Biomass of Black Birch Trees in Black Rock Forest, Cornwall, New York



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ABSTRACT

Forests store and cycle most of the earth's terrestrial biomass, and therefore play a major role in the global carbon cycle. When measuring carbon storage in a forest, it is first necessary to calculate the total forest biomass, and then extrapolate carbon storage from the carbon concentrations of the trees. A study of changes in composition and biomass in Black Rock Forest, located in Cornwall, New York, suggests that the emergence of the black birch species as a major component of the understory could lead to changes in carbon storage in Black Rock Forest. This thesis tests the only known equation for estimating the biomass of black birch trees, as well as a general equation for estimating the biomass of all hardwood trees, to determine the accuracy of these equations in estimating the biomass of black birch trees in Black Rock Forest. Newly measured biomass values from seven black birch trees of varying diameter at breast height (DBH) are compared to the estimated biomass values from the two equations. Statistical analyses are performed to determine the accuracy of the known equations in estimating biomass for the black birch population in Black Rock Forest. It has been found that the existing equation for estimating the biomass of black birch trees is accurate for trees with a DBH greater than five inches, but inaccurate for smaller trees. A new equation has been developed that is accurate for all trees sampled in this study. This equation can be used in future studies of the biomass of black birch trees in Black Rock Forest.

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Introduction

The measurement of forest carbon has become a global interest, as forests store and cycle most of the earth's terrestrial biomass, and therefore play a major role in the global carbon cycle (Dixon et al. 1994). Photosynthetic activity in forests absorbs enormous amounts of atmospheric carbon dioxide each year, mitigating large amounts of carbon dioxide released by fossil fuel combustion (Schuster 2011). According to the Intergovernmental Panel on Climate Change, forest management techniques, including afforestation and reforestation are among the most cost-efficient techniques in mitigating anthropogenic carbon dioxide emissions (IPCC, 2014). Temperate deciduous forests, such as the oak-dominated Black Rock Forest in Cornwall, New York, in the Hudson Highlands region, experienced enormous regrowth following extensive forest clearing in the 1800's, and are now some of the most substantial carbon sinks in the world (Pacala et al. 2001; Myneni et al. 2001). In fact, carbon storage in the biomass of Black Rock Forest nearly tripled between 1930 and 2000 (Schuster et al. 2008).

Throughout most of the Hudson Highlands, oak trees have dominated for most of the last ten thousand years (Abrams 1992; Maenza-Gmelch 1997). Oak forests like Black Rock Forest dominate much of the eastern United States, but a number of threats to oak trees, and the widespread failure of oak regeneration, indicates that the future of these forests is uncertain (Falxa-Raymond et al. 2012). It has been observed that forest composition is changing in Black Rock Forest (Schuster et al. 2008), and this could have serious implications on the carbon storage capacity of the forest. This study tests the accuracy of biomass equations for

black birch trees in Black Rock Forest so that the potential for carbon storage in this forest can be analyzed accurately.

Tree biomass estimation

Carbon content is dependent on biomass within a forest, so it is necessary to have an accurate and practical method of measuring biomass in forests in order to evaluate the carbon storage in any particular forest. It is impractical and unsustainable to fell and weigh an enormous quantity of trees to determine above ground biomass, and so regression equations are used to estimate biomass in forestry and ecosystem studies (Tritton and Hornbeck 1982). Because biomass is related to tree dimensions, regression analysis can be used to estimate the constants or regression coefficients required to calculate biomass without felling a tree and measuring its weight directly (Tritton and Hornbeck 1982).

The United States Department of Agriculture has compiled many studies of biomass that resulted in the development of regression equations for various tree species found in northeastern forests, conducted mostly in the 1960's and 1970's (Tritton and Hornbeck 1982). Tritton and Hornbeck confined the equations included to ones that were developed in forests in North America, north of Georgia, east of Minnesota, and south of New Brunswick Canada (Tritton and Hornbeck 1982). The most common forms of equations used to calculate above ground biomass are exponential ($y = ae^{bx}$), quadratic ($y = ax^2 + bx + c$), and allometric ($y = ax^b$), where the independent variable is a parameter easily measured in the field, such as diameter at breast height (DBH) or a combination of DBH and height (Tritton and Hornbeck 1982). In studies for which expenses and time constraints

prevent the development of a site-specific biomass equation, the known equations can be used to estimate the general aboveground biomass of a population (Tritton and Hornbeck 1982). It is suggested, however, that more than one equation developed by different authors be used to estimate a range of possible biomass values (Tritton and Hornbeck 1982).

While the report from the Department of Agriculture consists of multiple equations for many tree species, there is only one reported equation for the biomass of black birch (*Betula lenta)* (Tritton and Hornbeck 1982). This is an obstacle when studying the above ground biomass in northeastern forests similar to Black Rock Forest, where black birch is emerging as one of the largest populations in the understory (Schuster et al 2008). The existing equation for above ground biomass of black birch trees was developed in a location with similar conditions and species composition to that of Black Rock Forest, and equations from studies at similar latitudes or the same forest type can sometimes produce similar biomass results, but they may just as often produce very different results (Schuster et al 2008, Tritton and Hornbeck 1982). It is not possible to know that the equation developed by Brenneman et al in 1978, in West Virginia, is accurate for the black birch population in Black Rock Forest without testing the equation against additional data (Brenneman et al 1978).

Changes in Black Rock Forest

It is likely that the reason there has been little focus on the development of equations for the biomass of black birch trees is that the species has not been prevalent in northeastern forests until recently. A study of tree populations and environmental change in Black Rock Forest from 1930 to 2006 indicates that while the canopy of the forest has remained primarily red oak (*Quercus rubra*) and chestnut oak (*Quercus prinus*), the understory has begun to transition from an oak and maple mix to a mix of primarily red oak and black birch (Schuster et al 2008). Black birch trees were once a minor component of northern hardwood forests, but are now increasing in density within these forests due to widespread oak and hemlock deaths in the canopy level (Ward and Stephens 1996; kizlinski et al. 2002). Black birch has already become a common component of forest regeneration in southern New England (Kittredge and Ashton 1990). As the black birch population in the understory continues to grow, it may become a significant contributor to forest biomass, rendering it necessary to have an equation that can accurately estimate the biomass of black birch.

Schuster et al. reported that the long-term forest plots in the study of Black Rock Forest composition exhibited mortality in large canopy trees that had been growing at reasonable rates, resulting in a significant decrease in aboveground biomass in those plots (2008). Over the past century, northeastern forests in the United States have experienced the loss of many dominant tree species, including the American chestnut (*Castanea dentate*) American beech (*Fagus grandifolia*) and eastern hemlock (*Tsuga Canadensis*). Now, recent studies document a tripling of oak

tree mortality and a fifteen percent loss of oak canopy biomass in Black rock Forest between 1999 and 2008 (Schuster et al. 2008). There are numerous factors leading to oak tree loss in northeastern forests. The aging of canopy trees, soil acidification, insect herbivory, and pathogens, along with climate change are some factors in changing forest composition (Abrams 1992, Lovett et al. 2006, Cha et al. 2010). Additionally, excessive deer browsing on seedlings and heavy consumption of acorns are greatly reducing oak regeneration rates (Loftis and McGee 1992; Townsend et al. 2002; Tripler et al. 2005). Fire-suppression strategies have also lead to decreasing oak populations. Large fires lead to high tree mortality, favoring fire-resistant species such as oaks. With an absence of fires over long periods of time, oak seedlings are outcompeted by fast-growing, fire-sensitive species such as red maple (Chapman et al. 2006; Drury and Runkle 2006). Another possible threat to oak populations is sudden oak death (SOD), a disease caused in trees by infection with the pathogenic water mold *Pythophthora ramorum* (Garbelotto and Rizzo 2001, Rizzo et al. 2002). According to modeling studies, eastern deciduous forests may be susceptible to SOD (Meentemeyer et al. 2004; Magarey et al. 2005). In as little as fifty years, it is expected that forests of the Hudson Highlands region will have lost more tree species, such as northern hardwoods. The species that are expected to increase in dominance include red maple, yellow poplar, and black birch (Schuster 2011).

In Black Rock Forest, I have observed that most young black birch trees are growing in areas where the canopy is open and light due to the loss of large oak canopy trees. Studies of controlled plots in Black Rock Forest have shown that oak

girdling leads to an increase in the growth rate of black birch trees (Falxa-Raymond et al 2012). Tree girdling is the process of removing the bark, including the phloem, around the circumference of a portion of a tree, resulting in the loss of nutrient transport and the eventual death of the tree. In the past, considerable black birch growth responses have been observed following substantial hemlock decline as well (Kizlinski et al. 2002). It has been found that black birch seedlings are particularly likely to take advantage of the greater availability of nitrogen following oak loss. Oak mortality leads to fewer trees taking up nitrogen, as well as an increased supply of nitrogen belowground due to root decay (Falxa-Raymond et al. 2012). Furthermore, oak mortality leaves openings in the canopy with greater sunlight penetration. With more nitrogen accumulating in their leaves, black birch trees are able to take greater advantage of the increased light penetration to drastically increase growth rates (Falxa-Raymond et al. 2012).

Implications of changing forest composition

Black Rock Forest acted as a carbon sink for most of the twentieth century and is still capable of sequestering carbon, but the deaths of canopy trees and changes in species composition suggest substantial future changes in the carbon storage of the forest (Schuster et al. 2008). For example, the increase in red maple and black birch populations in the understory could result in a forest that will store much less carbon (Schuster et al 2008). Red oak trees on long term plots in a study by Schuster et al. increased in biomass at a rate more than twice the rate that red maple and black birch trees of the same initial size gained biomass (Schuster et al

2008). Deciduous tree biomass consists of approximately 0.5 grams of carbon for every gram of wood (Birdsey 1992). Tree species that grow at a much slower rate than the current canopy trees will store significantly less carbon. It is also important to note that the full grown oak trees that have died contained significantly more biomass than the black birch seedlings growing in their place. The average tree biomass in the highlands is 380 kilograms (Schuster 2011), while the biomass of black birch trees with a diameter at breast height (DBH) of about 5.5 inches, a relatively large tree size for the understory, has been found to be less than 100 kilograms.

Oak mortality may not only have impacts on forest carbon cycles, but also on forest nitrogen cycles. The loss of oaks from Black Rock Forest has significantly altered nitrogen cycling dynamics, with important implications for plant nutrient uptake (Falxa-Raymond et al. 2012). Oak forests feature particularly high retention of atmospherically deposited nitrogen (Lovett et al. 2004). Oak tree leaves and litter have specific qualities that affect carbon and nutrient cycling, slowing decomposition and nitrification (Finzi et al. 1998; Lovett et al. 2004). Black birch seedlings are nitrogen foragers, and play a role in the distribution of nitrogen in the forest ecosystem (Crabtree and Bazzaz 1992). If northeastern deciduous forests transition from oak forests to forests dominated by black birch trees, these forests may no longer retain carbon as effectively (Falxa-Raymond et al. 2012).

An accurate allometric equation is important in understanding the roles that black birch trees may play in chemical cycling in Black Rock forest and similar northeastern forests, which could have implications not only in carbon

sequestration and nitrogen retention, but also in forest management strategies. A recent study tested the accuracy of known allometric equations for the biomass of red oak and chestnut oak trees in Black Rock Forest (Hirshan 2013), but no studies have been performed to evaluate the accuracy of the known equation for the biomass of black birch trees (Brenneman et al 1978). Disturbance history, successional age, and community composition all influence carbon storage in a forest over time, but there are few site-specific equations that account for changes in species composition and reactions to environmental change (Ryan et al 1997, Caspersen et al 2000, Brown 2002). Therefore, it is important to test these equations as forest compositions change. An accurate allometric equation can be used in determining what role black birch trees may play in forest carbon and nitrogen cycles.

In this study, total biomass data were collected from seven black birch trees of varying diameter at breast height (DBH) in Black Rock Forest. These data served to test the accuracy of the published allometric equation for estimating the biomass of black birch trees (Brenneman et al 1978), as well as a published allometric equation for the biomass of general hardwood trees (Monteith 1979). It was expected that the existing equation for the biomass of black birch trees would be accurate and could be used to extrapolate the cumulative biomass of black birch trees in Black Rock Forest, as well as to estimate the amount of carbon stored in these trees. Statistical analyses revealed that the published equations are not accurate for trees with a DBH less than five inches, and that the equation for the general hardwood equation is particularly inaccurate for trees with a DBH greater than ten

inches. The observed data were used to generate a new allometric equation that can be used to estimate the biomass of black birch trees in Black Rock Forest.

Methods

Overview

Black Rock Forest is a northeastern temperate deciduous forest located in Cornwall, New York, in the Hudson Highlands region New York State. The 1550 ha (3,830-acre) preserve has a mixed hardwood composition with a canopy of about 67% oak and 33% non-oak trees. The canopy is dominated by red oak and chestnut oak, and the understory is dominated by red maple (Schuster et al. 2008). Air temperatures are seasonal, ranging from a mean of -2.7°C in January to 23.4 °C in July. The average annual precipitation is 1200 mm (NOAA 2002). The forest has over one hundred woody plant species, including fifty tree species.

In this study, total of seven black birch trees were felled in Black Rock Forest, ranging in DBH from 0.6 inches to 15.67 inches (Table 2). There is a significant gap in data for trees ranging in DBH between 1.45 inches and 5.55 inches, as well as between 9.72 inches and 15.67 inches. With more time, one tree with a DBH of approximately three inches and one with a DBH of approximately twelve inches would have been felled. Each black birch tree was felled in an area where black birch growth occurs due to natural conditions, rather than human disturbance. The trees were weighed in the field, and then samples of the stem were dried in a lab. Trees with a DBH greater than five inches were weighed with accuracy to the nearest 0.1 pounds, and smaller trees were weighed with accuracy to the nearest 0.1

grams. The drying factor calculated from these samples was used to determine the observed dry weight of each tree. The observed dry weight was then compared to the estimates from existing equations for biomass, and statistical analyses were performed to determine the accuracy of the known equations for black birch trees and for general hardwood trees at this site (Brenneman et al 1978; Monteith 1979).

Tree felling

Seven black birch trees ranging in diameter at breast height from 0.60 inches to 15.67 inches were felled. The trees used in this study were selected from regions with natural openings in the canopy due to the deaths of large oak canopy trees. Clearings from roads and construction in the forest were strictly avoided when selecting a tree. The locations of felling were distributed throughout much of the forest, and each tree was at least ten meters from the nearest trail or gravel road. Most black birch trees used in the study were found at elevations at least three meters higher than the nearest stream.

The diameter at breast height, 1.37 meters from the base of the tree on the uphill side, was measured in the field before each tree was felled. DBH measurements were precise to the nearest tenth of an inch. Black Rock Forest staff used heavy machinery such as tractors and chainsaws to fell each tree with a DBH greater than four inches, and a small handsaw was used to fell smaller trees. Once each tree was felled, the height was measured using a measuring tape that was stretched from the lowest cut on the tree to the tip of the stem. The height of the stump of the tree was measured and added to the total height measurement. The

diameter of each stump was also measured so that the volume of the stump ($2\pi r^2$) could be calculated. The biomass of the stump could later be calculated through proportions. Trees with a DBH greater than five inches were sliced into manageable sections in the field and the wet weight of each section was measured using a digital scale suspended from a tractor to determine the total wet weight of each tree. Trees with a DBH less than five inches were quickly returned to the lab where they were sliced into manageable sections and weighed on a digital top-loading Metler model PB5001 scale.

Calculating biomass

Four samples of stem were weighed separately in the field and then placed in a drying oven in the lab for several days. Oven-dry weight is used as a dependent variable in calculating observed biomass because it is a replicable, constant base for comparison within and among tree species (Tritton and Hornbeck 1982). Once it was determined that the stem sections were dry, the dry weights were recorded. The quotient of the dry weight and the weight wet was calculated as a drying factor, which was then multiplied by the total wet weight measured in the field to calculate total dry aboveground biomass (Table 1). The estimated aboveground dry biomass is then calculated from the equation, biomass = $(1.6 * DBH^{2.7})/2.2$ (Brenneman et al 1978). A general equation for the estimation of the biomass of hardwood trees is, biomass = $5.5-(0.33*DBH) + (0.0065*DBH^2)$ (Monteith 1979). This equation will also be used to estimate the biomass of each tree. Diameter at breast height is the preferred independent variable to use in

developing allometric equations, rather than height, because it is challenging and time consuming to make accurate measurements of height in the field (Tritton and Hornbeck 1982). Diameter at breast height can be measured from the ground at eye level, using only a DBH measuring tape.

No calculations of carbon content in each tree were performed in this study, as this study aimed only to test the accuracy of the known allometric equations for biomass (Brenneman 1978; Monteith 1979). However, samples of each tree felled in this study have been stored for future research on carbon content. Because carbon content is dependent on biomass, the carbon storage in the black birch population of Black Rock Forest may be extrapolated in future studies (Birdsey 1992).

Step 1	Step 2	Step 3	Step 4	Step 5
Total wet weight measured in field	Sum of stem sample wet weights	Sum of stem sample dry weights	Drying Factor	Total above ground dry biomass
TotalWW	SampleWW	SampleDW	$DF = \frac{SampleDW}{SampleWW}$	TotalAGB = TotalWW*DF

Table 1: Calculating observed aboveground dry biomass.

Analysis

The estimated biomass values from the known equation for the biomass of black birch trees were then compared to the measured biomass. The data were compared in a plot of measured versus predicted biomass values (Figure 1), as well as in a paired bar graph (Figure 2). The observed data were also plotted against the exponential allometric curve from the known equation for the biomass of black birch trees (Figure 3) (Brenneman et al 1978).

The data were then also compared to the predicted biomass values from an equation for biomass of general hardwood trees (Monteith 1979). The data were again compared in a plot of measured versus predicted biomass (Figure 4), and in a paired bar graph (Figures 5). A plot of observed data points against the polynomial allometric curve for biomass of general hardwoods was also made (Figure 6).

In the plots of measured biomass data against allometric curves, R^2 values were calculated and used to determine the correlation between predicted and measured biomass values. A new regression equation for the biomass of black birch trees in Black Rock Forest was developed using the measured biomass data (Figure 7).

Results

Data are limited, but it appears that the known allometric equation for biomass of black birch trees is accurate for trees with a DBH greater than five inches, and less accurate for trees with a DBH less than five inches (Table 2) (Brenneman et al 1978). Figure 1 shows a linear correlation between the observed and predicted

biomass values (Brenneman et al. 1978) with the linear equation, Predicted = 0.9(Measured) + 2.0, and an R^2 value of 0.999 (Figure 1). The trend line, with a slope less than one and a vertical shift of about two, indicates that the predicted values from the known allometric equation (Brenneman et al. 1978) will be greater than the observed values up until the observed value is about thirty kilograms, at which point the known allometric equation will underestimate the observed biomass (Figure 1). This, however, is not the case for the data collected. Table 2 and Figure 2 show that the existing allometric equation for black birch biomass underestimates biomass values for every tree felled to date. The allometric curve (Brenneman et al. 1979), however, produces an R^2 value of 0.999, indicating a strong correlation with the measured biomass data (Figure 3).

DBH (in)	Wet Weight (kg)	Stem Drying Factor	Observed Dry Weight (kg)	Brenneman-Predicted Biomass (kg)	Monteith-Predicted Biomass (kg)
0.60	0.9	0.49	0.4	0.2	1.9
0.85	1.9	0.52	1.0	0.5	1.3
1.45	5.8	0.59	3.4	2.0	2.1
5.55	151.6	0.56	84.9	71.7	88.5
8.53	415.6	0.59	245.2	224.9	240.4
9.72	582.4	0.54	318.4	314.6	322.1
15.67	2017.7	0.61	1230.8	1134.4	909.9

Table 2: For each tree felled, DBH, wet weight, drying factor, and observed and predicted dry biomass are shown

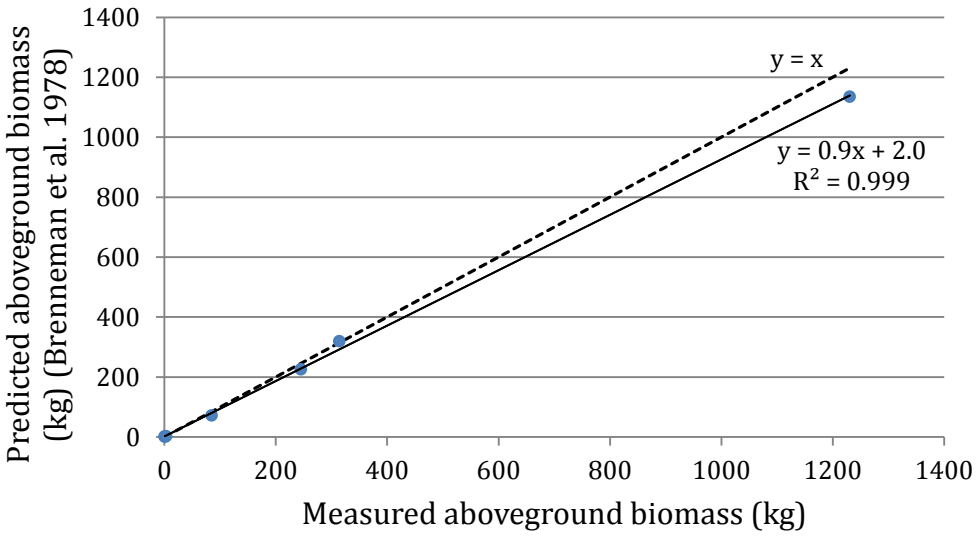


Figure 1: Observed vs. estimated aboveground dry biomass for the seven trees felled to date (Brenneman et al 1978).

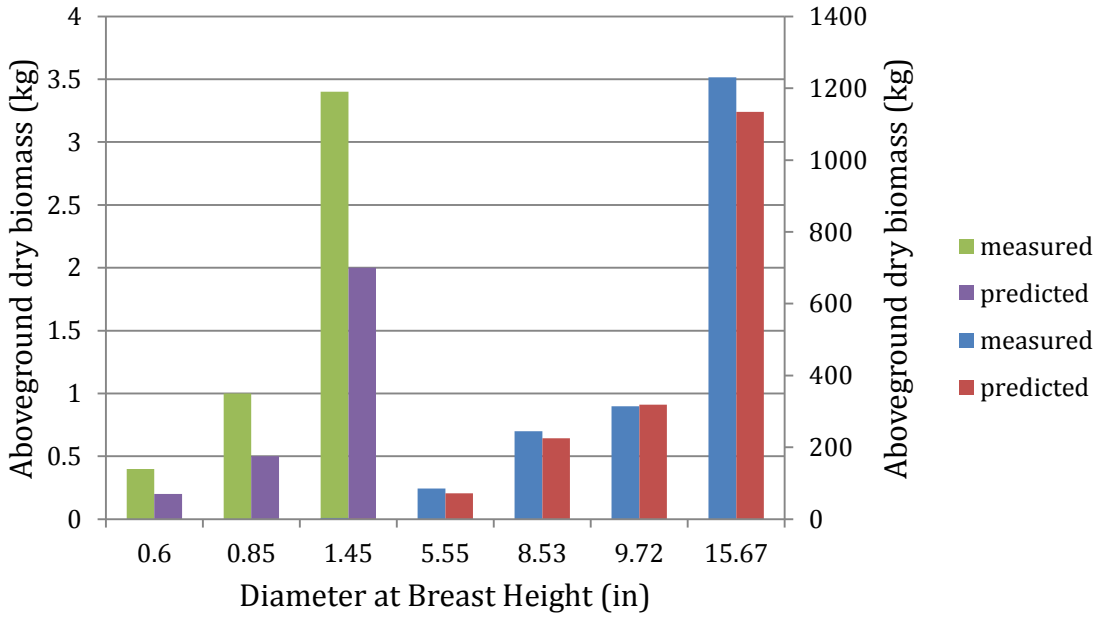


Figure 2: This paired bar graph of the measured biomass vs. predicted biomass from Brenneman et al. (1978). The primary vertical axis shows the scale for the biomass of trees with a DBH < 5 inches, and the secondary axis shows the scale for biomass of trees with a DBH > 5 inches.

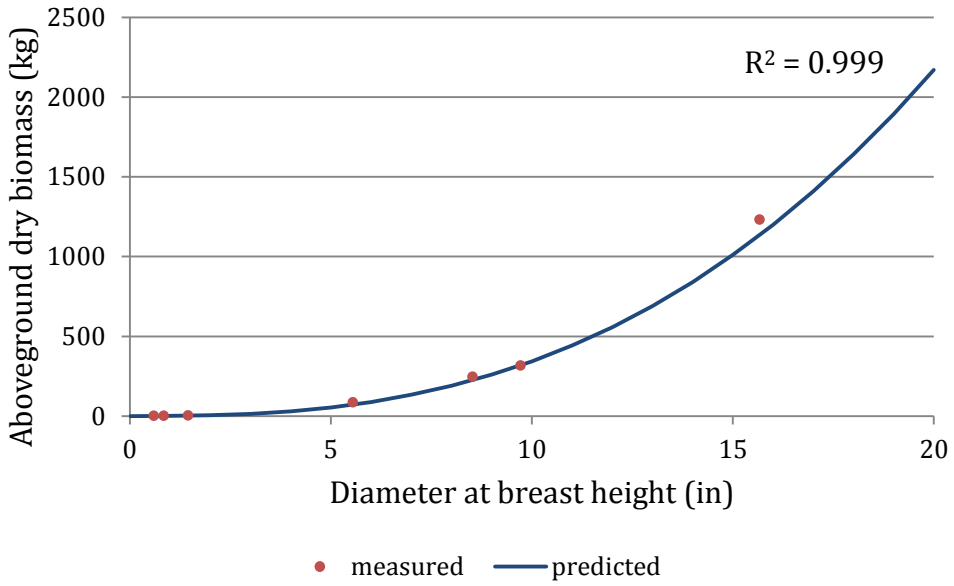


Figure 3: This graph shows the observed biomass data plotted against the allometric curve for the published equation for biomass of black birch trees (Brenneman et al 1978).

Figures 4, 5, and 6 show that the polynomial allometric equation for the biomass of general hardwood trees has a strong correlation with the observed data. Figure 4 shows that the plot of measured versus predicted biomass (Monteith 1979) is significantly far from the line y = x. Figure 5 shows large error between predicted and observed values, particularly for the trees with a DBH less than five inches and greater than ten inches. Although an R^2 value of 0.988 was calculated for the data collected, it is clear that the equation for biomass of general hardwood trees will increasingly underestimate biomass as DBH increases. The equation for general hardwood trees follows a polynomial curve, while the biomass data collected follow an exponential curve (Figure 7).

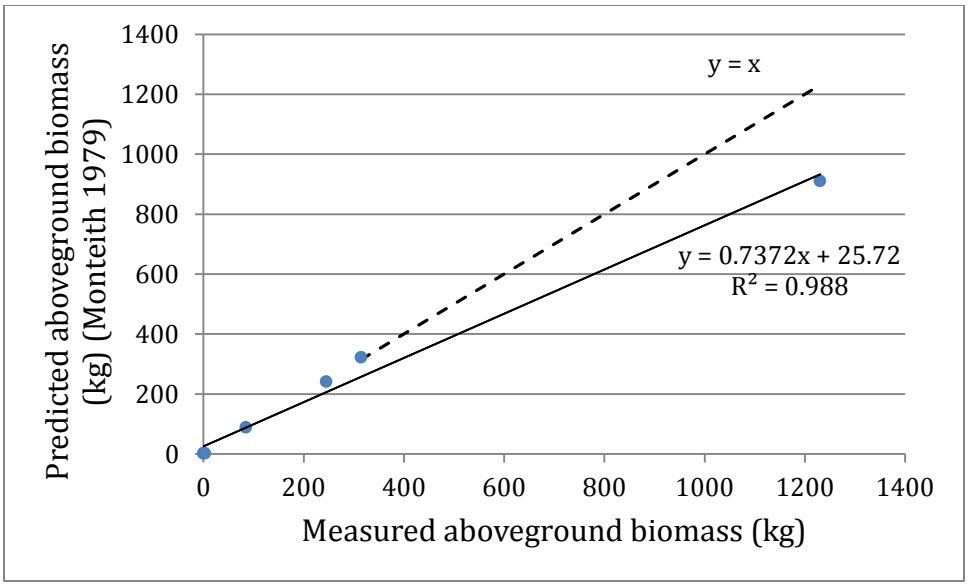


Figure 4: Measured vs. predicted aboveground dry biomass for the seven trees felled. The predicted values are calculated from a published equation for biomass of general hardwood trees (Monteith 1979).

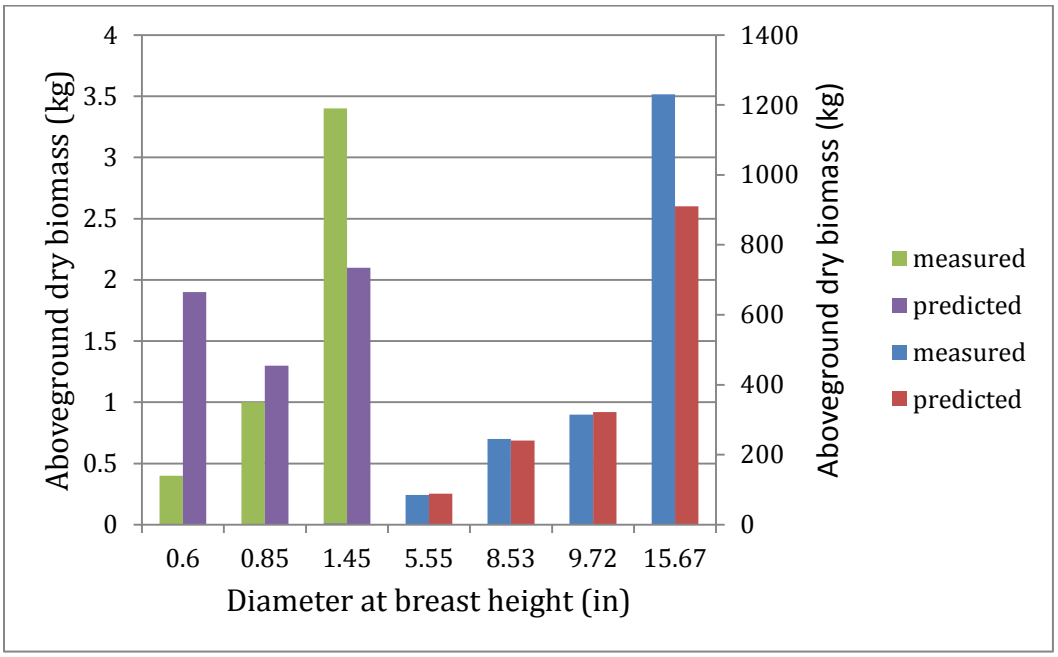


Figure 5: This paired bar graph of the measured biomass vs. predicted biomass from Monteith (1979). The primary vertical axis shows the scale for the biomass of trees with a DBH < 5 inches, and the secondary axis shows the scale for biomass of trees with a DBH > 5 inches.

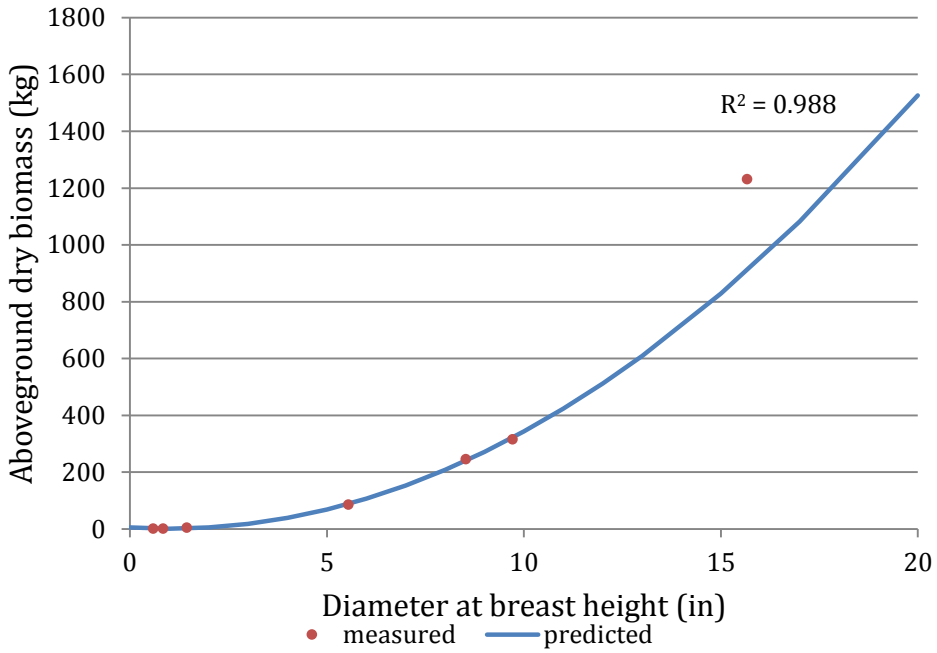


Figure 6: This graph shows the observed biomass data plotted against the allometric curve for the published equation for biomass general hardwood trees (Monteith 1979).

Based on the comparisons of observed data to predicted values, it was concluded that a new allometric equation should be developed that is accurate for black birch trees in Black Rock Forest. Figure 7 shows an exponential regression for the measured biomass data. The equation developed in this study shows that the dry above-ground biomass of black birch trees in Black Rock Forest can be calculated as, biomass = $1.4*DBH^{2.4}$.

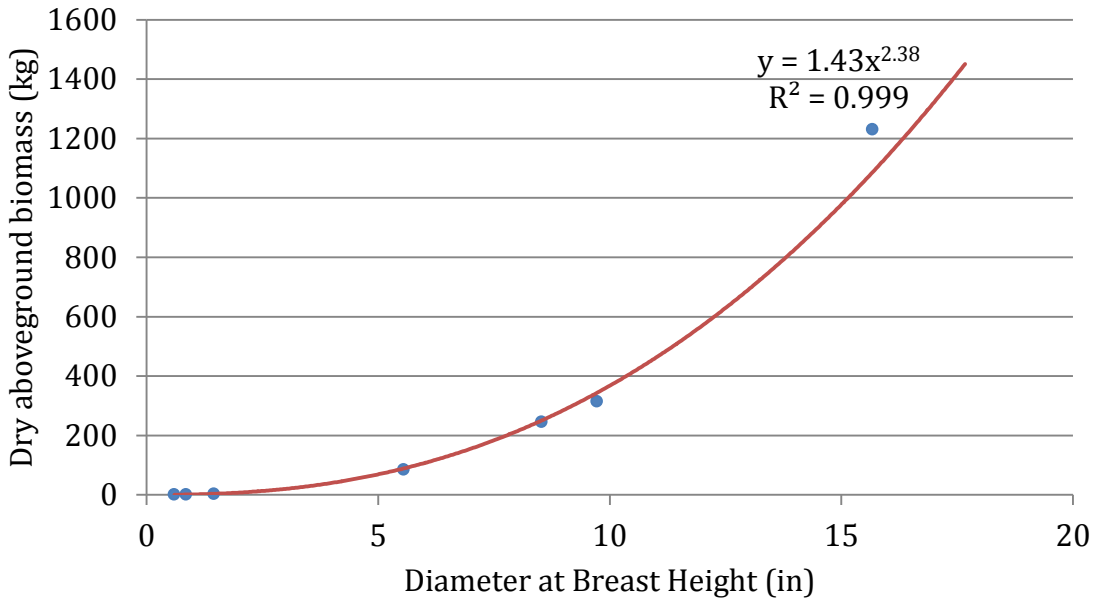


Figure 7: This graph is a regression model for an equation for biomass, calculated from the observed data.

Discussion

Figures 2 and 5 show the substantial difference in biomass values between large trees with a DBH greater than five inches and small trees with a DBH less than five inches. The published equation for biomass of black birch trees (Brenneman et al. 1978) underestimates biomass of smaller trees by nearly half the observed biomass (Figure 2). These data support the statement that the Brenneman equation for biomass of black birch trees is significantly inaccurate for small black birch trees. However, Figure 3 shows that the allometric curve has a strong correlation with the set of collected biomass data. Because trees with a DBH greater than five inches will play a more significant part in forest biomass and carbon storage, the Brenneman equation can be used to reliably predict biomass of black birch trees in black rock

forest, and to extrapolate total biomass and carbon storage in the black birch population.

All data indicate that the equation for biomass of general hardwood trees (Monteith 1979) is not reliable in predicting the biomass of black birch trees in Black Rock Forest. Although an R^2 value of 0.988 indicates a strong correlation between the predicted and measured biomass values, the polynomial shape of the allometric curve will lead to significantly low biomass predictions for the largest black birch trees in Black Rock Forest (Figure 6). This could lead to a substantial underestimation of total biomass and carbon storage in the black birch population.

Although the published allometric equation for black birch trees was found to be accurate for black birch trees in black rock forest, it is still important to note that this equation underestimates biomass for every black birch tree that was felled in this study. Therefore, the equation generated from the biomass data measured in the field may still be the most accurate and reliable equation for predicting biomass of black birch trees in Black Rock Forest (Figure 7). The data used to produce this equation, however, are limited. An equation developed using more data, with fewer gaps in DBH, would be more reliable.

Broader implications of research

An accurate equation for biomass of black birch trees is vital in understanding the effects of the changes in species composition of Black Rock Forest. A reliable allometric equation for biomass can be used to extrapolate total carbon content for each tree in this study. With an estimate of the black birch

population size in Black Rock Forest, further extrapolation could lead to an estimate of total carbon storage in the black birch population of Black Rock Forest. The analyses conducted in this study have shown that the published equation for biomass of black birch trees (Brenneman et al. 1978), as well as the equation produced from measured biomass data (Figure 7), can be used in future studies to determine the biomass, nitrogen retention, and carbon storage within the black birch population. Future studies will determine whether a transition away from an oak-dominated forest, toward a red maple and black birch-dominated forest will have a significant impact on biomass, nitrogen retention, and carbon sequestration rates in Black Rock Forest and similar temperate deciduous forests.

Conclusion

Of the two allometric equations tested, the exponential curve for the biomass of black birch trees is most accurate in predicting the biomass of black birch trees in Black Rock forest. This equation, biomass = $(1.6 * DBH^{2.7})/2.2$, is significantly inaccurate for trees with a DBH less than five inches, but is accurate in predicting the biomass of larger black birch trees, which play a more significant role in carbon sequestration. The allometric equation developed from the data collected in this study, biomass = $1.4*DBH^{2.4}$, may also be used to estimate the biomass of black birch trees in northeastern temperate deciduous forests.

Recommendations

While data are limited in this study, statistical analysis has shown that the published equation for biomass of black birch trees is accurate in estimating the biomass of large (DBH > 5 inches) black birch trees in Black Rock Forest. The equation developed in this study from the measured biomass data may also be used to predict black birch biomass. In order to generate an even more reliable equation than the one developed in this study, more trees of well-distributed sizes should be felled, and an equation should be generated from more data points to eliminate potential error due to small sample size.

If further studies are performed on carbon concentration in black birch trees of varying DBH in Black Rock Forest, the published equation (Brenneman et al. 1978) and the equation developed in this study should be used together to estimate biomass and extrapolate total carbon content for each tree. With an estimate of the black birch population size in Black Rock Forest, further extrapolation could lead to an estimate of total carbon storage in the black birch population of Black Rock Forest. If future studies find carbon concentrations in black birch to be significantly lower than concentrations in the oak canopy species, forest management policies may change in order to promote carbon sequestration in Black Rock Forest. Policies may transition to forest management that encourages oak growth and inhibits black birch growth in locations of oak deaths.

In addition to testing carbon concentrations, further studies may test nitrogen concentrations in black birch trees in order to understand the role that the black birch species plays in the nitrogen cycle in Black Rock Forest. The equation

from Brenneman et al. (1978), and the equation developed in this study, can be used to extrapolate concentrations of any important nutrients and chemicals in the black birch population.

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Appendices

A.

Tree	DBH	wet weight of stem samples	dry weight of stem samples	drying factor
A	0.60	4530.2 g	2499.4 g	0.5398
B	0.9	176.2 g	86.2 g	0.4892
C	1.5	291.7 g	150.5 g	0.5159
D	5.6	823.8 g	1474.6 g	0.5587
E	8.5	4487.0 g	2641.7 g	0.5909
F	9.7	582.6 g	346.3 g	0.5944
G	16	9494.3 g	5793.5 g	0.6102

Figure 8: Calculations of drying factor for each black birch tree.

B.

Tree	Date Felled	DBH (in)	Wet Weight	Stem Drying Factor	Measured Aboveground Biomass (kg)
A	5/1/2015	9.72	1283.9 lb.	0.54	314.578
B	6/9/2015	0.6	872 g	0.49	0.427
C	6/15/2015	0.85	1882.7 g	0.52	0.979
D	7/2/2015	5.55	151.636 kg	0.56	84.916
E	7/2/2015	8.53	916.2 lb.	0.59	245.193
F	8/7/2015	1.45	5809.8 g	0.59	3.428
G	10/9/2015	15.67	2017.700 kg	0.61	1230.797

Figure 9: All calculations of measured biomass from original wet weight measurements measured in the field.

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