ESTIMATING ABOVEGROUND CARBON STOCK at Franklin Pierce University

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ABSTRACT

With the increasing concentration of carbon dioxide in the Earth's atmosphere as the result of fossil fuel combustion (leading cause) and deforestation (secondary cause), there is a pressing need to estimate carbon pools in local forests. The present study was aimed at classifying forest types on Franklin Pierce University's campus and estimating above ground biomass and carbon stock using allometric equations. The Jenkins method of allometric equations was used to relate tree components obtained by non-destructive measurements to the oven dry biomass for trees in the United States. The results indicated that the Spruce Swamp had lower mean aboveground biomass (33.5 mt/ac) than the Deciduous forest (37.7 mt/ac) and Mixed Forest (45 mt/ac), while Coniferous Forest had aboveground biomass of 59.42 mt/ac. The type of forest did not have a significant effect (p=0.0597) on the amount of carbon stored because there is a lot of variation within each forest type and not a lot of variation between the forest types. The number of species sampled ranged from 2 to 10 per plot and the overall mean stand density was 389 stems/acre. Acer rubrum (31.23 percent), Picea rubens (29.15 percent), and Pinus strobus (9 percent) were the most dominant species. Most of the tree species belonged to the diameter at breast height class of 10–20 cm. The total aboveground carbon stock of the forest in the study area in 2018 was estimated at 40,679.66 metric tons.

Keywords: Aboveground biomass; Allometric equations; Forest Inventory, New Hampshire

Background

Global warming is caused by the continuous accumulation of greenhouse gases (GHG), especially carbon dioxide (CO_2), in the atmosphere driven primarily by the burning of fossil fuels and exacerbated by deforestation worldwide. Deforestation contributes to global warming because trees are cut down and burned, releasing carbon into the air, with tropical deforestation responsible for about 10 percent of all GHG which amounts to a yearly average of 3.0 billion tons of carbon dioxide or the equivalent of 600 million cars (Union of Concerned Scientists 2013). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems (2019) confirms that deforestation is a significant contributor to the current greenhouse gas (GHG) emissions problem and that forest loss causes warming in temperate zones. The increased CO_2 emitted needs to be sequestered to strike an ecological balance and reverse global warming trends.

Fortunately, forests are natural carbon sinks with live biomass, detritus, and soil organic matter storing roughly half of the world's terrestrial carbon (Anderson-Teixeira et al. 2016). There is a decline per decade of the carbon sink in South America (-0.69 Pg C), increase in Africa (0.25 Pg C), and increases in the temperate forests (0.87 Pg C ha^{-1}) globally and boreal forests of North America (0.49 Pg C ha^{-1}) with an alarming 1.12 Tg C of emissions in one year over 23,613 hectares in the Peruvian Amazon due to gold mining while deforestation caused by gold mining and logging concessions accounted for carbon emissions of 0.42 Tg C yr^{-1} between 2006 and 2009 (Asner et al. 2010, Xu et al. 2019, Ovidiu and Asner 2020). There is an estimated potential of 0.4 to 5.8 gigatonnes of carbon dioxide sequestered per year from reducing deforestation and forest degradation (IPCC 2019).

Therefore, forests play a critical role in regulating the future increase of CO_2 levels by sequestering atmospheric carbon through the process of photosynthesis and converting excess carbon into the growth of woody biomass (Brown and Pearce 1994). Tree carbon sequestration rates vary widely with forest type, tree species, climate, forest stand age, and location, but younger and faster growing forests generally have higher annual sequestration rates or net primary productivity (NPP). This is the reason that afforestation on abandoned agricultural land, like that of the study location, acts as a carbon sink and continues to sequester carbon (Woodbury et al. 2007).

The Northeastern United States is largely covered by a transition zone of trees that is positioned between the northern hardwood - conifer forests to the north and oak - pine forests to the south (Prasad et al. 2014). The growth and distribution of forests has an important impact on atmospheric carbon dioxide concentrations and is a central issue in global change research. Fossil fuel burning, deforestation, and other human activities have driven a 25 percent increase in atmospheric carbon dioxide (CO_2) since 1900 (Thompson et al. 2013). Humans cut down a lot of trees, making deforestation the second biggest source of the 36 billion metric tons of CO_2 emitted annually from over 7,500 large CO_2 emission sources (Le Quéré et al. 2018, IPCC 2005). IPBES' 2019 Global Assessment Report on Biodiversity and Ecosystem Services, the first global biodiversity assessment since the Millennium Ecosystem Assessment (2005), confirms that terrestrial ecosystems became a net sink for carbon emissions around the middle of the last century, with a gross sequestration of 2.8 gigatons of carbon per year (the equivalent of some 30 percent of global anthropogenic emissions). In addition, it mentions that deforestation has been much more intensive in temperate regions historically (IPBES 2019). The Northeastern United States is specifically afflicted with past and continued deforestation.

The history of forests in the northeast is one of colonization and anthropocentric land use change. Though the United States was heavily forested at the beginning of European settlement, much of it was cleared for farmland in the 19th century. In 1630, Northeastern forests occupied over 117,940,000 acres (Kellogg 1909). It is estimated that by the 1920s at least 50 percent of the eastern forest had been cleared (Whitney 1994). Farmland abandonment, beginning in the mid-1900s and continuing through the study period, has led to a natural regrowth of forest. Unfortunately, there has been an increase in forest clearing over the last few decades for housing, coal mining and energy development associated with fracking, with approximately nine million acres cleared since the 1970s (Biello 2010). Today, while the forest area has grown to 84,796,000 acres in the Northeast, less than one-tenth of a percent of these forests are undisturbed with very few old growth forests remaining (Biello 2010).

Forests in the Northeastern United States are currently a major recovering carbon sink. U.S. forests capture about 2 billion tons of carbon every 10 years and counteract 10 percent of our fossil fuel emissions (Smith 2008). Through photosynthesis, live trees emit oxygen in exchange for carbon dioxide, a greenhouse gas, they pull from the atmosphere. As a tree grows it stores carbon in cellulose, hemicellulose, lignin, and other compounds that form the wood above and below ground. The amount of carbon in the biomass varies from between 35 to 65 percent of the dry weight, depending on species ranging from 41.9–51.6 percent in tropical species, 45.7–60.7 percent in subtropical/Mediterranean species, and 43.4–55.6 percent in temperate/boreal species, with 50 percent often used in equations as a default value (Karsenty et al. 2003, Thomas and Martin 2012). As forests grow over time, the amount of sequestered carbon increases. Carbon storage in vegetation represents an important reservoir within the global carbon cycle, and changes in carbon uptake by and storage within vegetation and soils can have a significant impact on the global carbon balance.

While forest carbon stocks in the United States are estimated at a national level using data from the United States Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis (FIA) program, there is a significant difference in estimates of carbon stocks at the local and national scales, according to Domke et al. (2012). They further reported those national scale estimates by individual U.S. states for the entire 1990-2019 time series, with New Hampshire storing 481 million metric tons of carbon dioxide equivalent in 2019, 144 million of which is aboveground biomass. Therefore, it is important to estimate local forest carbon stock based on field measurements for accuracy and precision. The FIA program uses a set of generalized allometric regression models to predict oven-dry biomass in tree components for all tree species in the U.S. (Jenkins et al. 2003). The Jenkins method was developed using a version of meta-analysis where more than 1,700 regression predictions were refitted for more than 100 species and groups of species.

The objective of this study was to estimate tree aboveground biomass (AGB) and carbon storage in the forests at Franklin Pierce University to provide a benchmark with which the university can track the change in carbon stocks to reduce net emissions from deforestation and degradation and to track enhanced carbon sequestration through campus tree harvest planning. Aboveground biomass includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. While it is easy to visualize the carbon stored in AGB, a substantial proportion of forest net primary production (NPP) is directed toward maintenance and accumulation of belowground biomass (BGB). Belowground biomass can be estimated as a percentage of AGB. Santantonio et al (1977) conclude that there is a consistent relationship between root-system biomass and stem diameter at breast height with a BGB of at least 20 percent of AGB (sometimes up to 30 percent). Understory herbaceous vegetation rarely is a significant factor in the ecosystem carbon budget. Soil estimates require more data than covered in this study.

Research Methods

The study site is located in N'dakina (Abenaki word for their ancestral territory). The boundaries of the study area are the property lines of the university as determined by the 2018 Town of Rindge Plat map and sales history (Figure 1). Located in the southwestern New Hampshire section of the Hillsborough Inland Hills and Plains within the U.S. Forest Service's Vermont-New Hampshire Uplands, Franklin Pierce University's campus (42°46'45.0"N 72°03'20.7"W) in Rindge, New Hampshire is dominated by small rocky hills and moist depressions. The average annual temperature in Rindge is 7.36 °C (45.24°F) and average annual rainfall is 1206.245 mm (47.49 in).

The land is situated within both the Millers River and Contoocook River watersheds and makes up the headwaters of both which flow into the Connecticut and Merrimack rivers, respectively. Wetlands can be found at the margins of most forests in this area. These include peatlands, scrub-shrub marshes, and a red maple basin swamp, not included in this study. In addition, there is a large spruce swamp, which is explored in this study.

Upland soils in this region are mostly well-drained, shallow, stony and formed from glacial tills and glacio-fluvial deposits as a result of the Laurentide glacial retreat approximately 5,000 years ago. The terrain is hilly, having a range in altitudes from 315m to 360m above mean sea level.

The study site lies within the hemlock-white pine-northern hardwood forest system with the dominant natural community in this system being the Hemlock-Beech-Oak-Pine forest (HBOP), a very common, broadly defined transitional community found on glacial till in mid elevations in central and southern New Hampshire. There are several other natural vegetation community types covering these 1120 acres, including but not limited to: Semi-Rich Mesic Sugar Maple Forest, Hemlock-Beech Northern Hardwood Forest, Dry Red Oak and White Pine, Hemlock-White Pine Forest, Black Spruce Larch Swamp, and Red Maple Swamps. Most of the area is currently used as a college but formerly for grazing livestock as evident on antique maps.

Thirty-nine 20-m x 20-m plots were measured in 2003, 2008, and 2017-2018. These plots were previously established by Singleton and Koning in 2003 for a buckthorn study based on forest type and former land use (Koning and Singleton 2013). Plots were categorized into forest type based on species distribution and dominance and prior land use. These plots were then recategorized into generalized forest types. Four generalized forest types were represented by these plots – deciduous, coniferous, mixed, and spruce swamp. For example, A1C consists of 18 trees with Sugar Maple and White Ash as the dominant species (relative abundance is > 10 percent). This would categorize the forest as Semi-Rich Mesic Sugar Maple Forest and then recategorize it as a deciduous forest. Using this method resulted in twenty-two mixed forest plots, one coniferous forest plot, seven deciduous forest plots, and nine spruce swamp plots (one was not included in calculation due to missing data).

All live trees in the sample plots greater than 10 cm diameter at a height of 1.4 m above the ground (DBH) were measured using a dbh measuring tape during the Fall 2017/Spring 2018 semesters. Trees with DBH < 10 cm were not measured since they normally contribute a small amount of biomass. Aboveground biomass in respective measurement plots was calculated with the following allometric equation: $[\ln(biomass) = b_0 + b_1 \ln(dbh)]$, using coefficients based on species identification developed by Jenkins et al. (2003) for individual aboveground tree biomass estimation. Estimated AGB in each plot was converted to AGC stock using the conversion factor of 0.5.

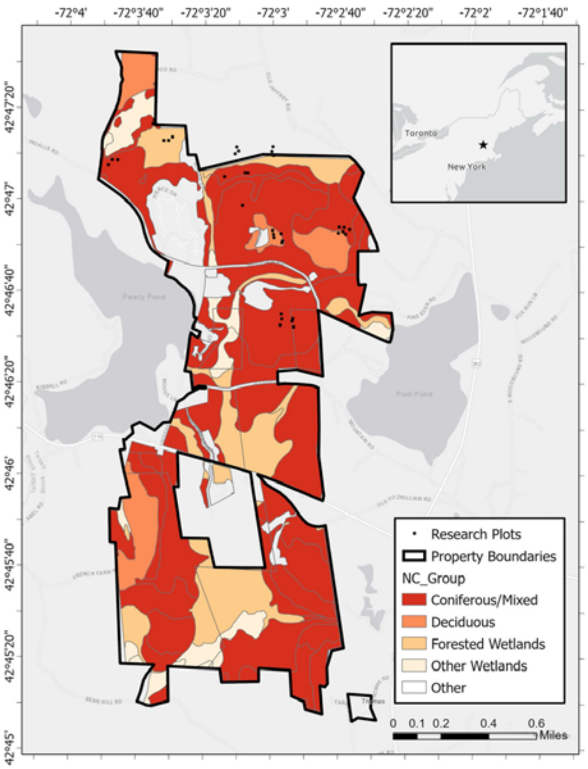

Figure 1. Map of property boundaries and plot locations.

The available aboveground carbon stock was estimated by applying allometric equations to the inventoried individual trees, averaging the Carbon per plot per forest type, and extrapolated to the entire area. Plot totals were calculated and combined into totals for the forest type. This total was divided by the number of plots to get the average Carbon per plot per forest type. Each plot is roughly one-tenth acre, so this was multiplied by 10 to get average carbon per forest type per acre. Plots were extrapolated to the full-acre area, which was then applied to the total number of acres of this kind of forest, as determined by remapping (Figure 1) in a geographic information system to produce carbon-stock estimates in each of the stratified forest types.

The map to determine forest type acreage was created based on examination of the 2011 New Hampshire land use land cover maps, a natural community classification map, and aerial photography interpretations. Aerial photography (0.30-meter, 4-band) was sourced from the

2015 High Resolution Orthoimages for New Hampshire by the U.S. Geological Survey on GRANIT captured on May 6, 2015 with Microsoft UltraCam and Eagle (UCE) large format digital camera and corrected for atmospheric errors (New Hampshire GRANIT 2001).

Results

Fifty-eight acres of FPU land are deciduous Sugar Maple/Beech/Birch, including plots A1C, A1M, A1T, B1C, B2T, B3M and B3T; 238 acres are coniferous Hemlock-Spruce Hardwood, including plot D3T; 153 acres are Spruce Swamp, including all of the E plots; 427 acres are mixed Hemlock/Beech/Oak/Pine, including all remaining plots; and the remaining 244 acres are developed land, or wetlands (Figure 1).

Nineteen canopy tree species were recorded in the forest, 80 percent of which are deciduous. Among the study species, red maple (n = 361), spruce (n = 337), white pine (n = 104), hemlock (n = 88), and sugar maple (n = 57) were the five most abundant trees, collectively representing more than 80 percent of the total sample. Mean dbh ranged from 10.9 cm to 39.85 cm for species in the study with white pine having the largest mean dbh followed by hemlock (25.9 cm), yellow birch (26.6 cm), white ash (24.1 cm), and red oak (30 cm). The range of dbh values varied widely by species in the analysis, with white pine showing the largest variation across its respective range.

In this study, all live trees with a dbh >10 cm were included in the analysis. A total of 1,156 individual live trees were sampled throughout 39 plots. Of the 1,156 individual trees, 27.71 percent were Red Maple and 30.70 percent were Spruce. Table 1 shows the total aboveground carbon per species. For example, Red Maple as a species has the most aboveground carbon at 52,235.90 kg due to it being the most populous species. Table 1 also shows the average aboveground carbon per individual. For example, Red Oak averaged the most at 229.24 kg and Grey Birch averaged the least at 19.48 kg.

TREE SPECIES	**C (KG)**	**#**	**AVERAGE C (KG) STORED PER TREE**
BALSAM FIR	844.41	19	44.44 ± 31.62
BEECH	781.21	20	39.06 ± 20.47
BLACK BIRCH	2578.51	31	83.18 ± 122.45
BLACK CHERRY	4465.81	35	127.59 ± 122.16
GRAY BIRCH	38.95	2	19.48 ± 0.9
HEMLOCK	10507.01	88	119.40 ± 144.35
HORNBEAM	95.82	4	23.95 ± 4.25
OSTRYA	200.60	4	50.16 ± 13.69
PAPER BIRCH	815.62	9	90.62 ± 70.91
RED MAPLE	52235.91	361	144.69 ± 165.09
RED OAK	4584.86	19	229.24 ± 233.71
SPRUCE	15733.66	337	46.69 ± 35.13
SUGAR MAPLE	6997.55	57	122.76 ± 140.14
WHITE ASH	10649.75	47	226.59 ± 235.65
WHITE PINE	43649.76	104	416.71 ± 387.21
YELLOW BIRCH	4013.29	18	222.96 ± 179.31

Table 1. Total Aboveground Carbon stored per tree species.

Calculations were made two ways. First, the total carbon stored in living aboveground biomass as of 2018 in each forest type was calculated. Table 2 displays the average and total per generalized forest type. The mixed forest contains an average of 4,500.68 ± 1,217.85 kg of aboveground carbon per plot for a total of 99,014.99 kg C in 22 plots. Figure 2 graphs the carbon per plot and the means. Extrapolated out over 427 acres, the mixed forest type on campus totals 19,217.91 metric tons of carbon stored. The coniferous forest plot contains a total of 5,942.42 kg C (n=1). While this is the highest average carbon per plot stored, the low sample number and fact that this plot has never been harvested could influence the results. Extrapolated out over 238 acres, the coniferous forest type on campus totals 14,142.97 metric tons of carbon stored. The spruce swamp contains an average of 3,353.37 ± 1,305.73 kg of carbon per plot with a total of 26,826.93 kg C in 8 plots. Extrapolated out over 153 acres, the spruce swamp forest type on campus totals 5,130.65 metric tons of carbon stored. The deciduous forest contains an average of 3,772.63 ± 10,68.84 kg of carbon per plot from a total of 26,408.41 kg C in 7 plots. Extrapolated out over 58 acres, the deciduous forest type on campus totals 21,88.13 metric tons of carbon stored. This equals a grand total of 40,679.66 metric tons of carbon stored in the aboveground biomass of the forests on campus.

Forest Type	**Total C (kg)**	**# of Plts**	**C (kg)/plot**	**Acres**	**C Tot (metric tons)**
Mixed	99014.9	22	4500.68 ± 1217.85	427	19217.91
Conifer	5942.42	1	5942.42	238	14142.97
Spr Swamp	26826.9	8	3353.37 ± 1305.73	153	5130.65
Deciduous	26408.4	7	3772.63 ± 1068.84	58	2188.13
TOTAL	158192.62	38		876	40679.66

Table 2. Carbon storage in each forest type.

Next, the total carbon in the 38 research plots was calculated at 1581.93 metric tons; that is a carbon density of 41.63 metric tons per acre. Extrapolating that out over the 876 forested acres leads to a total of 36,467.88 metric tons on campus. While this is a generalized calculation, it is important for comparison to see if there is a difference in doing it by straight acreage or by forest type. The difference between the calculations is 4,211.78 metric tons of carbon with a higher number accounting for the forest type method.

However, an analysis of variance (ANOVA) test shows there is not a strong significant difference ($p = 0.0597$) among the four generalized forest types. There is a 5.97 percent chance that the differences between the average carbon stored in each forest type is due to random chance. This supports preliminary research that suggested aboveground live carbon is not significantly different between coniferous and deciduous stands around this location (Suzzi 2017). The type of forest did not have a significant effect on the amount of carbon stored because there is a lot of variation within each forest type and not a lot of variation between the forest types ($F=3.67$).

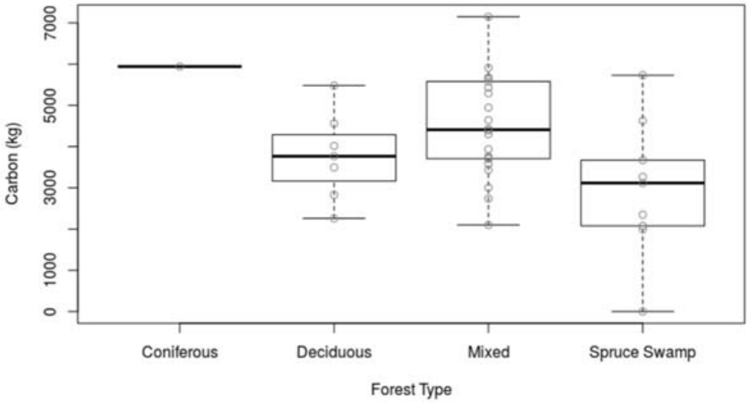

Figure 2. Carbon in each plot, grouped per generalized forest type.

Discussion

The average old growth forest in northern New England contains total carbon stocks of approximately 79 metric tons per acre for northern hardwoods and 98 metric tons per acre for softwoods, of which 54 percent and 47 percent was in aboveground biomass, respectively (Hoover et al. 2012). The carbon density at Franklin Pierce University at 46.44 (forest type) - 41.6 mt/ac (straight acreage) is less than the average old growth northern New England forest. Extrapolating Hoover's AGC calculation out over 876 acres gives an estimate of 38,544 mt – overestimating the actual storage by 2,135 mt if using the forest type calculation or underestimating the actual storage by -2,076.12 mt if using the straight acreage calculation. Therefore, using Hoover's estimate to calculate the carbon storage of local forests would give fairly accurate results.

Limitations of this study include the forested wetland South of Rt 119 which is listed as Spruce Swamp on the map; however species composition information is not available. Furthermore, the logged areas South of Rt 119 have no plot data. These areas were estimated based on aerial photography, however plots located in this area would provide more accurate data. In addition, developed areas and non-forested wetlands were not included in this study, but are still important in the carbon budget with wetlands storing large amounts of carbon in the soil because anoxic conditions slow decomposition and lead to the accumulation of organic matter.

In addition, soil and detritus are globally important reservoirs of carbon, containing three times more carbon than the atmosphere (Lal 2004). While these numbers were not calculated for this study, the soil carbon can provide an important source or sink because soil disturbance releases CO_2. Interestingly, forest floor carbon is significantly different between hardwood and softwood forests (Hoover et al. 2012). Therefore, calculating soil carbon based on forest type would be an excellent continuation of this study.

Factors discussed in this study that affect forest carbon budgets include region and forest type. Other factors that could influence the tree growth and subsequent carbon storage include the past land use, site conditions (including soil and other abiotic factors), forest age, and the neighboring trees. Neighborhood traits that impact competition include root and crown distributions, wood density, specific leaf area, and maximum height (Kunstler et al. 2016). Additionally, clearing and abandonment have favored well-dispersed early successional species (such as red maple) and an associated decline in longer-lived shade-tolerant species (Dyer 2006).

The obtained results may have some practical significance for forest management. Carbon accumulation slows after 200 years, which means the forests on campus are still accumulating carbon but will start to slow down if not managed. While past studies found that prior land use and forest succession in this area does not change the amount of carbon storage (Rodrigues 2017), changing and current land use does affect carbon storage. Specifically, reforestation of the land on Ingalls Road since the 1940s increased the amount of carbon sequestered on campus. To further increase sequestration, the University could allow afforestation of grassy areas, prevent conversion of forests to non-forest, and improve forest management practices. Afforestation of grassy areas will show significant gains in sequestered carbon in 20-30 years. Increasing productivity through forestry practices can include weed control, fertilization, and stocking choices.

Forests play an important role in sequestering atmospheric carbon dioxide (CO_2). This study set out to quantify the carbon stored in the forests on Franklin Pierce University's campus. The total aboveground carbon stock of the forest in the study area in 2018 was estimated at approximately 40,679.66 metric tons. While this study answered the original question, it creates more questions. What about the carbon storage of the 244 other acres of land? What about the carbon sequestered belowground? How can researchers use emerging remote sensing to validate this data? This research lays the foundation for further forestry and carbon storage research to be conducted within this region, and this baseline may serve as a valuable reference guide to not only track the change in carbon stocks to reduce net emissions from deforestation and degradation, but also to enhance carbon sequestration through campus tree harvest planning.

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