of oak species declines substantially over the period in both regions. The Piedmont sees a decline from just over 20% to 13.5%. In the mountains, the decline is even more dramatic. In 1974, oaks comprised approximately 30.4% of the total trees within the region. Present data indicates that this proportion has declined to 19%. Figures 2 and 3 illustrate the decline of oak species and the rise in prominence of especially red maple, but also sweetgum, within the Piedmont and Mountain regions.

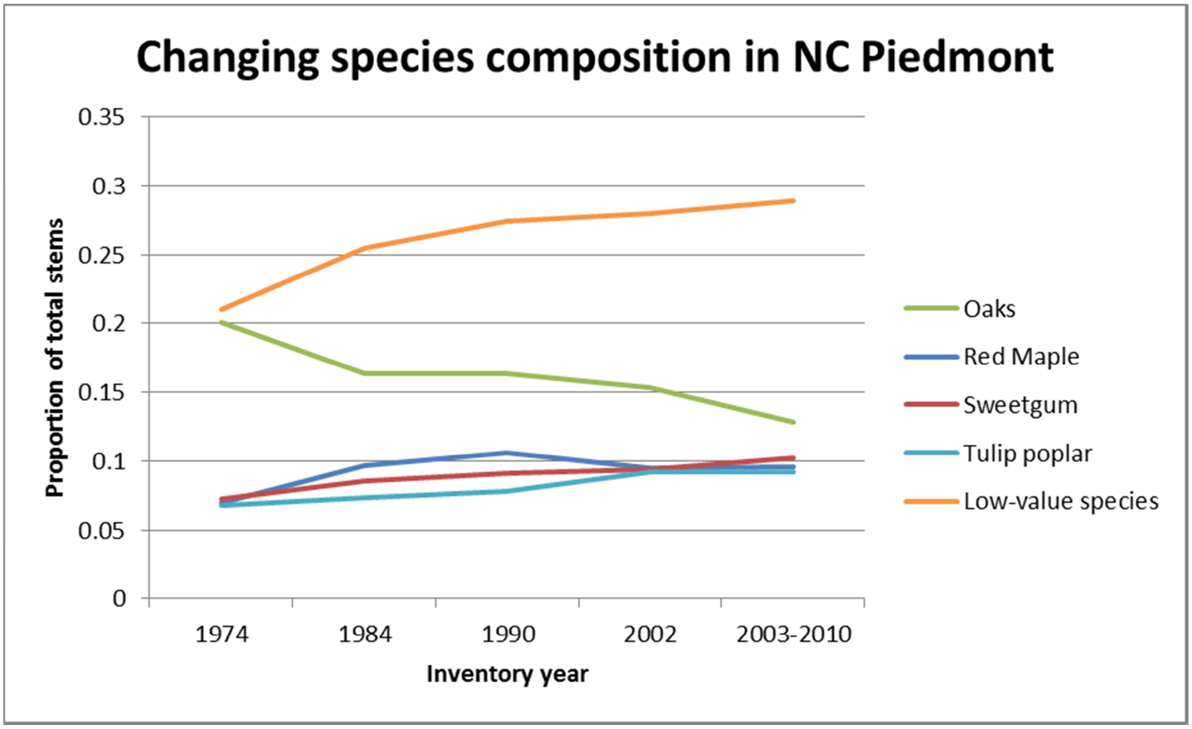


Figure 5 shows the percentage of total stems belonging to each species or species group using FIA data since the 1974 survey to the present annual surveys.

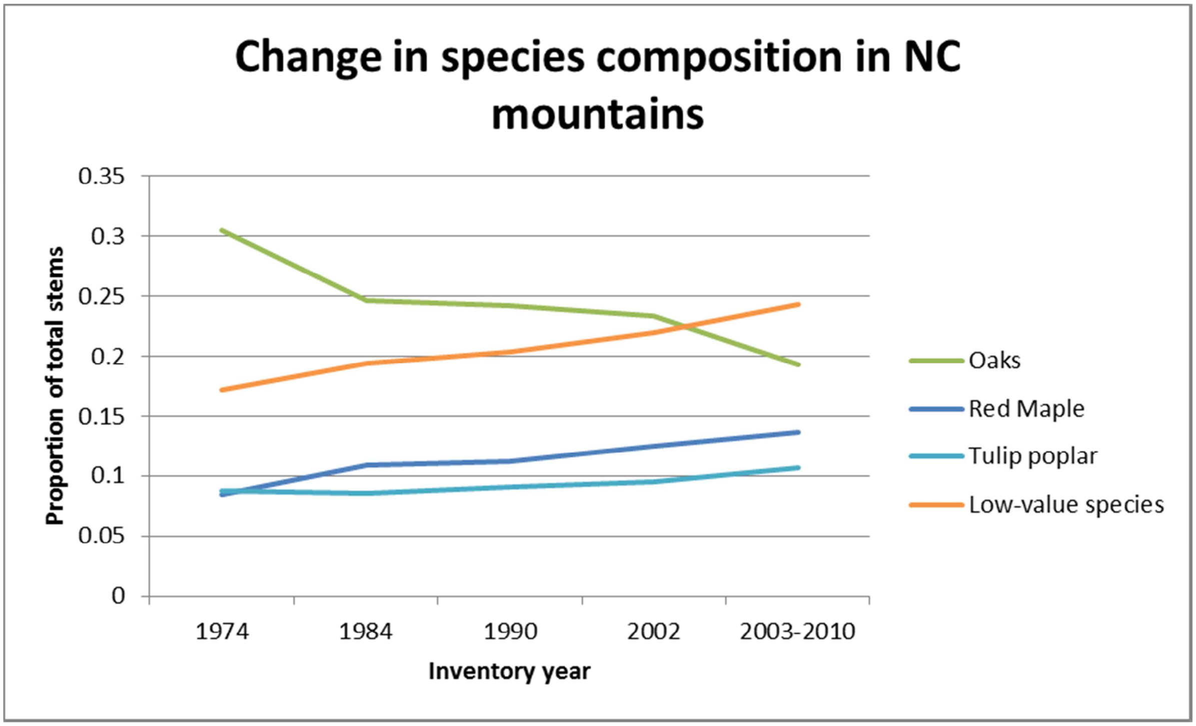


Figure 6 shows the percentage of total stems belonging to each species from the 1974 FIA inventory to the present annual inventories. The prominence of oaks declines and the amount of red maple increases.

Within the northern and southern Coastal Plain, the change in the species composition reflected a different mechanism. The forests of the Coastal Plain are historically pine forests, or mixed oak and pine. Therefore, the proportion of oaks in 1974 is not nearly as high in the Coastal Plain as in the other two regions in the state. Though, the dramatic decline in oak species is not apparent in these two regions, oaks do decline as a proportion of overall trees. This decline does not seem to be correlated with a dramatic increase in red maple or sweetgum. The species dynamics in these regions are slightly more complicated. This is not altogether unexpected as oak species generally change from the Piedmont to the Coastal Plain. Closer to the coast are more turkey oaks, which share habitat with pine species, as well as coastal species such as live oaks. However, the biomass estimates from these two regions will still be included into the total estimate of biomass from small-diameter red maple and sweetgum from hardwood stands. Red maple and sweetgum that have infiltrated pine stands can still be harvested to provide biomass for energy. However, this biomass will not be included in estimates of available biomass through hardwood stand improvement operations. Stand improvement operations in pine, such as pre-commercial thinnings, salvage harvests, or other thinnings can harvest small-diameter red maple and sweetgum for biomass purposes. Figures 4 and 5 show the changes in species composition in the northern and southern coastal plains of North Carolina since 1974.

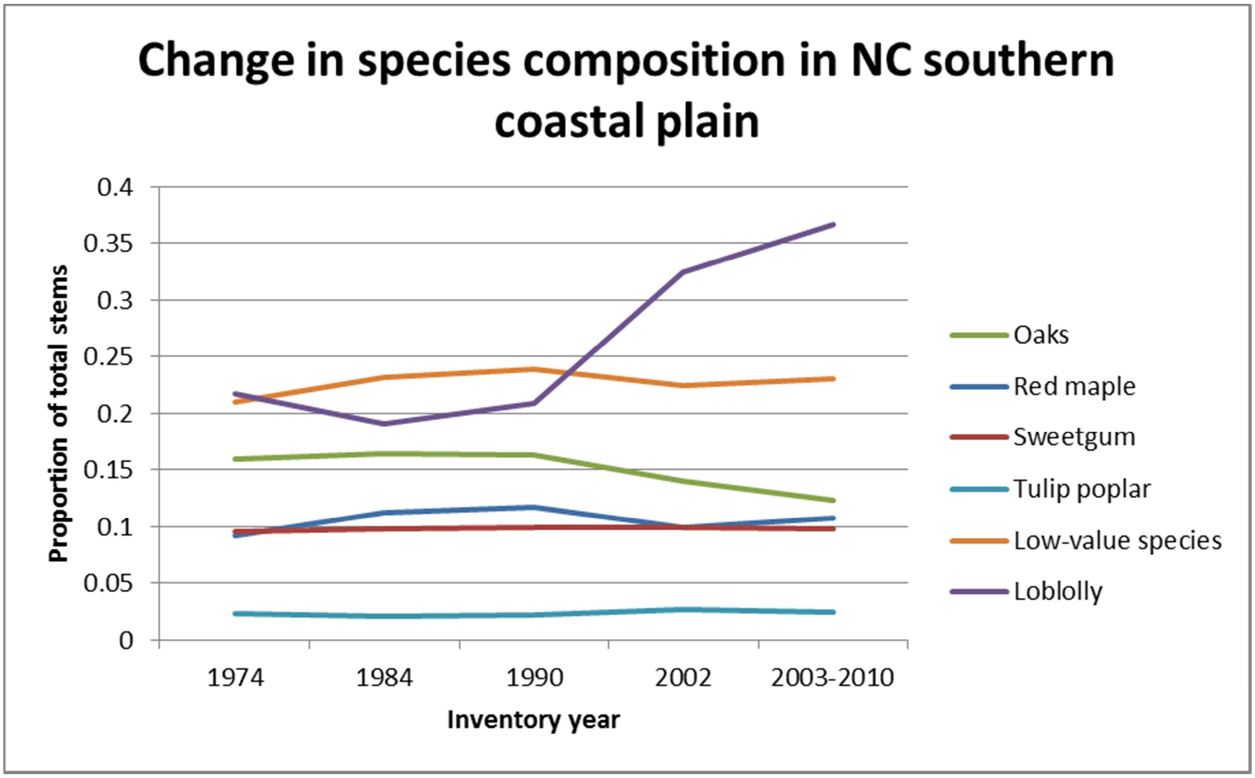


Figure 7 shows the percentage of total stems belonging to each species from the 1974 FIA inventory to the present annual inventories. The prominence of oaks declines with the increase of loblolly pine.

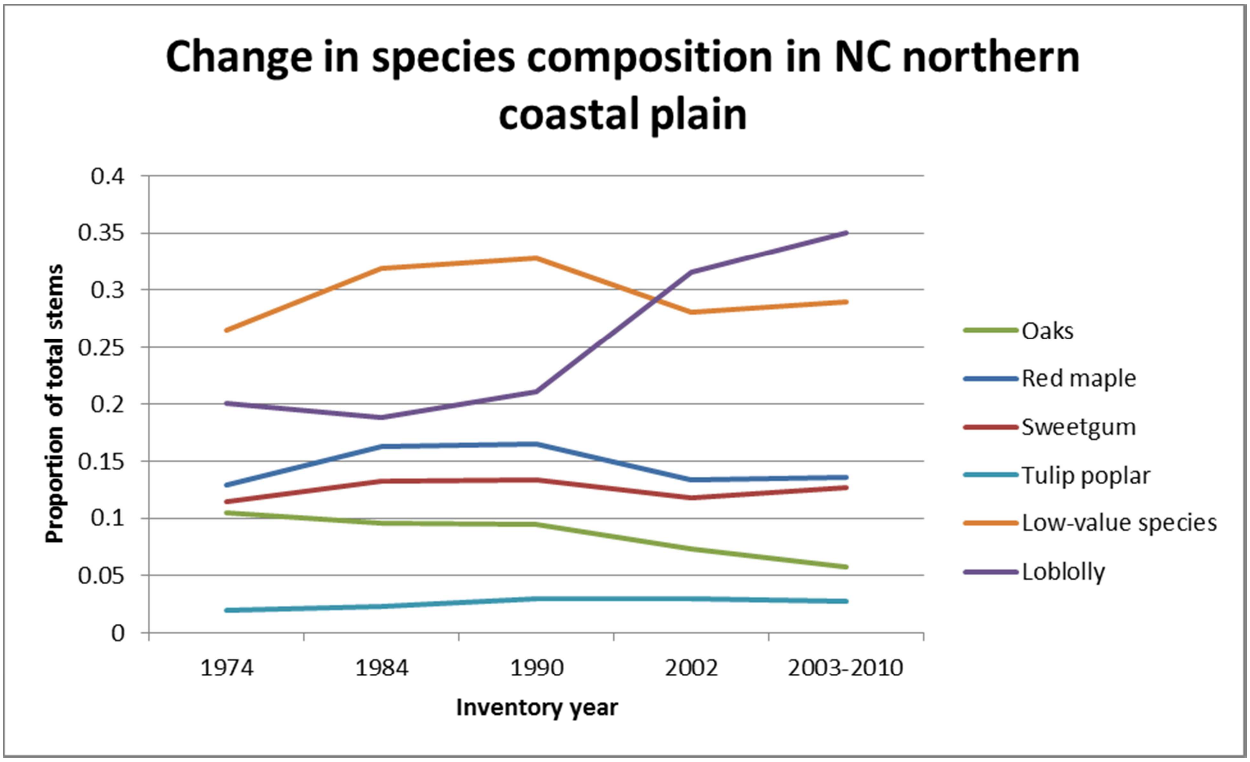


Figure 8 shows the percentage of total stems belonging to each species from the 1974 FIA inventory to the present annual inventories. Oaks make up a small proportion of total stems, but decline with the increase of loblolly pine.

Biomass estimates

Changing species composition, especially in the Mountains and Piedmont regions of the state, show an increasing amount of red maple and sweetgum, while oaks are declining. The Mountains, however, have little to no sweetgum, being slightly out of the range of the species. In the Coastal Plain, a decline in the number of oak stems can be explained by the increase in loblolly pine plantations. In the Piedmont and Mountains, the story appears to be more complicated. Small red maple and sweetgum trees occupy the mid-story in a forest can restrict the regeneration of oaks, by not allowing enough light to reach the seedlings. This analysis investigated the total amount of standing biomass in small-diameter red maple and sweetgum trees across the state. This total amount of biomass was constrained to find the amount available solely from hardwood stands. Table 2 summarizes the results of the analysis and projects the amount of biomass available across the state.

Table 2

Live Biomass from small-diameter trees (< 5 in. Diameter)

		Biomass - all stands (dry tons)	Biomass - oak stands (dry tons)	Oak stands (green tons)	Available*
Southern Coastal Plain	Red maple	5,021,388	1,123,725	2,247,451	1,460,843
	Sweetgum	3,561,226	1,085,620	2,171,240	1,411,306
Northern Coastal Plain	Red maple	5,966,735	1,194,226	2,388,453	1,552,494
	Sweetgum	4,292,395	1,029,571	2,059,142	1,338,443
Piedmont	Red maple	4,752,750	2,959,014	5,918,027	3,846,718
	Sweetgum	4,438,187	2,746,043	5,492,085	3,569,855
Mountains	Red maple	4,322,957	3,830,712	7,661,424	4,979,925
	Totals:	32,355,637	13,968,911	27,937,823	18,159,585

* *includes 65% utilization rate*

Using the FIA data from the last 5 annual surveys, which each cover 20% of the state, there are an estimated 18 million tons of available biomass from small diameter red maple and sweetgum trees in oak stands. The utilization rate is used to estimate how much of the small diameter biomass would be available on the state level to generate energy. On individual sites where harvests take place, the actual recovery of biomass material will be much higher. However, some sights will be too far from biomass facilities to make a harvest viable, while some landowners may not want to participate in stand improvement operations if they have other management objectives besides timber.

A sustainable harvest rate was calculated using the relationship between age and diameter shown in Figure 7. Sweetgum takes an average of 22.5 years to achieve a diameter of 5 inches. However, this is the age at diameter height, or 1.5 meters. Therefore, 2.5 years were added to the total in order to reflect the average age of a sweetgum tree that has a diameter of 5 inches. Table 3 displays the average amount of low-value biomass from red maple and sweetgum available on an annual basis.

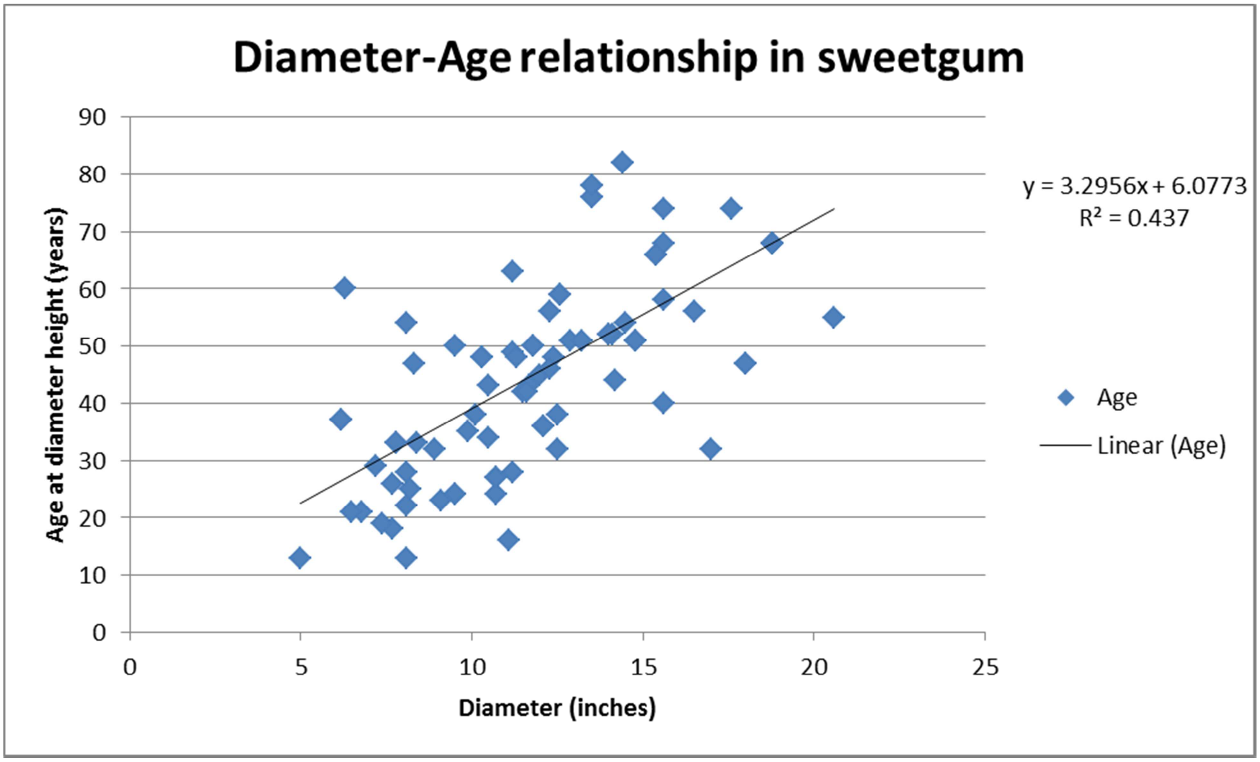


Figure 9 shows the relationship between diameter and age in sweetgum trees in North Carolina sampled in the annual inventory years from 2005-2010.

Table 3

Sustainable annual removal of low-value species

		Biomass - all stands (dry tons)	Biomass - oak stands (dry tons)	Oak stands (green tons)	Available*
Southern Coastal Plain	Red maple	200,856	44,949	89,898	58,434
	Sweetgum	142,449	43,425	86,850	56,452
Northern Coastal Plain	Red maple	238,669	47,769	95,538	62,100
	Sweetgum	171,696	41,183	82,366	53,538
Piedmont	Red maple	190,110	118,361	236,721	153,869
	Sweetgum	177,527	109,842	219,683	142,794
Mountains	Red maple	172,918	153,228	306,457	199,197
	Totals:	1,294,225	558,756	1,117,513	726,383

* *includes 65% utilization rate*

The 726,000 green tons of available biomass is distributed across the state, making it difficult to economically deliver large quantities to the few biomass energy facilities in North

Carolina. In addition, biomass from stand improvement or thinning operations is more expensive to harvest than other sources of biomass, such as forest residues. Forest residues can be more easily gathered and delivered for chipping during harvesting operations, leading to a lower cost. Figure 8 shows supply curves of residual biomass and biomass from thinnings. The biomass from thinnings assumes a harvesting cost that is double that of biomass from harvest residues. Transportation costs, which comprise the bulk of biomass costs, are assumed to be the same for each source of biomass.

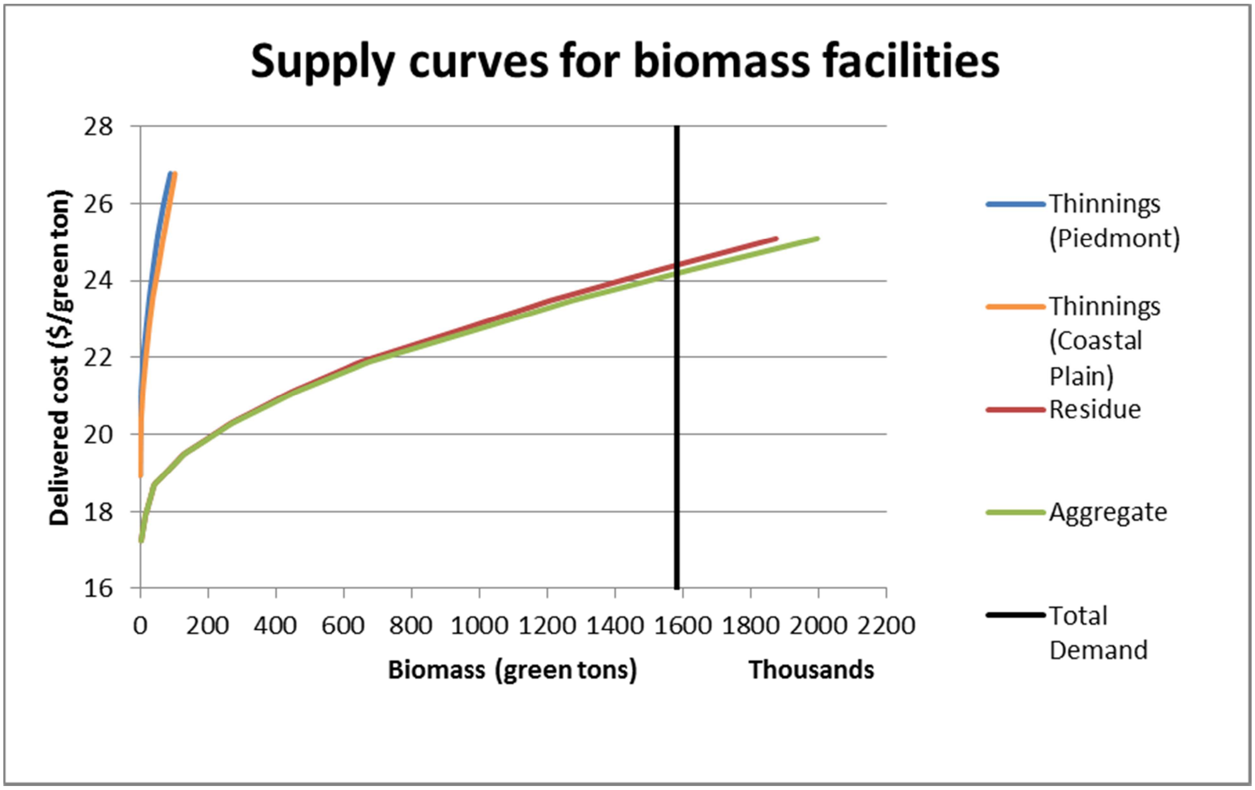


Figure 10 shows the biomass supply curves for the biomass facilities in the Piedmont and Coastal Plain. Supply curves from residues are also plotted. Assumes the same transportation costs, but the harvest cost of thinnings is twice that of residues.

In stand improvement operations to promote oak regeneration, it may also be necessary to remove a certain percentage of pulpwood in order to achieve the necessary light regime. Table 4 estimates the biomass available in red maple and sweetgum pulpwood trees less than 8 inches in diameter. The larger pulpwood trees (up to 10 inches) would likely be left to mature into sawtimber. Pulpwood sized trees would likely not be used for biomass energy, but could fetch a higher price as clean chips or as pulpwood. This could also contribute to landowner income in stand improvement operations. The total biomass available in oak stands from pulpwood less than 8 inches in diameter is summarized in Table 3.

Table 4

Biomass from pulpwood under 8 inches

		Biomass - all stands (dry tons)	Biomass - oak stands (dry tons)	Oak stands (green tons)
Southern Coastal Plain	Red maple	3,095,119	800,472	1,600,945
	Sweetgum	2,405,061	957,985	1,915,969
Northern Coastal Plain	Red maple	3,463,325	641,598	1,283,195
	Sweetgum	2,873,904	576,702	1,153,404
Piedmont	Red maple	3,557,072	2,604,701	5,209,401
	Sweetgum	3,399,526	2,217,895	4,435,791
Mountains	Red maple	4,453,499	3,967,133	7,934,266
	Totals:	23,247,505	11,766,486	23,532,972

The financial impact on the landowner was also calculated for biomass removal in TSI operations. A stumpage value of $1 per green ton was used considering that areas with more developed biomass markets, particularly near the biomass energy facility in New Bern, stumpage for biomass can reach this level. Analysis of the FIA data indicates that an average site has only 5 tons of biomass in low-value species. However, a number of sites with the highest density of small-diameter trees have between 20 and 30 dry tons of biomass per acre. When harvested, this amounts to rough 40 to 60 green tons of biomass on each acre of the stands with the highest stocking.

The amount received for small diameter biomass is in addition to any revenue from pulpwood on the site. Analysis of the FIA data indicates an average site has approximately 20 tons of pulpwood of red maple and sweetgum, which demands a significantly higher price than does waste wood for biomass. In 2010, the price was reduced from its high before the recession, but still averaged $4.29 per ton for hardwood pulpwood. Therefore an average landowner who removed the small-diameter and small pulpwood trees of red maple and sweetgum could receive approximately $85 per acre to offset the costs of the stand improvement operations, while landowners with the most biomass may see a windfall of $140 per acre. The biomass component of the harvest can comprises up to 40% of the total revenue. Thus, the presence of strong biomass markets can provide incentives for landowners to conduct stand improvement operations that may not otherwise be financially viable, increasing the value of their forests in the land term. Thinning from below is substantially more expensive than prescribed burning, but the addition of the biomass harvests can bring the costs more closely in line.

Discussion

Northern and Southern Coastal Plain

The species composition of forests in all regions of North Carolina show several trends over the years of FIA survey data. Specifically, the proportion of oak trees declined in every region, though this decline is likely due to different causes in different regions. The decline in oaks in the Coastal Plain is likely from an explosion in the amount of loblolly pine in the region, probably in the form of plantations. It is interesting to note that the predicted increase in red maple and sweetgum and the decline of oaks is seen in the Coastal Plain, though it is complicated by the large increase in loblolly pine. Red maple and sweetgum were increasing in number and oaks were declining slightly until the large increase in loblolly pine from expanded plantations. All hardwood species, red maple, sweetgum, and oaks showed a decline corresponding to the dramatic increase in loblolly. However, after the decline seen in 2002, red maple and sweetgum once again continued to expand their populations, while oaks continued to decline. This suggests that red maple and sweetgum were increasingly prevalent in hardwood stands prior to conversion to pine plantations. However, they remain an increasing component in the remaining hardwood stands as oaks continue to decline.

This increase in loblolly pine corresponds to a large change in timberland ownership, which can help explain the change in species composition. Beginning in the mid-1990s through the mid-2000s, vertically integrated forest products companies began to divest timberland holdings to private owners as seen in Figure 7. Many of these private owners were investors represented by TIMOs, or timber investment management organizations. TIMOs differ in their management strategies, but some harvest very intensively, managing loblolly pine on a 15-year rotation in order to maximize returns for their investors. The change in ownership to investment organizations corresponds to the huge jump in loblolly pine stems between the 1990 and 2002 inventories. The large increase in loblolly pine can be explained by the large tracts that were bought by TIMOs and managed very intensively.

A change in the tax status of timberland was the driver of divestiture in timberlands by large forest products companies (Gunnoe and Gellert, 2011). Other companies restructured themselves to separate ownership and operations of timberland and milling (Lonnstedt and Sedjo, 2011). The new entities are real estate investment trusts (REITs) and receive the same tax preferences of private owners. Private investors that own timberland are taxed at the capital gains rate (15%) for any income relating to timber. However, vertically integrated companies are taxed on total profits at the corporate tax rate of 35%. Dividends given to investors by forest products companies are then taxed at the capital gains rate of 15%. Therefore, investors in forest products companies effectively find themselves taxed twice on the value of timber (Gunnoe and Gellert, 2011). By selling land to TIMOs, or by converting to (REITs), forest products companies can provide greater returns to their shareholders. Private landowners also receive greater returns on timber investments than could be achieved by investing in traditional vertically integrated forest products companies.

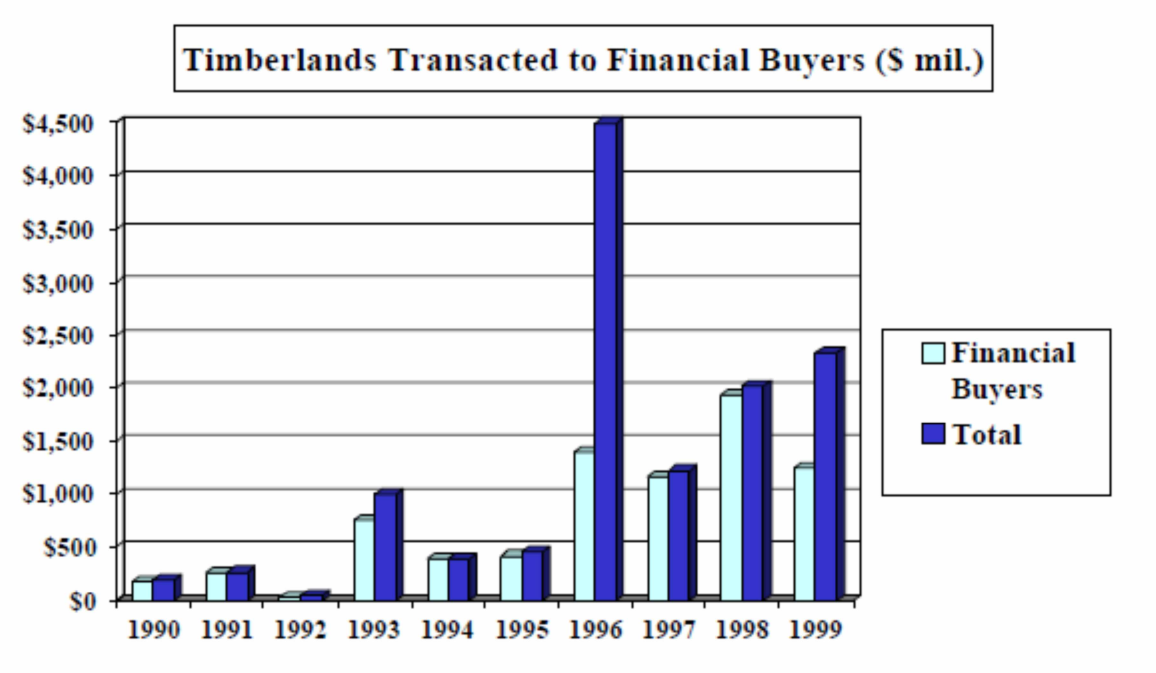


Figure 11 shows the amount of timberland changing ownership in the 1990s. Financial buyers, which are dominated by TIMOs, continued to buy huge amounts of timberland into the early 2000s. Source: Block and Sample (2001).

Piedmont and Mountains

In the Mountains and Piedmont regions, the decline in the dominance of oaks is not from conversion to plantations of other species, but can be explained by the lack of regeneration. Several factors combine to influence the lack of regeneration of oaks. High-grading of hardwood forests was especially prevalent during portions of the 20th century. High-grading is a term for selective harvesting in which only the highest value trees are removed. The trees removed would be only good specimens of high value species. What is left in the forest is a mixture of low value species and poorly formed trees. High-graded stands often do not regenerate to their pre-harvest conditions due to the lack of healthy seed sources and the presence of low value species which are released to proliferate. These conditions can also increase the difficulty of restoration.

A history of fire suppression also plays a role in oak decline. Traditionally, Native Americans burned woodlands to keep them open for a variety of reasons, including to improve hunting, to promote berry and fruit production, to enable the gathering of acorns and chestnuts, and to create firebreaks around villages (Trani et al. 2001; Brose et al. 2001). These open woodlands were dominated by oaks that thrived in the environment created by frequent low intensity ground fires (Brose et al. 2001). Early European settlers also burned large tracts of wilderness in an effort to keep the land suitable for grazing (Trani et al. 2001). In addition, early settlers adopted Native American techniques for managing the forest through the use of fire. It was not until the onset of high productivity forest harvesting in the southern Appalachians in the 19th century that there was a significant change in the fire regime (Brose et al. 2001). Frequent low-intensity ground fires were suppressed and were eventually replaced by rare stand-replacing fires. In the absence of periodic low-intensity fires, an understory and mid-story of fire intolerant trees developed, which enable fires to expand into the canopy. The danger of large fires was seared into the public's consciousness by the early 1900s and fire suppression was to be rigorously applied throughout much of the century. It is only recently that the benefits of prescribe fire have become better understood.

The absence of fire in mature mixed hardwood stands is one of the main causes of the increase in red maple and sweetgum in these stands. Oaks are better adapted to fire and can survive low-intensity periodic ground fires, which can clear out many understory species such as red maple. In one experiment, mid-story and understory trees were reduced by 54% on different plots that underwent different prescribed burn treatments, while the density increase 4% in the control plots (Barnes and Van Lear, 1998). An open mid-story and understory is considered essential for advanced oak regeneration. The experiment found that the increased root to shoot ratio of oak regeneration allowed them to sprout back after other species had been killed by the prescribed fire (Barnes and Van Lear, 1998). Increased root to shoot ratio means that oak trees store more energy in their roots, allowing for enhanced regeneration following a top-kill, such as a fire event.

In modern forest management, prescribed fire can be difficult to administer in light of fragmented parcels, conflicts with development, and air quality concerns. Yet prescribed fire is the easiest way to facilitate the regeneration of mixed hardwood stands where oak is a major component. Soft silvicultural methods involving thinning stands from below can mimic the impacts of prescribed fire. Thinning from below removes small-diameter understory and mid-story trees in order to increase the amount of light reaching the forest floor. This treatment is significantly more expensive than prescribed fire because of increased labor costs and the need for mechanical operations. However, the low-value trees removed from the understory of a mixed hardwood stand could be utilized for biomass energy, offsetting some of the costs of the improvement operations.

Biomass supply potential

The latest FIA data indicate a recoverable amount of over 18 million green tons in sapling and pole-sized red maple and sweetgum trees located in oak hardwood stands. This amount of biomass may seem high, especially compared with 5.9 million green tons per year as the latest estimates of biomass from recoverable logging residues (Connor and Johnson, 2011). However, the 18 million tons represents a timber stock, while logging residues are available on an anuual basis. The FIA data indicates that over 27 million tons is the complete standing stock of pole-sized red maple and sweetgum. The estimate of 18 million green tons of available biomass reflects a recovery or utilization rate. Different factors combine to affect the utilization rate, including the technical recovery ability of loggers using current technology and the adoption rates of biomass recovery among loggers. Using estimates of these two values, it is possible to estimate an overall utilization rate for the state. This is a statewide average which combines areas where there may be no biomass harvest with others that may be heavily harvested for biomass.

The total available biomass from low-value trees in each region gives an estimate of aggregate small-diameter biomass in North Carolina. However, the practicality of biomass supply, especially from small-diameter trees, depends upon the distance to biomass markets. Currently there are two large biomass facilities located in North Carolina. In addition, Duke Energy has applied to co-fire biomass at two coal burning facilities. One of these facilities is in North Carolina, while the other is just over the border in South Carolina. The maximum economic haul distance for biomass is typically found in the literature at about 50 miles (Galik et. al. 2009; Abt et al. 2010). The cost of transportation for wood averages $0.16 per ton-mile (Abt, 2010, TimberMart South, 2011). Currently, biomass demands no stumpage price in many locations, though areas with more developed markets often have stumpage prices of $0.50 per ton to as high as $1 per ton. Pulpwood stumpage prices the 4th quarter of 2010 averaged $4.29 for hardwood pulpwood and $6.60 for softwood pulpwood. Transportation costs limit the availability of residual biomass to markets. After a certain distance, pulpwood can become cheaper than residual biomass if it is sourced from within a certain proximity to the facility. Assuming no stumpage price for low-diameter biomass, it is competitive on price with hardwood pulpwood within 35 miles and softwood pulpwood within 50 miles.

Once the total amount of biomass available from low-value, small diameter trees has been estimated, it will be possible to estimate the total biomass that could be made available to biomass energy facilities. The amount of the potential biomass resource that is collected for energy use is called the utilization rate of biomass. Most studies that project biomass supply use a utilization rate between 50% and 65%, suggesting slightly over half of all available biomass could potentially be utilized for energy (Galik et al. 2009; Abt et al. 2010). However, some estimates of utilization rates have reach as high as 70% (Abt et al. 2010).

The utilization rate contains two components. First is the technical ability of loggers to harvest and transport biomass in an economical manner. Recently, one of the major barriers to widespread biomass utilization was developing a method to economically collect logging slash and other non-merchantable timber and move it to a stationary chipper. However, technological advances have made the harvest of biomass an option to combine with traditional harvests. In addition, with new equipment such as bundlers, small diameter biomass can also be harvested is an economic manner. The technical recovery rate of biomass, including limbs and tops, and non-merchantable trees has been found to be above 90%. Site characteristics including the slope, soil type, and the presence of streams or wetlands can all impact the technical recovery rate.

The other aspect of the utilization rate is how widespread it is adopted. Some loggers already practice biomass utilization, but most do not. Therefore, it is important to know the percentage of harvests or other forest operations, such as thinnings or stand improvement operations, throughout the state that contain a biomass harvest component. Of course, logger adoption of biomass harvested depends on the availability of a biomass market to deliver the harvested material. With only several large biomass facilities in the state, and a 50-mile economical haul distance, many areas may be unsuitable for biomass harvests because of the lack of markets.

Utilization rates for traditional biomass, which includes logging residues and coarse woody debris, are usually estimated around 65%, which is considered a good reference rate for most states (Abt, 2011). A utilization rate of 65% also assumes market saturation. This percentage does not reflect current biomass utilization, but a likely maximum given strong biomass energy development. The 65% utilization rate was applied to the calculation of total available biomass from small-diameter red maple and sweetgum trees. The technical feasibility of harvesting biomass, especially small-diameter material, is not 100% and the lack of distributed biomass markets throughout the state mean that the total potential of the biomass resource cannot be realized until markets develop.

Energy potential

The 18 million green tons is enough wood to supply a substantial amount of biomass energy. For example, the Craven County Wood Energy facility in New Bern, NC produces 48 MW of power at a 95% capacity factor using 500,000 dry tons each year. Thus, roughly 1.25 tons of biomass is needed to produce one MWh of electricity (Decker, 2011). However, only 725,000 tons state wide is estimated to be available from these low value hardwoods on an annual basis. Still this represents a considerable amount of potential energy production. Using conventional generation, such as that used at the Craven County facility, 725,000 green tons could provide roughly 440,000 MWh of electricity.

A more in depth analysis of the energy generation potential uses the supply area of the four biomass facilities within the state, current and proposed. The four facilities were the Craven County Wood Energy facility, Green Power Kenansville, the Buck Steam Station which has recently co-fired biomass, and the proposed Hertford Renewable facility. These four facilities have the combined biomass capacity of 154 MW of electricity generation. To produce to capacity the total yearly biomass demand, assuming a 90% capacity factor, is over 1,500,000 green tons of wood. This amount of wood, when factoring in the average 24.4% thermal efficiencies of biomass plants, and the 33% thermal efficiency of a coal co-firing plant, equates to 990,000 MWh of electricity.

However, these facilities will only use a small portion of the biomass available from TSI in the state. The supply curves generated for the facilities indicate that only 12% of the biomass available from TSI state-wide would be used in the scenario. The reasons are twofold. First, the resource is distributed, which means to maximize use of biomass from TSI, the biomass would need to be transported long distances. Since transportation is the largest component of the cost of biomass, a centralized facility makes utilization of a distributed resource cost prohibitive. Second, biomass from TSI is more expensive to harvest than biomass from forest residues, the other source of biomass in the scenario. Forest residues will be utilized first and biomass from TSI will only become economical if forest residues have large transport distances associated with them. Therefore, a network of distributed biomass facilities could better utilize the available biomass resources of the state. In addition, distributed thermally led biomass energy uses have high efficiencies, greatly increasing the amount of energy available from the biomass resource. Table 5 depicts the energy comparisons between conventional and distributed thermal biomass applications. Thus, distributed biomass networks can provide large amounts of thermal energy, while maintaining sustainability of biomass harvesting and benefitting landowners and communities with large forest resources.

Table 5

Energy comparisons among utilization scenarios

Plant	Yearly biomass demand (green tons)	Energy content (MMBtu)	Energy produced (MWh)
Craven County Energy	500,000	4,250,000	303,571
Hertford Renewables	600,000	5,100,000	364,286
Green Power Kenansville	342,000	2,907,000	207,643
Buck co-fire	140,000	1,190,000	114,976
TOTAL	1,582,000	13,447,000	990,476
Biomass from TSI used by plants (from supply curves)			
	87,527	743,980	53,141
Distributed, high efficiency utilization of biomass from TSI			
	726,383	6,174,259	1,536,335

Conclusions

There are clear trends in species composition in hardwood forests across the state. Oak trees as a dominant component of the forest are declining and low-value species such as red maple and sweetgum are increasing dramatically. These trends are a product of past management history that has included a history of fire suppression and high-grading of our forests. However, timber stand improvement operations can remove small pole-sized trees of low-value species and encourage oak regeneration. The removal of these species can contribute to biomass to be used for energy.

Biomass from TSI can contribute 725,000 green tons a year and over 1.5 million MWh of energy equivalent each year, if properly utilized. Efficient use of the resource, which will allow biomass to be sustainable ecologically, requires a distributed utilization network to account for the distributed nature of the resource. Small-scale biomass in a distributed network is also highly efficient, producing much more useful energy than centralized electricity plants.

The total potential for energy generation from small diameter biomass in the state of North Carolina is significant. However, there are also potential positive effects on landowners seeking to use stand improvement operations in hardwood stands. A stumpage price of $1.00 per green ton is seen in areas of high biomass demand within the state and this could increase under high biomass demand. While the greatest benefit to landowners will be from an improved forest stand, the financial windfall from biomass removal, while small, can provide some offset for the cost of improvement operations. The average landowner may only see a small windfall of less than $5 per acre, though some will see values from biomass removal as high as $60 an acre. This value, however, is small compared to the benefit for communities that can generate their own energy from nearby resources. These communities will keep more money within their local area, while also increasing the value of their local forest resources, and that is a win-win scenario.

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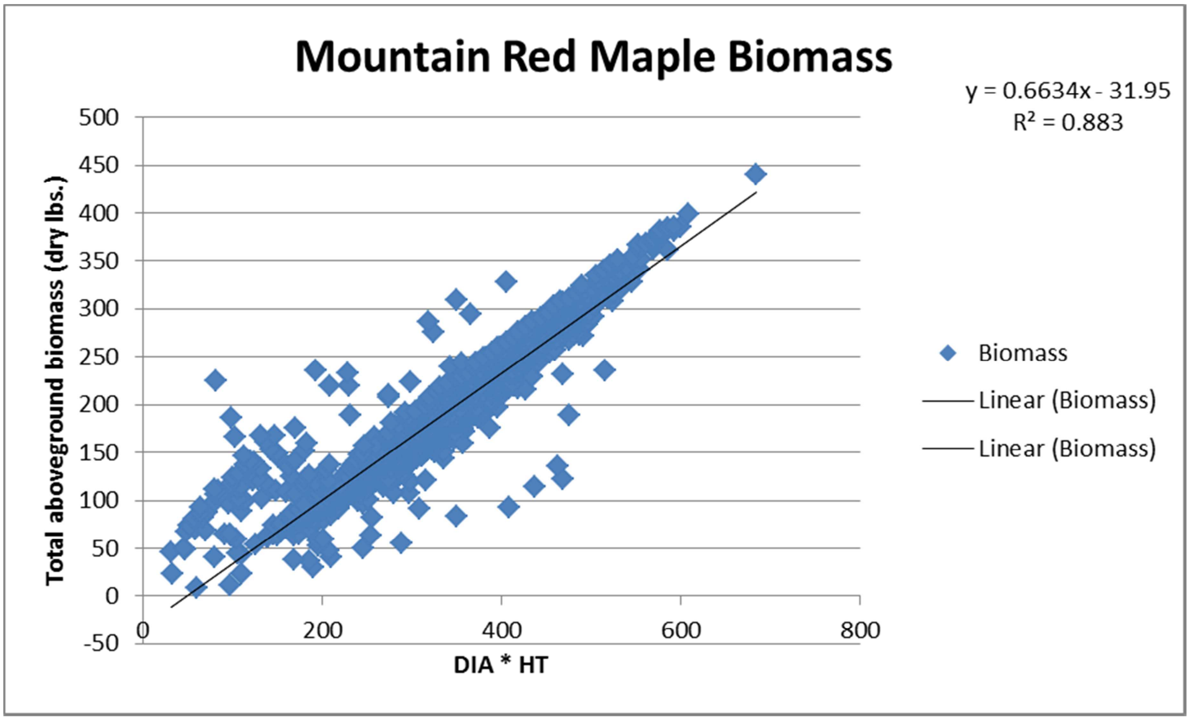
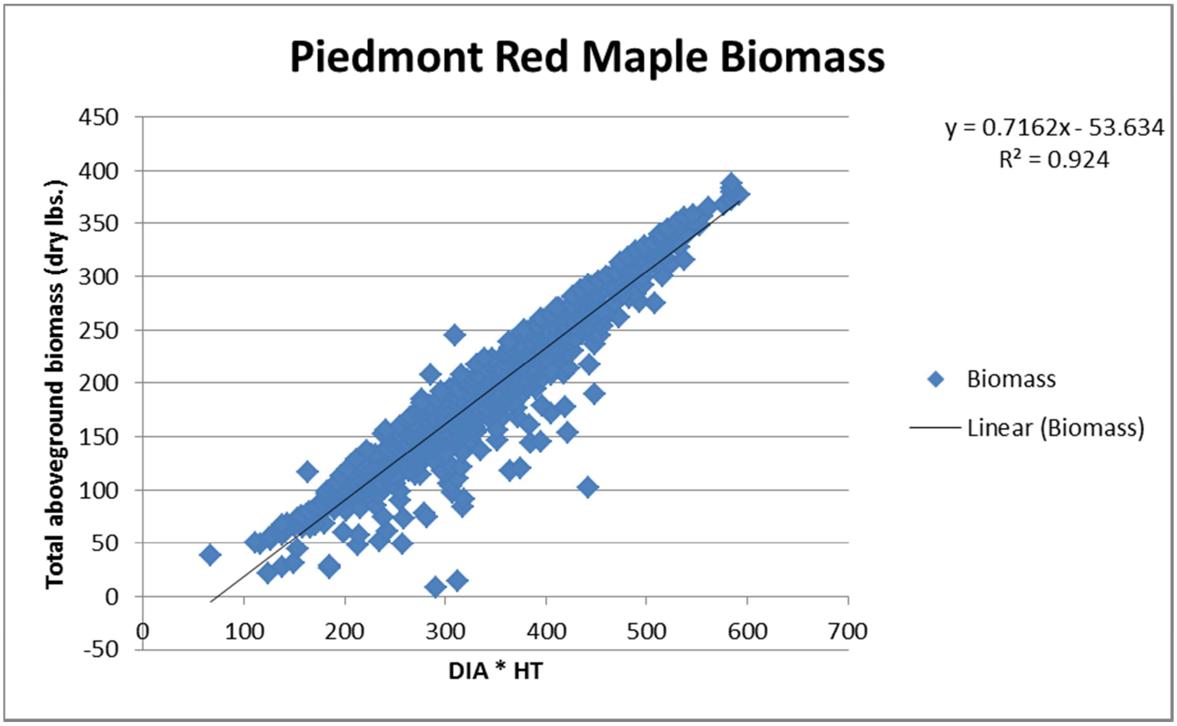
Appendix

Regression results

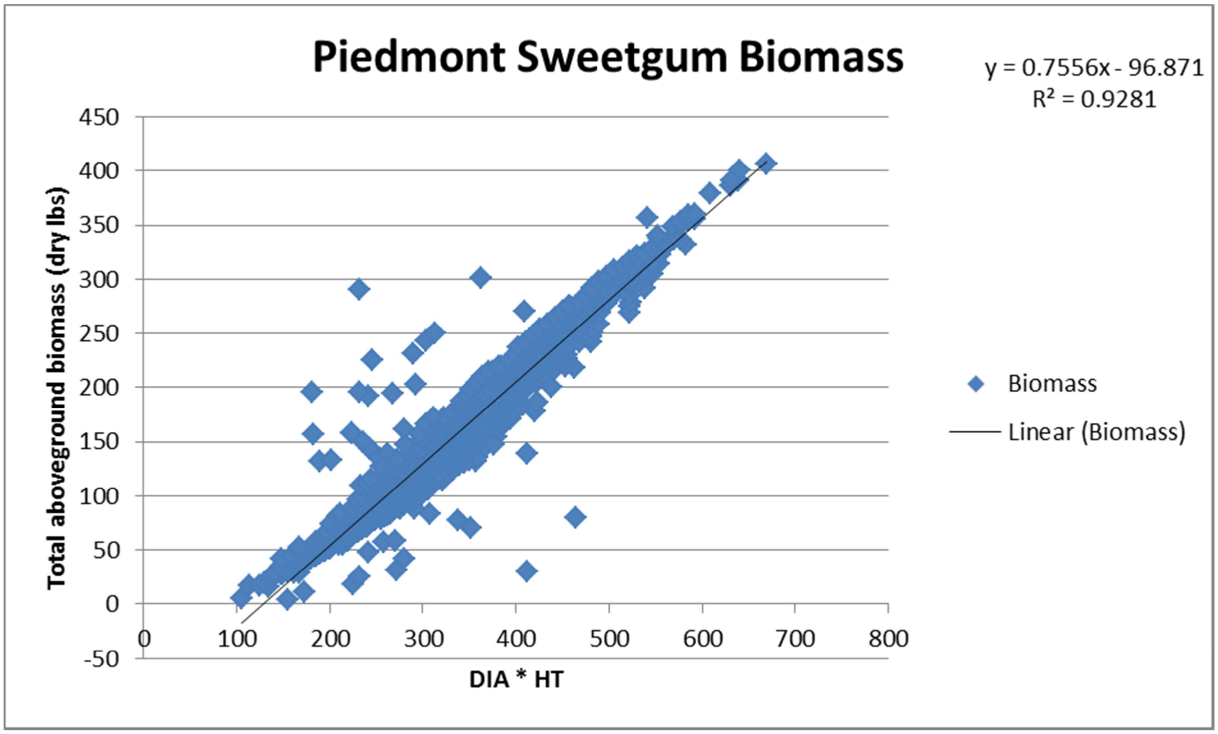
Regressions were carried out on biomass and an indicator of tree size. Several different variables were tried in order to find a combination that gave the best relationship. These variables used tree diameter (DBH) or a combination of DBH and tree height. Four different variables were used including DBH, DBH+HT, DBH*HT, and DBH*HT^2. These variables were plotted against total aboveground biomass to determine their relationship. The combination variable DIA*HT gave the best relationship when plotted against biomass. This relationship was nearly linear, though there was some spread, especially with lower values. Part of this spread may be due to partially dead trees, where cull sections may remove biomass from consideration, though the diameter and height measurements may be unaffected. The similar regression equations from each species and region create confidence that these equations can be used to complete the table for the trees with the missing biomass values.



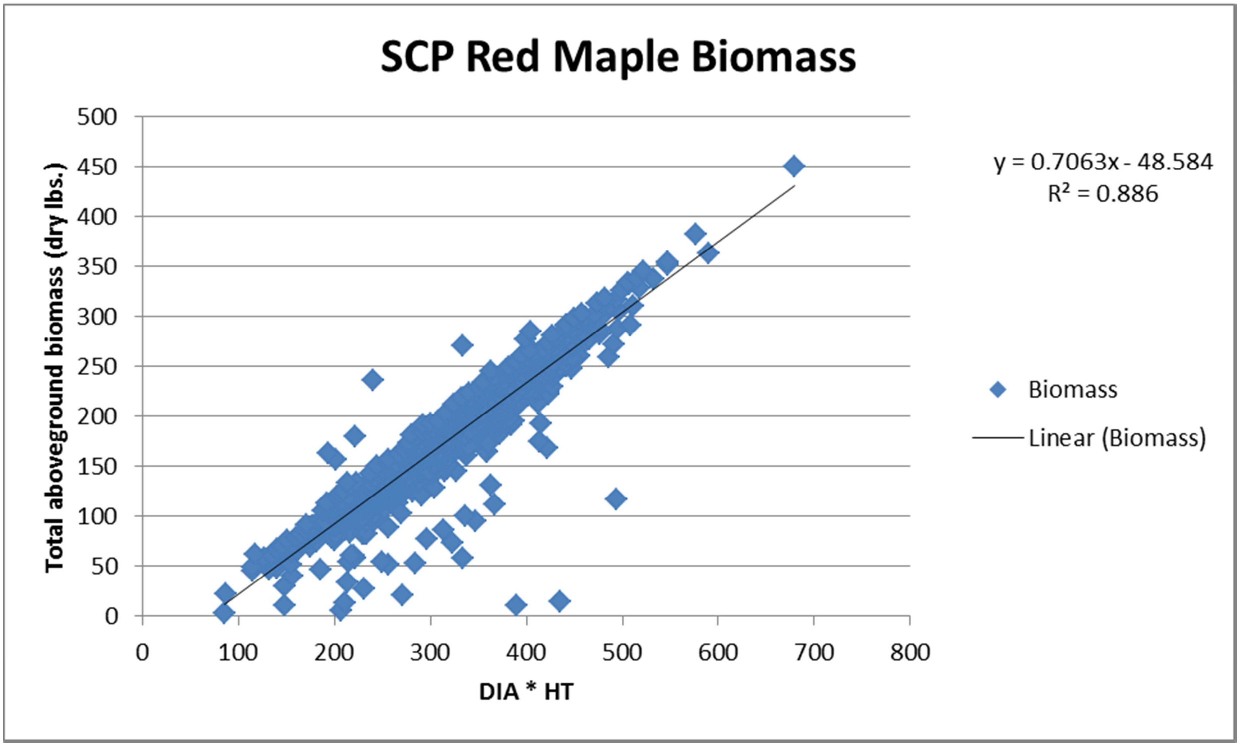
Appendix Figure 1 shows the diameter-height and biomass relationship for red maple in the mountains.



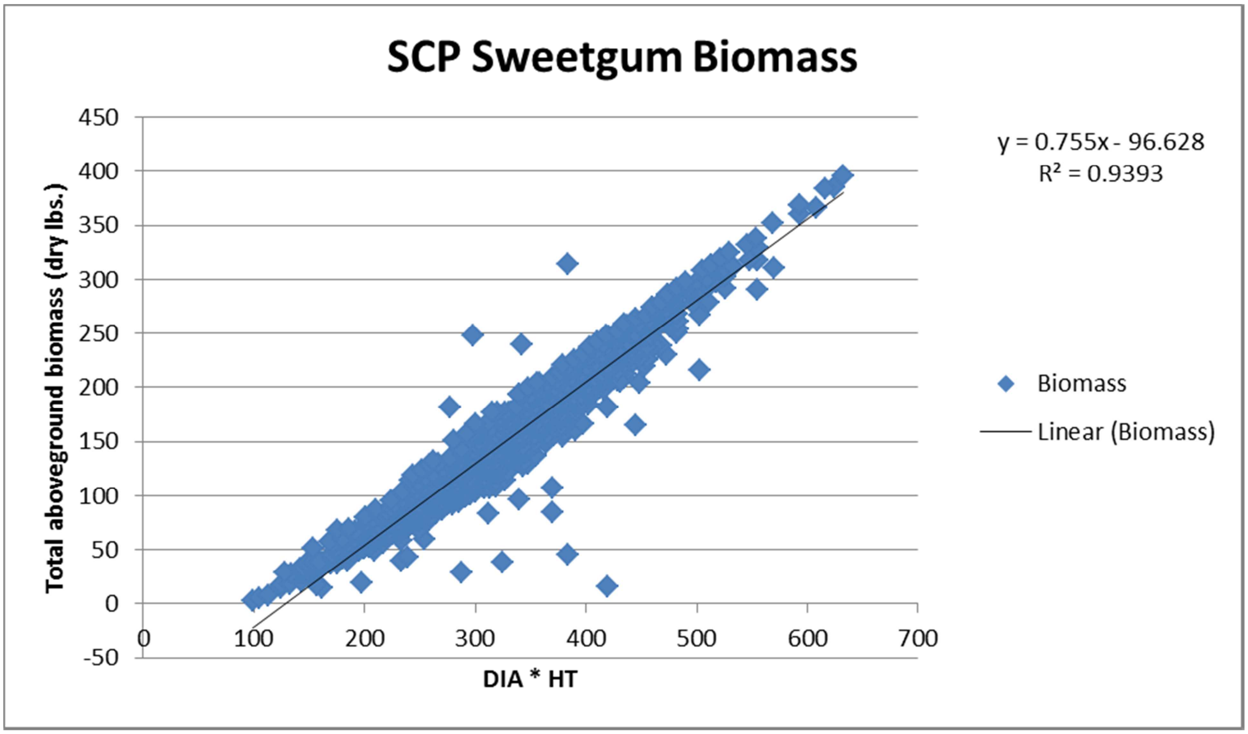
Appendix Figure 2 shows the diameter-height and biomass relationship for red maple in the Piedmont.



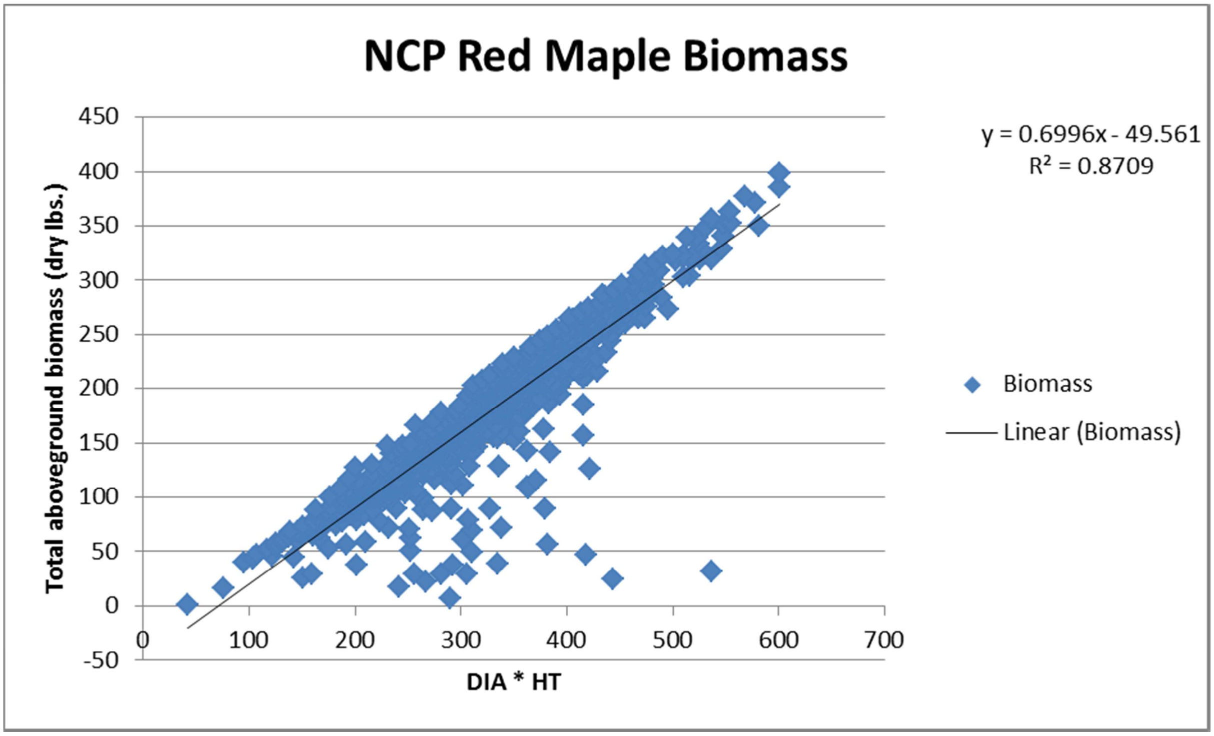
Appendix Figure 3 shows the diameter-height and biomass relationship for sweetgum in the Piedmont.



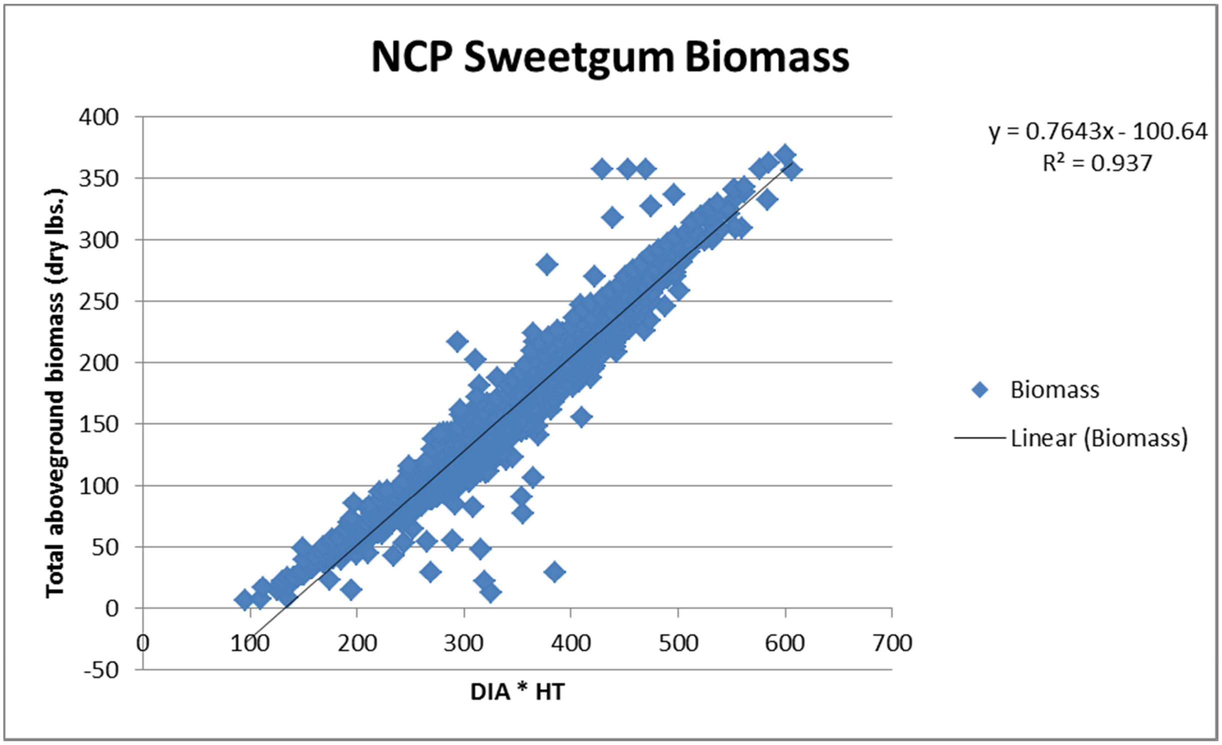
Appendix Figure 4 shows the diameter-height and biomass relationship for red maple in the southern coastal plain.



Appendix Figure 5 shows the diameter-height and biomass relationship for sweetgum in the southern coastal plain.



Appendix Figure 6 shows the diameter-height and biomass relationship for red maple in the northern coastal plain.



Appendix Figure 7 shows the diameter-height and biomass relationship for sweetgum in the northern coastal plain.