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Assessing the Carbon Impacts of Colby College's Biomass Plant

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Assessing the Carbon Impacts of Colby College's Biomass Plant

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by

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Abstract

Biomass energy plants are considered to be carbon neutral systems under some definitions. However, this concept of carbon neutrality needs to be rethought in order to understand the true carbon impact of biomass plants upon global climate change. A biomass plant's wood source, the extent to which the biomass plant emits carbon dioxide, and the timescale over which the biomass plant emits carbon should all be taken into account. In this study, I consider the Colby College biomass plant's role in carbon cycling. Colby's Physical Plant Department provided me with information on how much carbon (tons of woodchips) is used in the biomass plant annually. Using data on tree growth collected by the Forest Inventory Analysis National Program of the United States Forest Service I calculated annual forest growth rates of forested plots in Kennebec County. I then determined the area of land that would accumulate carbon (in tree growth) at the same rate as the biomass emitted carbon (tons of woodchips combusted). I argue that if these carbon emissions equal local forest growth rates, Colby's biomass plant would be part of a carbon neutral system. Further, I explain how following this same logic, a fossil-fuel plant that emits carbon at a rate equal to carbon sequestration rates would be carbon neutral. Reducing carbon emissions, and not simply matching carbon emissions to carbon sequestrations, would be a much more effective way to mitigate climate change.

Introduction

The increasing mean global temperature is a result of cumulative greenhouse gas emissions in the atmosphere (e.g. Allen et al., 2009; Intergovernmental Panel on Climate Change, 2006). Carbon dioxide is the primary heat-trapping greenhouse gas that contributes to climate change. Increasing temperatures, other climatic changes, and ocean acidification due to carbon dioxide emissions have altered global systems in a way that threatens natural ecosystems and human civilization. Internationally, policy makers have agreed upon the goal of keeping global temperature rises to below 2° C (3.6° F) in an effort to avoid severe climate change (UNFCC: United Nations Framework on Climate Change, 2009). However, many scientists argue that this limit in temperature rise is still too high to avoid drastic climate change and emphasize that a policy goal that would require more drastic emissions reductions should be defined (Victor and Kennel, 2014; Hansen et al., 2013; Jordan et al., 2013). It is predicted that if climate change continues at its current rate, many dramatic infringements upon human rights to life, health, water, food, and more will be experienced (Office of the United States High Commissioner for Human Rights, 2015). Further, researchers note that temperature is an inaccurate and indirect indicator of the intensity of climate change. It is suggested that indicators that are directly tied to climate change, such as CO2 concentrations, should be used in policy decisions (Victor and Kennel, 2014).

Despite uncertainty over what indicators best reflect the state of climate change, it is generally accepted that carbon dioxide emissions must be reduced immediately to mitigate the effects of climate change. Toward the goal of reducing global CO_2 emissions, many institutions hope to limit their contribution through “carbon neutral” energy use. For example, The American College & University Presidents’ Climate Commitment is a group of 697 colleges who have committed to reaching carbon neutrality as soon as they can (American College & University Presidents' Climate Change Commitment). Carbon neutrality is commonly defined as an institution, business, or individual that removes the same amount of carbon dioxide from the atmosphere as they emit (Congressional Research Service, 2015). The goal of carbon neutrality is to have a net zero effect upon the atmospheric CO_2 balance, thereby eliminating any contribution to climate disruption.

Institutions strive toward carbon neutrality using a number of approaches, such as increasing energy efficiency, converting to renewable energy sources, and purchasing carbon offsets. One popular approach has been to substitute renewable biomass for fossil fuels in energy and heat generation. In April of 2015, the Oregon State Senate declared that they would treat biomass as a carbon neutral energy source (FierceEnergy, 2015). Johnson (2008) lists five prominent carbon accounting frameworks that assume biomass energy to be inherently carbon neutral. In November of 2014, the EPA issued a memo stating that "waste-derived feedstocks and certain forest-derived industrial byproducts are likely to have minimal or no net atmospheric contributions of biogenic CO_2 emissions, or even reduce such impacts, when compared with an alternate fate of disposal," (US EPA, 2014). The Intergovernmental Panel on Climate Change lists emissions from biomass plants as accounting for zero emissions in the energy sector (Intergovernmental Panel on Climate Change, 2015). Due to questions about this decision, the IPCC has since provided the explanation that biogenic emissions are accounted for in the Agriculture, Forestry, and Other Land-Use section (Intergovernmental Panel on Climate Change, 2015).

Biomass is a growing energy source in the United States (US Energy Information Administration, 2012). As a renewable energy source, biomass energy is seen as a more reliable and sustainable form of energy production than fossil fuels. In Maine, biomass plants can be locally sourced, support the wood harvesting economy, and provide opportunities for employment. In 2013, 25% of Maine's electricity was generated by wood products (US Energy Information Administration, 2013). Maine consumes 93.6 trillion tons of biomass energy, making it the single most consumed energy source in the state (US Energy Information Administration, 2013). The Maine Forest Service reports that 3,047,731 green tons of biomass were harvested from Maine in 2008, 21% of the green (freshly cut) tons of wood harvested from Maine throughout the year. Figure 1 shows the upward trend in biomass harvesting that has occurred in the state since the 1980s. While not being able to predict the exact outcomes of increased biomass harvesting in the state, the Forest Service notes that this trend will intensify pressure on Maine's forest supply and create more competition between wood-using facilities (Department of Conservation, 2010).

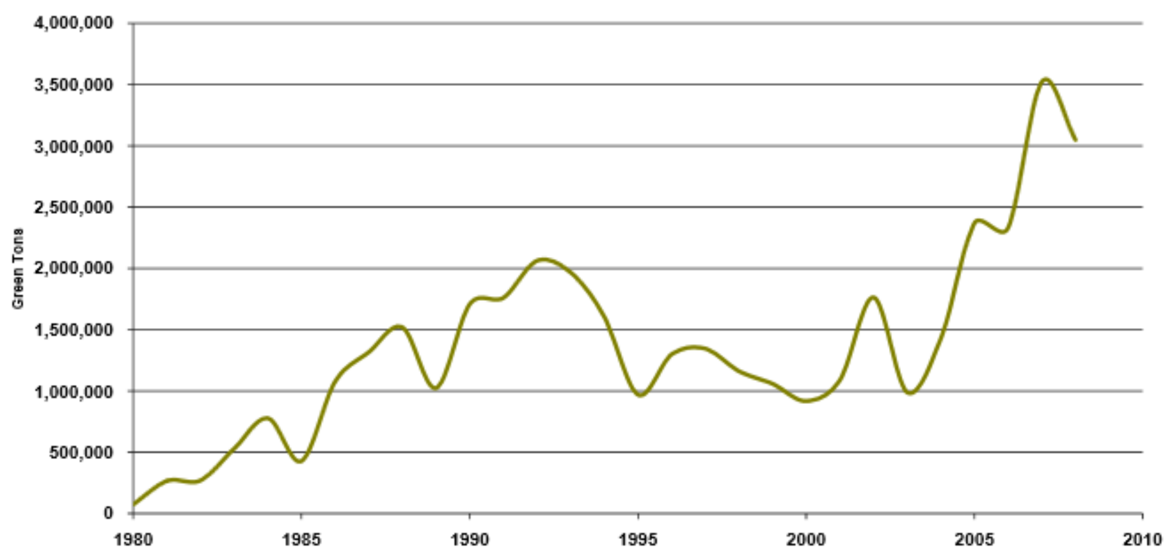

Figure 1. Maine's biomass harvests in green tons from 1980-2008.

Biomass plants are sometimes considered to be carbon neutral sources of energy. Ideally, sustainable harvesting allows forests to reach a steady state in which they sequester an equal or even greater amount of CO_2 than is being released by a biomass plant (Marland and Marland, 1992). Harvesting can "release" forests, causing their growth rates to increase after logging projects that provide more open space for regeneration (Manomet Center for Conservation Studies, 2010). Also, many biomass plants are said to use forest residues for energy generation. These residues are wood scraps such as branches, tree tops, and small pole trees left over from other logging projects (US EPA Combined Heat and Power Partnership, 2007). It is argued that this residue wood, if left in the forest, would rot and release an equivalent of CO_2 to what would be released by burning that wood in a biomass plant (Schlamadinger et al., 1997). However, scientists and environmental advocates have called for better accounting of biomass CO_2 emissions based upon empirical evidence rather than theoretical constructs (Natural Resources Defense Council, 2013, Searchinger et al., 2009).

Assessing the Carbon Impact of Biomass Plants

There are several tools for evaluating the carbon impact of biomass plants. Different methods of assessment have resulted in different conclusions about the contribution of biomass plants to atmospheric carbon dioxide levels. Assessment techniques vary in scale, ways to measure greenhouse gas emissions, and how forests are modeled (Helin et al., 2013). One commonly used tool is to consider biomass energy generation through a Life Cycle Assessment. Life Cycle Assessment is a general way to consider the environmental impacts of a product or process throughout its lifetime, from "cradle to grave." For carbon neutrality, this is done by tracking the cycling of carbon through the bioenergy system, from its harvest in the forest, to when it is burned in the biomass plant, to its role as atmospheric carbon, to its eventual re-sequestration (e.g. Cherubini et al., 2011; Lippke et al., 2011).

Using a hypothetical Life Cycle Assessment can result in the conclusion that biomass plants are carbon neutral (Helin et al., 2013). A certain amount of wood is harvested for the biomass plant, that wood is burned and then released as atmospheric CO_2, and then that CO_2 is recaptured by the harvested forest as it continues to grow. However, this use of Life Cycle Analysis is being challenged by scientists who say that this application of LCA does not truly capture a biomass plant's contribution to atmospheric carbon levels (Helin et al., 2013).

There are at least four reasons why there is disagreement over the carbon neutrality of biomass plants. First, forests are important carbon sinks. A carbon sink is a reservoir (such as an ocean or a terrestrial biome) that absorbs more carbon than it emits. These carbon sinks are of vital importance in mitigating climate change. Any harvesting from forests impacts the sequestration of atmospheric carbon in these carbon sinks, and therefore contributes to climate change. Terrestrial biomass (which includes forests and soils) is estimated to absorb nearly as much atmospheric carbon as do oceans (Global Carbon Project, 2010), yet the disruption of terrestrial biomes is a major contributor to atmospheric carbon levels (Intergovernmental Panel on Climate Change 2007; Luyssaert et al., 2008). It is predicted that the transition from fossil fuels to biomass energy sources will contribute to major removals of terrestrial biomass (Bottcher et al., 2012), therefore decreasing global carbon sinks and contributing to climate change. Scientists who wrote a letter to the EPA regarding biomass policies stated that if the nation converted to using biomass plants, national timber harvest would increase by 70% (Scientists' Letter to EPA, 2015). Forests store carbon in trees, soil, woody debris, and peat bogs, and all of these pools of carbon can be disturbed by harvesting (Dixon et al., 1994). Furthermore, it is often argued that sustainable harvesting practices increase forest growth rates, and therefore carbon storage. However, unmanaged forests have been found to result in greater carbon storage than stands undergoing any type of management (from clear-cutting to sustainable harvesting) (Manomet., 2010; Nunery, 2010). Because undisturbed forests store the greatest amounts of carbon, biomass that remains in forests is reducing climate disruption. Conversely, biomass removed from these forests to generate biomass energy deteriorates forests' ability to absorb carbon. A 2010 study also points out that climate change is increasing tree mortality (Allen et al). Trees are under greater physiological stress because of climatic changes and also are at greater risk of experiencing events such as disease outbreaks and wildfire. Allen et al. highlight that increased tree mortality will degrade our forests' ability to act as carbon sinks. These findings indicate that forest conservation (through reduced harvesting and through mitigating climate change) is key to maintaining our forests' carbon-sequestering capacities.

Second, there is controversy over the role that residue wood plays in biomass plants. Residue wood left to decay in the forest does not release all of its carbon into the atmosphere (Admunson, 2001) and therefore has lower carbon impact than does the combustion of that residue wood. Also, the decomposition of this wood occurs slowly as opposed to the instantaneous release of carbon in a biomass plant, so its climate impact is delayed (Partnership for Policy Integrity, 2011). There are also questions as to how feasible it is to remove residue wood after logging projects and whether it requires extra time and costs. A study done in Massachusetts stated that typical logging practices in the state would require extra costs to recover the residue wood from logging projects (Manomet, 2010). This is because under manual harvesting (the standard logging practice in the state) tree tops and other residue wood are left in the forest and not brought to a landing site. Therefore, extra work would have to be completed to retrieve residue wood for use in biomass plants, reducing cost efficiency and further disturbing soil carbon pools. Also, it could be more cost efficient for operators to harvest whole trees specifically for biomass use instead of recovering residue wood.

Third, biomass plants emit more CO_2 per BTU than do fossil fuel plants (Manomet 2010; Partnership for Policy Integrity, 2012). According to PFPI, “biomass plants emit 150% the CO_2 of coal and 300-400% the CO_2 of natural gas, per unit of energy produced.”

The fourth point is that the timing of carbon fluxes are usually not taken into account when analyzing the carbon neutrality of biomass plants. Many scientists argue that to accurately estimate the carbon impact of biomass plants, the time frame within which carbon is released and then sequestered must be considered in LCA (Cherubini et al., 2011; Helin et al., 2013).
The Manomet Center for Conservation Studies recently simulated the time needed for Massachusetts forests to recover carbon lost from a variety of management practices (Manomet, 2010). These simulated management practices ranged from unmanaged to clear-cut. Several biomass harvests of varying intensities were included in these scenarios. Each of these simulations was based on a one-time harvest at 0 years (2010) and then modeled for 90 years (until 2100). Forest growth rates were based on data gathered by the Forest Inventory Analysis program. The study concluded that Massachusetts forests harvested for biomass have the potential to recover the carbon lost, but only after a significant time period has passed (nearly 100 years) and if that forest does not experience further harvesting before it has recovered that carbon. This finding indicates that harvesting for biomass plants causes the rates of carbon emissions to be faster than rates of carbon sequestration.

This imbalance of emissions and sequestrations should be considered in the Life Cycle Assessment of biomass plants. While carbon neutrality may eventually be achieved by a biomass plant in the sense that the carbon emitted could eventually equal the carbon sequestered, the biomass plant has already contributed to climate change in the time period before carbon neutrality is reached. Ricke and Caldeira (2014) have shown that temperature increase consequences of carbon emissions are quickly realized (within the decade) and are long-lived. This is shown in the figure from their research which is included below (Figure 2).

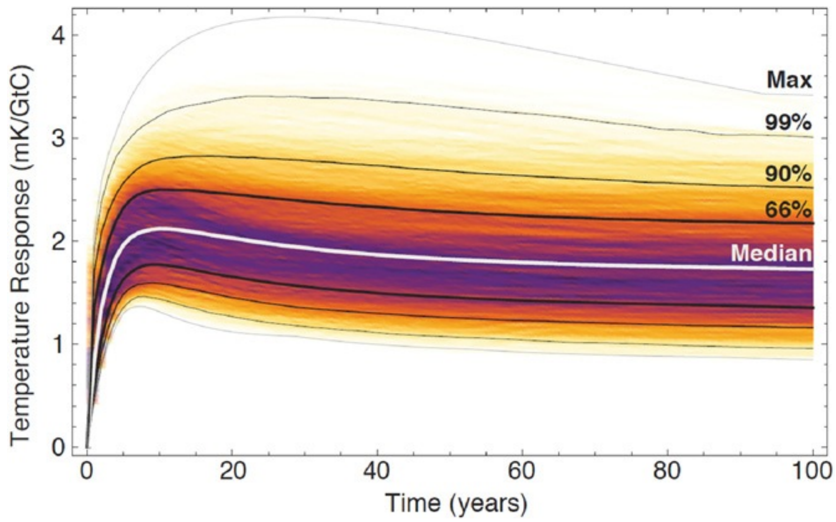

Figure 2. Temperature increase from an individual emission of carbon dioxide (CO_2). Time series of the marginal warming in mK (=milliKelvin = 0.001 K) per GtC (=1015 g carbon) as projected by 6000 convolution-function simulations for the first 100 years after the emission. Maximum warming occurs a median of 10.1 years after the CO_2 emission event and has a median value of 2.2 mK GtC−1. The colors represent the relative density of simulations in a given region of the plot. (Ricke and Caldeira, 2014).

Under Manomet's simulation of 90 years passing before carbon neutrality is reached by a biomass plant, nine decades have gone by in which that biomass plant is emitting carbon that contributes to climate change. This is the effect of just one harvest in this 90 year time frame. For these reasons, the timing of carbon fluxes within the system of the biomass plant need to be considered when assessing the carbon impact of the plant.

Due to these findings about the carbon impact of biomass plants, many scientists are urging for more accurate carbon accounting from biomass energy (Searchinger et al., 2009, Johnson, 2008). In 2013, a federal court ruled that the Environmental Protection Agency must include biomass-burning energy plants in the Clean Air Act's limits on carbon dioxide emissions (Natural Resources Defense Council, 2013). Scientists are working to expose that the carbon neutrality of biomass plants is not inherent and should be carefully assessed. This understanding of biomass energy generation is important in guiding climate change mitigation.

Requirements for Carbon Neutrality

Under what conditions can a biomass plant be carbon neutral? The goal for a carbon neutral biomass plant would be for the plant's carbon emissions to equal the dedicated forest's carbon sequestration within a short time period, such as a year. Here, I describe what requirements a biomass plant would need to meet in order to achieve carbon neutrality.

1. It must be known how much biomass is required to power the biomass plant. Once this basic information is known, then the amount of forest in terms of area and wood volume needed to support the biomass plant can be determined.
2. The forest harvested for biomass needs to be monitored for carbon removal. The amount of biomass removed to generate energy should be tracked, and any other harvesting projects that occur on the forest should also be followed. While carbon removals caused by other harvesting projects are not technically removals that are tied to the biomass plant, they will affect the forest's ability to store carbon and the amount of forest available for biomass harvesting.
3. The forest harvested for biomass needs to be monitored for carbon storage. Growth rates of the forest should be estimated and continuously monitored as harvesting may alter these rates.
4. The forest should also be monitored for carbon loss and storage from other pools such as soils and woody debris.
5. Carbon removal (carbon emissions) needs to equal carbon storage in the forest within a short time frame (a year).

Colby's Biomass Plant and Carbon Neutrality

Colby College has taken several steps towards reducing its CO_2 emissions, including the purchase of carbon offsets, installing a geothermal heating system for two buildings, and the installation of a biomass plant that co-generates heat and electricity (Colby College News, 2013).

In this thesis, I will examine to what extent the Colby biomass plant is carbon neutral. I will consider Life Cycle Assessment of carbon, timing of biomass plant emissions and sequestration, as well as logging and forest management practices used to supply the biomass plant in this study. My information comes from personal communication with those involved with the biomass plant, harvesters for the biomass plant, and US Forest Service data This thesis will explain where the biomass plant currently is in the path to carbon neutrality, and what steps could be taken to reach total carbon neutrality.

Methods

Data Source

All growth rate calculations reported in this study were made using data from the Forest Inventory Analysis (FIA). The FIA program works to collect and publish data about tree growth, volume, condition, and use throughout the nation. They have four regional offices, and the Northeastern Research Station gathered and published the dataset used in this study. The FIA begins with remote sensing in order to determine forest classes. The program then collects data on real plots, and the plot design that is currently used was developed in 1993. The dataset used in this study is data collected by FIA in Kennebec County, Maine.

Data Analysis

Tree growth rates for Kennebec County were calculated from a dataset including tree diameters measured throughout the county (USDA Forest Service, 2015). This county data is used as a proxy for all areas that may be harvested for Colby College's biomass plant because the plant is located in Kennebec County and the wood for the plant is locally sourced. Out of the variables included in the dataset, this analysis focused on the survey plot, subplot, tree identification number, tree species, tree diameter, and the previously recorded diameter for 2,647 trees in 75 plots. Plots were made of four subplots, totaling 0.1667 acres in size. The dataset was interpreted using *The Forest Inventory and Analysis Database: Database Description and User Guide for Phase 2 (version 6.0.1).* Diameter at breast height (DBH) was the measurement used for the majority of diameters taken. DBH refers to a commonly used measure of tree diameter taken at four and a half feet above ground level.

Each tree included in these calculations was surveyed at least twice at five year intervals (1999-2004, 2000-2005, 2001-2006, 2002-2007, 2003-2008, 2004-2009, 2005-2010, 2006-2011, 2007-2012). Data collected on softwood tree species were deleted from the data set as the biomass plant exclusively uses hardwood trees. Data points collected in 1995 were deleted from the dataset because these trees were never resurveyed, and therefore did not provide information on diameter changes. Other data points that did not have an entry for the tree's diameter or its previous diameter were also deleted. The original dataset included information on 12,868 trees, yet I was only able to include 2,647 of these due to lack of needed information and because softwood trees were excluded from these calculations. Diameter values were originally reported in the dataset as inches and were converted into centimeters. Then, tree biomass (kg dry weight) and its biomass measured five years previously were calculated for each diameter and previous diameter. This was done using a formula designed to estimate tree biomass from diameter: $Bm = \mathrm{Exp}(\beta_0+\beta_1 \ln dbh)$ Coefficients for tree species groups were empirically determined (Jenkins et al., 2003). Each tree's previous biomass was subtracted from its current biomass to obtain change in biomass and then divided by five to get the tree's change in biomass per year. The change in biomass for all trees was summed and divided by the number of data points to obtain the average change in biomass per tree per year. A tree's carbon content is standardly assumed to be 0.5 of its dry biomass (USDA Forest Service, 2014; Manomet, 2010). This was applied to the tree growth in Kennebec County to calculate the yearly average change in carbon per acre.

The percentiles of growth per plot were used to simulate various growth rate scenarios. The 95th percentile, the 75th percentile, the median, the mean, the 25th percentile, and the 5th percentile were all calculated from the dataset. This provides six growth rate scenarios for plots in Kennebec County. These six scenarios were then expanded to a per acre basis by dividing an acre by the area of the plot (0.1667 acres).

The amount of land needed to support the biomass plant was calculated for the six tree growth rate scenarios. Colby's Physical Plant Department (PPD) reports that Colby used 14,549.35 tons of wood in the biomass plant from July 1st, 2013 to June 30th, 2014 (Appendix; Table A1). This figure, the most up to date report on yearly biomass use, was used in the following calculations.

The first step in calculating land area needed was to convert the tons of wood used by the biomass plant into tons of dry biomass. The wood used by the biomass plant is typically at 37%-45% moisture content. Percentage moisture content is equal to the weight of water in wood. The range of moisture contents was averaged to 41%. Wood that is delivered to Colby and then stockpiled for later use typically loses 10% or less of its weight (10% of its moisture), so any stockpiled wood was assumed to be 31% moisture. In the year reported, 2,237.41 tons of wood were stockpiled before use in the biomass plant. These 2,237.41 stockpiled tons were multiplied by .31 to calculate the water weight. The remaining tons were multiplied by 0.41 to calculate their water weight. The sum of these two figures was subtracted from the total tons of woodchips (14,549.35) to calculate the total tons of dry biomass weight used by Colby's biomass plant from July 1st, 2013 to June 30th, 2014. Then, this figure was converted to kilograms. Next, the area of forest needed to provide the biomass plant with wood at a rate equal to that of forest growth was calculated for each forest growth rate scenario (95th, 75th, 25th, and 5th percentiles, median, and mean). The dry kilograms of biomass used by the plant was divided by the growth rates for each scenario. This provided the acreage needed to supply Colby's biomass plant with harvest rates equaling growth rates for each forest growth scenario.

When considering the area of forest needed to provide biomass, it is important to account for land needed for the harvesting operation such as are for skid roads that allow access to and transportation of wood. Lensky reports that in following low-impact forestry methodology, about 10% or less of the acreage of harvested forest should be used as skid roads (Lansky, 2002). Final acreage reported in this study is the acres required under each growth scenario plus 10% to account for the land needed to skid roads.

In addition, a map of the plot locations (Figure A1) and a table describing growth per plot (Table A2) were produced. The map of plot locations was made in Google Earth. Plot locations were those reported by the FIA for plots in Kennebec County. The exact locations of these plots have been slightly altered by the FIA to protect individual land owners (US Forest Service, 2014). Growth rates calculated in this study were used to determine the scale of plot markers on the map. The table describing growth per plot was developed using data from the FIA. Habitat types were determined using the help of the US Forest Service's designation of habitat types (McWilliams et al., 2003).

Results

Per plot forest growth in Kennebec County is highly variable (Figure 3). The minimum growth rate included in the dataset was -146.73 kg of dry biomass per year while the maximum growth rate in the dataset was 614.85 kg of dry biomass per year. One plot, as indicated by the minimum growth rate in the dataset, experienced a net loss of biomass in a year. The distribution of growth rates is skewed right, with most of the data points lying between a growth rate of 125 kg of dry biomass/year and 475 kg dry biomass/year. Variation in growth rates shows no obvious relationship to geography (Appendix; Figure A1). Many of the more slowly-growing forests appeared to be dominated by softwoods (Figure A1), but all surveyed forests contained a mixture of hardwoods and softwoods.

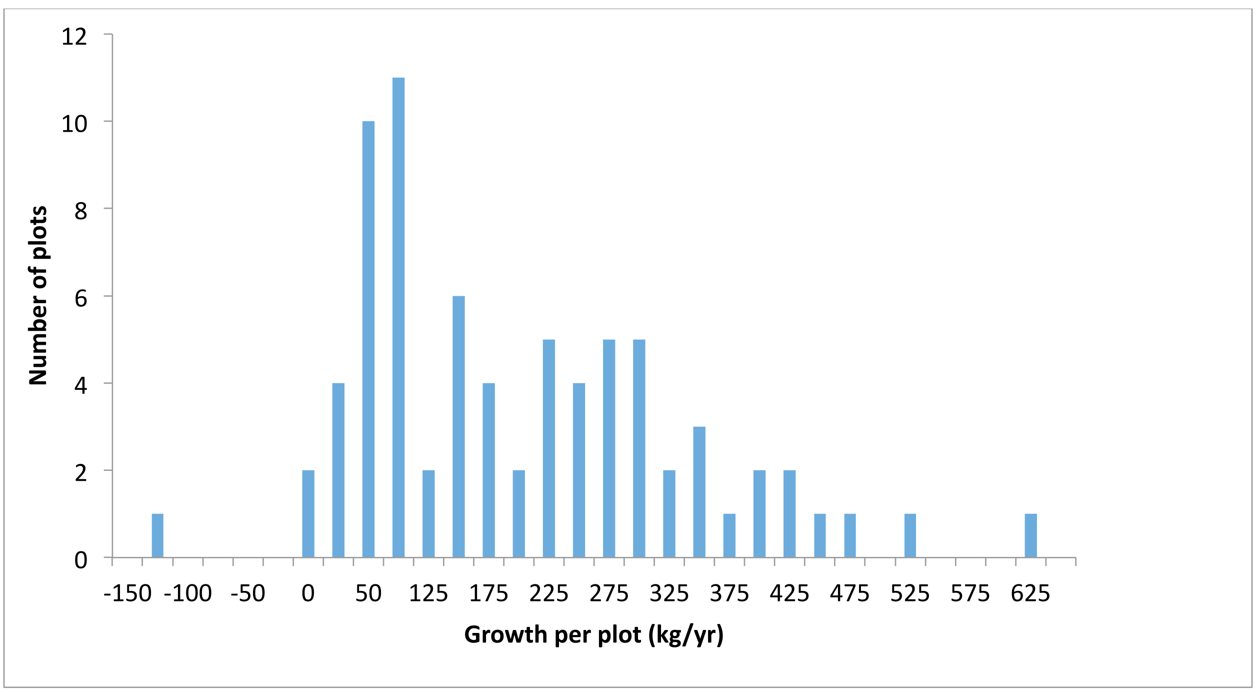

Figure 3. Frequencies of hardwood growth rates per year for FIA plots surveyed in Kennebec County.

The range of annual growth per acre was 2609 kg of biomass (1304.5 kg carbon). The median growth per acre was 982.28 kg/yr (491.14 kg/yr carbon) (Table 1).

Table 1. Annual biomass and carbon growth per acre for various growth rate scenarios for hardwood trees growing in FIA plots in Kennebec County.

	95th Percentile	75th Percentile	Median	Mean	25th Percentile	5th Percentile
Biomass (kg/yr)	2611	1650	982	1078	319	2.4
Carbon (kg/yr)	1306	825	491	539.	160	1.2

The total kilograms of dry biomass used in the plant from July 1st, 2013 until June 30th, 2014 was 8,026,644.57 (8,847.86 tons).The acreage estimated to supply the biomass plant at this rate was 8172 acres growing at the median growth rate. Table 2 shows the acres needed for each growth scenario. Calculations accounting for skid roads increase the area needed for each growth scenario by 10%.

Table 2. Acres of land needed to be solely dedicated to the biomass plant for various forest growth rate scenarios with and without skid roads.

Scenario	Acres required/yr	Acres required/yr + 10% area
95th percentile	3,074	3,381
75th percentile	4,864	5,350
Median	8,172	8,989
Mean	7,445	8,189
25th percentile	25,131	27,644
5th percentile	3,403,436	3,743,780

Discussion

Growth Rates

In Kennebec County, hardwood tree growth per plot and acre is highly variable. The 95th, 75th, 25th, and 5th percentiles of growth rates were calculated in this study in order to describe this variability. These percentiles also help with understanding what growth rates can be expected when considering an appropriate harvest rate for the biomass plant. Both the mean and the median of the growth rates were used in this analysis. Due the skewed distribution of the data, the median is a more accurate descriptor of growth rates than is the mean, which can be affected by skewed data.

Trees included in the FIA dataset were resurveyed every five years and the dataset as a whole spans the length of eight years. Due to this timeframe, the dataset may have captured stochastic events in weather or disease outbreaks that add to the variability of growth rates. Plot growth rates were calculated from real data on plots surveyed by FIA and are expected to be fairly accurate representations of tree growth in Kennebec County. However, acre growth rates were found by expanding plot growth rates and are therefore expected to be less accurate than the plot growth data.

The per acre growth rates calculated in this study are potentially overestimated. FIA survey plots are small in size (0.1667 acre) and are most likely consistently forested. When expanding growth rates to per acre, it can be assumed that acres include more geographic variability (swamps, cliffs, etc.), and therefore are not consistently forested. Applying growth rates from a consistently forested plot to an entire acre does not account for this geographic variability, and therefore, variability in tree density. This would lead to an overestimation of growth rates per acre.

Previous Studies on Biomass Availability and Growth in New England

Previous studies have been done at Colby regarding forest growth and the biomass plant. Forgrave '14 and Beck '14 found that Colby's biomass plant would use about 10-20% of the available biomass within a 50-mile drive of Colby. This was done by mapping out available forest lands surrounding the college. Fisher '14 and Palffy '14 completed a study on how Colby's biomass plant could comply with Land Endowment Action Plan (LEAP) certification (Fisher and Palffy, 2014). They determined that around 20,000 acres of forest would be needed to supply the biomass plant, and that a further 10,000 acres would be needed to meet LEAP regulations. They also found that Colby, using wood as their fuel source, has doubled its CO2 emissions since switching from oil as the fuel source.

My results can also compared to a similar project done by Middlebury students on their forest lands and biomass plant (Crosby et al., 2010). At Middlebury, biomass growth per year was estimated to be 3,169.86 kg/acre for hardwood trees. Authors reported accumulation of 4.93 tons of carbon per hectare per year. This figure is about three times higher than the average and median biomass growth rates in Kennebec County (1,078.18 kg/acre and 982.28 kg/acre, respectively) and is not included within the range (2.36 kg/acre to 2,611.36 kg/acre). The differences in these data by Middlebury students may come from a few sources. First, the figure reported in the Middlebury study was based on a site index and stage age model developed by Gough et al. (2008). The equation is included below:

$$0.4436 * e^{[0.143 * \ln(\text{stand age}) * \text{site index}]} * \text{area}$$

The 0.4436 is a coefficient of annual carbon storage determined by Gogh based off of tree growth rates in Northern Michigan. Middlebury students calculated the stand age and site index of their land to use in this equation with the aid of GIS techniques. The Middlebury students note that Gough's coefficient of annual carbon storage was developed based on growth rates of forests that are known to grow much faster than the maple-beech-birch forests of Vermont. This would lead to an overestimation of annual carbon storage rates. Further, an equation of carbon storage can generally be assumed to be less accurate at assessing growth rates than is real data. The data used for calculating growth rates in this study was collected over a number of years, capturing the variances in growth patterns, weather, and disease that affects forests. The equation used to calculate growth rates in the Middlebury study is not based on a data set of recorded tree growth, but on GIS images and a generalized growth coefficient. For these reasons, the growth rates reported in this study, while lower than those reported by Middlebury, may be a more accurate assessment of growth in New England Forests.

The Manomet Center for Conservation Sciences has modeled the aboveground accumulation of carbon in acres of forest under various management regimes for 90 years. The slowest growth rate modeled was for an unmanaged forest. This forest accumulated 21.99 metric tons of carbon in 90 years, and this was converted into 488.67 kg of biomass per acre per year. This figure is lower than the median reported in this study (982.28 kg/yr biomass) but is well within the range (2.36 kg/yr to 2611.36 kg/yr). The fastest growth rate they report is in a forest heavily harvested for biomass (Heavy Harvest BA 40). This forest accumulated 883.11 kg of biomass per year. Manomet's figure is just below the median biomass growth reported in this study, but is well within the range.

These two studies (Middlebury and Manomet) show the range of estimates of biomass accumulation in New England. The Maine State Forest Service reports that the entire state (hardwoods and softwoods) experienced an annual net growth of 51,329,665,840 kilograms of biomass in 2013 (McCaskill, 2014). This would translate to an annual growth rate of about 2,900 kilograms of biomass per acre. This growth rate may be higher because both hardwoods and softwoods are included, whereas this study only accounts for hardwood growth. Varying forest type throughout the state may also be a source of difference between growth rates for Kennebec

County reported in this study and the stateside growth rates reported by McCaskill. While discrepancies exist within levels of accuracy as well as estimation techniques, the differences in figures reported between the studies also indicate that tree growth rates are challenging to calculate accurately and are potentially highly variable from year to year or location to location. Understanding this variability is important when using estimates of tree growth to determine land use practices.

Acres required by the biomass plant

The six tree growth rate scenarios represent the land needed for Colby's biomass plant in order for it to be considered carbon neutral under each growth rate. This means that the area of land for each scenario has a growth rate equal to the rate at which Colby uses biomass; carbon intake in forests equals carbon loss through biomass harvesting. These acres of land are required to be dedicated solely to supplying Colby's biomass plant. If other logging projects were to be occurring on this land, the forests' growth rates (carbon sequestration rates) and carbon intake would no longer equal carbon loss.

The land needed for Colby's biomass plant to be carbon neutral is potentially a relatively small area of land. If using the median growth rate per acre of forest in the county, only 8,988.61 acres of forest would be needed to supply the biomass plant per year. This value accounts for the acreage required for a median forest growth rate with an additional 10% area for skid roads. Put in another perspective, this is about 14 square miles of land per year. If growth rates stay constant on this 14 square mile plot of land, Colby would only ever need to manage and harvest from this plot.

In the scenario that models the 25th percentile of the growth rate (319.39 kg biomass/acre/yr), 27,643.87 acres of forest would be required. This acreage equals about 43 square miles. This figure is substantially higher than the acres needed for the median growth rate. While it does represent the lower extreme of the variability in growth rates, this figure would be the most conservative one to use if Colby had the goal of achieving carbon neutrality in the years that forests experienced low growth rates. In the 75th percentile growth rate scenario, 5,350.11 acres would be needed each year (8.36 square miles). This figure is interesting to know and provides a high end of tree growth variability, but this amount of land would not allow the biomass plant to be carbon neutral as it represents an extreme of rapid tree growth.

While the amount of land needed under the average growth rate scenario may seem small, this land would have to be managed in a specific way in order for Colby to claim the carbon neutrality of its biomass plant. First, Colby would have to ensure that the land is solely dedicated to supplying the biomass plant in order to track carbon emissions and sequestration. Second, the growth rates of these acres of forest would need to be monitored throughout their use to ensure that they are growing at the rate at which the biomass plant emits carbon. Third, these numbers are calculated specifically for the amount of wood used by the biomass plant in the year of June 2013 to July 2014. If the biomass plant changed its rate of wood use, the acreage required to power the biomass plant would also change. Each of these three requirements ensure that the amount of wood going into the biomass plant each year equals the amount of wood growing on these dedicated plots each year. Also, it is important to remember that working with this area of land would mean that Colby's biomass plant would only achieve carbon neutrality during years when the forests grew at an average or higher than average rate.

It is important that Colby work within this one year time frame of tree growth and tree harvest. While it may be true that any amount of carbon would eventually be restored in forests, carbon dioxide contributes to climate change during the time that it is in the atmosphere regardless of whether or not it is eventually restored (Ricke and Caldeira, 2014). Working within the time frame of a year allows forests to grow a substantial amount and recapture the carbon emitted before it contributes to climate change.

Carbon neutrality: useful in climate change mitigation?

Under the same scenario in which the biomass plant could be potentially carbon neutral, a plant using a fossil fuel could also be carbon neutral. Suppose Colby were still burning Fuel Oil #6 in its heating system (as it did before installing the biomass plant). The amount of carbon used each year while burning Fuel Oil #6 could be calculated. From knowing this figure, Colby could secure an area of forest that grows at the same yearly rate as the yearly rate at which the heating system used carbon. This would be a carbon neutral system. Carbon neutrality cannot be assumed of biomass plants any more than it can be assumed of an oil-powered plant. Both systems release carbon dioxide and contribute to climate change. The carbon of both systems is sequestered through the growth of forests. In order to demonstrate carbon neutrality, it must be shown that carbon emissions equal carbon sequestration, and this can be done with both systems.

Globally, carbon emissions greatly outweigh carbon sequestration. This imbalance in the carbon cycle is what causes climate change. In order to balance out the carbon cycle, what is needed is a reduction in carbon emissions. Carbon neutral systems, like those described in this paper, add carbon to the atmosphere but then recapture it through mechanisms such as forest growth. However, when the global system is overloaded with carbon, even a "carbon neutral" system is contributing to climate change: when it adds carbon into the atmosphere and uses forests to sequester that carbon, those forests are then not sequestering the other excess carbon in the atmosphere (Scientists' Letter to EPA, 2015).

While biomass supports a local wood harvesting business and reduces our dependence on vulnerable fossil fuels, it does not necessarily mean that it has a low carbon impact. As mentioned before, burning biomass releases more CO2 per unit than do fossil fuels (Manomet., 2010, Partnership for Policy Integrity, 2012). Biomass and forests use can be managed as a carbon neutral system, but so too can fossil fuels and forests.

The most effective strategy for mitigating climate change is to have zero carbon emissions or to sequester more carbon than is emitted. This can be done through energy sources such as wind and solar and through protecting carbon sinks such as forests and oceans. Biomass plants are a dependable fuel-source option, but are not effective at mitigating climate change.

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Table A1. Colby College Biomass Use, 2013-2014

Colby 7-1-13 to 6-30-14

Comprehensive Land Technologies

Fuel Type	Loads	Tons	%	Comments
Hardwood bole chips	75	2,304.62	30.37%	
Hardwood whole tree	148	4,543.10	59.86%	
Hardwood stockpile	25	741.30	9.77%	Delivered as chips
	248	**7,589.02**	**52.16%**	

J&M Logging

Fuel Type	Loads	Tons	%	Comments
Hardwood bole chips	13	427.03	14.58%	
Hardwood whole tree	43	1,424.06	48.61%	
Hardwood stockpile	32	1,078.53	36.81%	Stockpiled roundwood
	88	**2,929.62**	**20.14%**	

Scott Kinney Logging

Fuel Type	Loads	Tons	%	Comments
Hardwood bole chips	31	1,062.91	30.02%	
Hardwood whole tree	60	1,966.05	55.52%	
Hardwood stockpile	9	305.41	8.63%	Stockpiled roundwood
Hardwood stockpile	6	206.55	5.83%	Delivered as chips
	106	**3,540.92**	**24.34%**	

Trees Limited

Fuel Type	Loads	Tons	%	Comments
Hardwood bole chips	0	0.00	0.00%	
Hardwood whole tree	6	184.17	37.60%	
Hardwood stockpile	18	305.62	62.40%	Stockpiled roundwood
	24	**489.79**	**3.37%**	

Grand Totals

Fuel Type	Loads	Tons	%	Comments
Hardwood bole chips	119	3,794.56	26.08%	
Hardwood whole tree	257	8,117.38	55.79%	
Hardwood stockpile	90	2,637.41	18.13%	
	466	**14,549.35**		

Table A2. Detailed information for each FIA plot assessed in this study.

OT	LAT	LON	GROWTH RATE (kg/yr)	GROWTH RATE W/O SOFTWOODS (kg/yr)	FOREST TYPE
2	44.37232	-70.1239	92.4	53.2	spruce/balsam fir
23	44.4471	-69.5207	154.3	147.7	oak/white pine
24	44.4833	-69.4749	364.6	161.0	cannot determine
32	44.54321	-69.7729	275.3	275.1	cannot determine
58	44.562	-69.9439	406.3	406.3	sugar maple/ash
114	44.46617	-69.6006	533.7	260.9	spruce/balsam fir
137	44.23516	-69.8272	-17.1	-146.7	spruce/balsam fir, beech red maple
150	44.35842	-69.7299	705.1	341.7	oak/white pine
219	44.40633	-69.5277	327.6	209.4	red maple/beech, sugar maple/ash
251	44.37182	-69.7038	28.5	28.5	red maple, beech
276	44.24101	-69.701	146.7	21.6	oak/white pine
297	44.46686	-69.8686	396.6	54.5	beech/red maple, hemlock/red spruce
319	44.41027	-70.0185	743.7	267.3	oak/white pine, sugar maple/ash
340	44.4482	-69.6661	219.8	94.7	spruce/balsam fir
399	44.33366	-69.7073	303.5	298.6	oak/white pine
425	44.31165	-69.6511	216.5	85.6	oak/white pine, red maple/beech
467	44.21526	-69.8712	356.6	192.8	oak/white pine
475	44.54402	-70.0131	381.8	381.4	sugar maple/ash, beech/red maple
478	44.46972	-69.7077	500.1	306.7	hemlock/red spruce, red maple/beech
574	44.39492	-69.7601	120.9	41.7	hemlock/red spruce, red maple/beech
590	44.41771	-69.9141	443.4	271.6	oak/white pine, spruce/balsam fir
604	44.20908	-69.6846	63.8	66.4	cannot determine
643	44.32812	-69.5805	279.6	31.8	spruce/balsam fir
740	44.51696	-69.5722	339.3	252.3	oak/white pine, beech/red maple
811	44.32523	-69.9392	251.2	142.0	beech/red maple, sugar maple/ash
818	44.23313	-70.0503	59.7	35.2	beech/red maple
902	44.37255	-69.9371	575.2	507.9	beech/red maple, oak/white pine
907	44.28997	-70.0102	470.2	222.1	oak/white pine
950	44.4883	-69.6493	536.9	394.3	sugar maple/ash
960	44.30292	-69.7777	851.3	339.3	oak/white pine
990	44.28274	-70.0568	694.6	614.9	oak/white pine,
1021	44.35539	-69.9991	568.3	240.6	spruce/balsam fir
1102	44.6198	-69.5633	279.2	247.0	sugar maple/ash,spruce/balsam fir
1124	44.28616	-69.5958	447.2	209.4	oak/white pine, hemlock/red spruce
1252	44.13854	-69.6959	266.2	30.2	oak/white pine, hemlock/red spruce
1323	44.39718	-69.8883	306.5	282.8	beech/red maple
1349	44.65998	-69.4764	507.3	374.7	cedar/black spruce, spruce/balsam fir
1391	44.54682	-69.4218	-3.6	-3.6	cannot determine
1443	44.47166	-69.942	106.3	104.6	beech/red maple
1449	44.16898	-69.8823	497.5	198.9	hemlock/red spruce, beech/red maple
1480	44.28067	-69.841	341.7	59.9	spruce/balsam fir, hemlcok/red spruce

1622	44.15329	-69.7477	539.4	265.5	oak/white pine
1671	44.58753	-69.5273	444.9	291.6	cedar/black spruce, beech/red maple
1765	44.31073	-69.5178	557.7	456.9	oak/white pine
1972	44.48926	-69.9988	32.9	32.9	beech/red maple
1985	44.34472	-69.5071	96.4	34.2	beech/red maple, oak/white pine
1994	44.37813	-69.5938	324.8	143.5	beech/red maple, hemlock/red spruce
2066	44.36284	-70.0739	449.0	230.5	oak/white pine, sugar maple/ash
2071	44.4996	-69.881	141.7	133.2	beech/red maple, sugar maple/ash
2095	44.60504	-69.4716	186.2	171.0	beech/red maple, spruce/balsam fir
2170	44.43012	-69.4741	413.7	208.9	beech/red maple, spruce/balsam fir
2213	44.2618	-69.7488	428.0	56.3	spruce/balsam fir, oak/white pine
2369	44.50899	-69.9289	377.4	325.5	hemlock/red spruce, beech/red maple
2373	44.56212	-69.8998	145.5	145.5	oak/white pine, beech/red maple
2488	44.18629	-69.7005	411.0	286.8	beech/red maple
2524	44.40572	-69.837	102.7	112.0	beech/red maple, spruce/balsam fir
2540	44.40391	-69.6436	497.3	429.8	beech/red maple
2557	44.34659	-69.8667	501.5	302.9	hemlock/red spruce, beech/red maple
2607	44.54919	-69.6874	280.0	238.7	beech/red maple, spruce/balsam fir
2636	44.21372	-69.9796	90.7	-4.0	hemlock/red spruce
2755	44.51159	-69.7358	50.6	50.6	cannot determine
2831	44.40029	-70.0017	177.5	172.4	beech/red maple, sugar maple/ash
2983	44.23407	-69.92	217.8	90.7	hemlock/red spruce, beech/red maple
3071	44.63917	-69.3963	91.9	36.4	spruce/balsam fir
3072	44.14027	-69.6615	57.0	10.3	hemlock/red spruce, beech/red maple
3160	44.41351	-69.6181	171.2	131.9	oak/white pine, beech/red maple
3206	44.46115	-69.7588	114.5	31.4	spruce/balsam fir, beech red maple
3236	44.34102	-70.0559	210.7	80.2	spruce/balsam, beech/red maple
3255	44.57006	-69.474	13.1	1.4	spruce/balsam
3426	44.16826	-69.9953	202.1	163.7	beech/red maple, oak/white pine
3456	44.22189	-69.7521	113.0	39.2	oak/white pine
3465	44.49083	-69.5335	505.4	403.4	oak/white pine, beech/red maple
3495	44.51399	-69.8751	166.2	77.1	oak/white pine, hemlock/red spruce
3510	44.55028	-70.028	270.6	217.6	beech/red maple, sugar maple/ash
3658	44.19267	-69.938	34.5	5.2	hemlock/red spruce

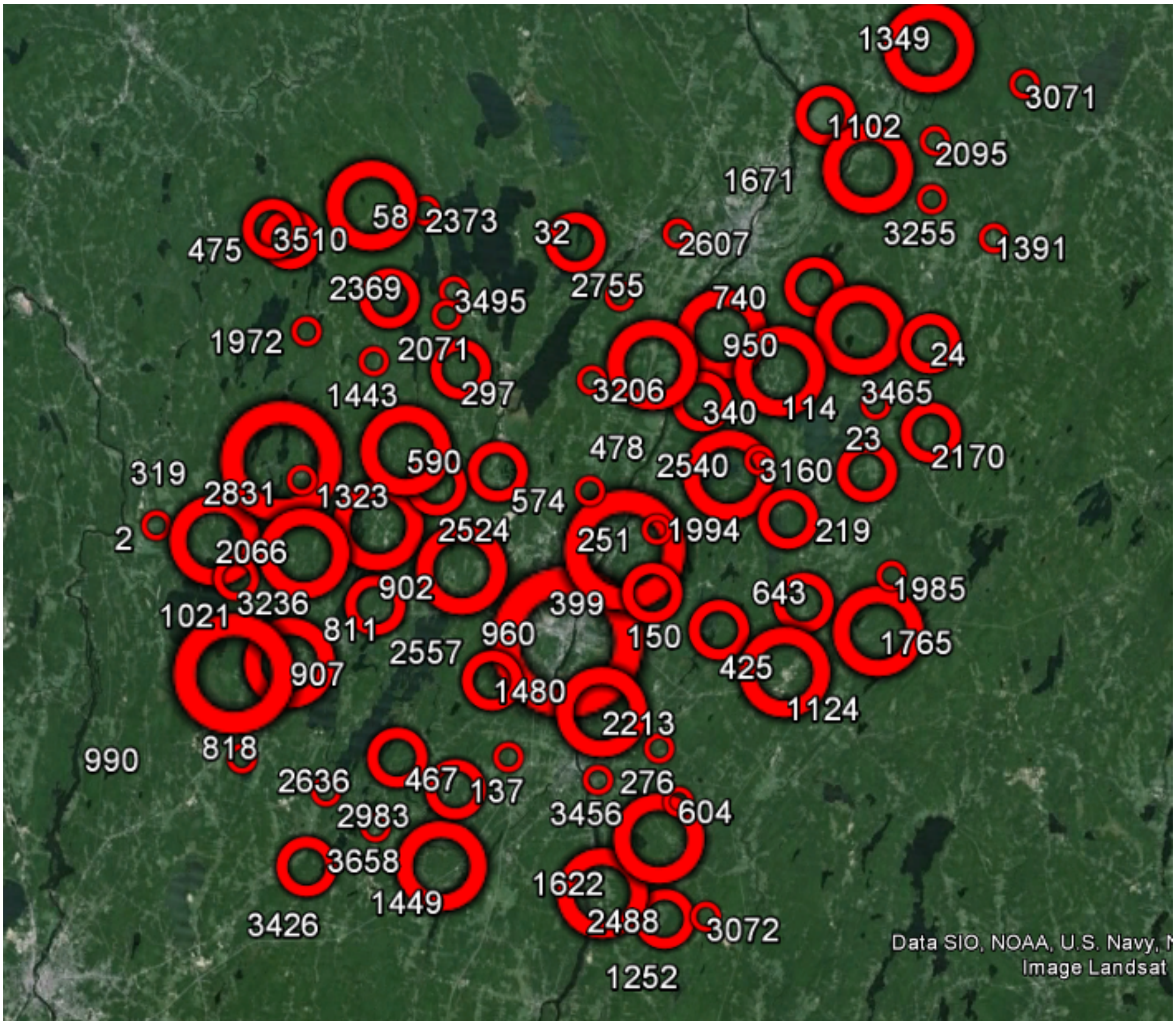

Figure A1. Map of FIA plot locations in Kennebec County. Labels refer to plot number. Outside circle diameter indicates growth rate of all species; interior diameter indicates growth rate for softwoods. Plot 3071, for example, is primarily softwood.