Carbon in Coarse Woody Debris on the Long-term Plots of Black Rock Forest, Cornwall, NY

By Emma Hoyt

Columbia College
Department of Evolution, Ecology, and Environmental Biology

Department Advisor: Don Melnick, Department of Evolution, Ecology, and Environmental Biology, Columbia College
Thesis Mentor: Peter Bower, Department of Environmental Biology, Barnard College

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Abstract

A set of methods was created to measure carbon in coarse woody debris and then applied to ten long-term plots in Black Rock Forest. Coarse woody debris is a relatively unstudied carbon pool in the forest ecosystem. Results show that the amount of carbon in coarse woody debris on the plots is on average 55% less than that of a fully mature forest. Carbon in coarse woody debris increased with plot age, indicating that this carbon pool accumulates over time. Carbon per hectare ranged from 4995 to 32,580 kg/ha with the average being 15,545 kg/ha and ranged as a percentage of total plot carbon from 1.63 to 12.39% with the average being 5.08%. The average percentage indicates that where coarse woody debris is concerned, Black Rock Forest has not reached the status of a fully mature forest. Results also showed that the ratio of the two types of coarse woody debris, namely snags and logs, can be used to predict the age of a plot. These data sets, while suggestive of trends, are not of sufficient size to attain statistical significance. However, it is unlikely that further data collection will reverse the trends observed. The creation of these methods is a major step towards measuring the total carbon and carbon sequestration of Black Rock Forest and evaluating its continuing ability as a carbon sink.

Introduction

Black Rock Forest (BRF) is a private, preserved forest located in the Hudson Highlands fifty miles north of New York City (Figure 1). It borders the property of West Point Military Academy in Orange County, New York (Figure 2). It is preserved by a Consortium that is made up of several nearby schools and school districts, universities, museums, and research institutions. The forest consists of 3750 acres of relatively untouched forest. Black Rock Forest was created in 1928 by Ernest Stillman to "illustrate a more efficient means of timber production" (Maher 1996). In 1949 when Stillman died he willed it to Harvard University, which maintained it as a preserve for research rather than for lumber. The administration of the forest was taken over by the Consortium in 1989. Today, the Consortium continues the tradition of maintaining and preserving the forest for research and educational purposes. Scientists and students from Consortium members such as the American Museum of Natural History, Columbia and New York Universities, and many local schools come to the forest to work and learn (Maher 1996). A major question being considered by those scientists who work in the forest today is how to continue managing it for the future.

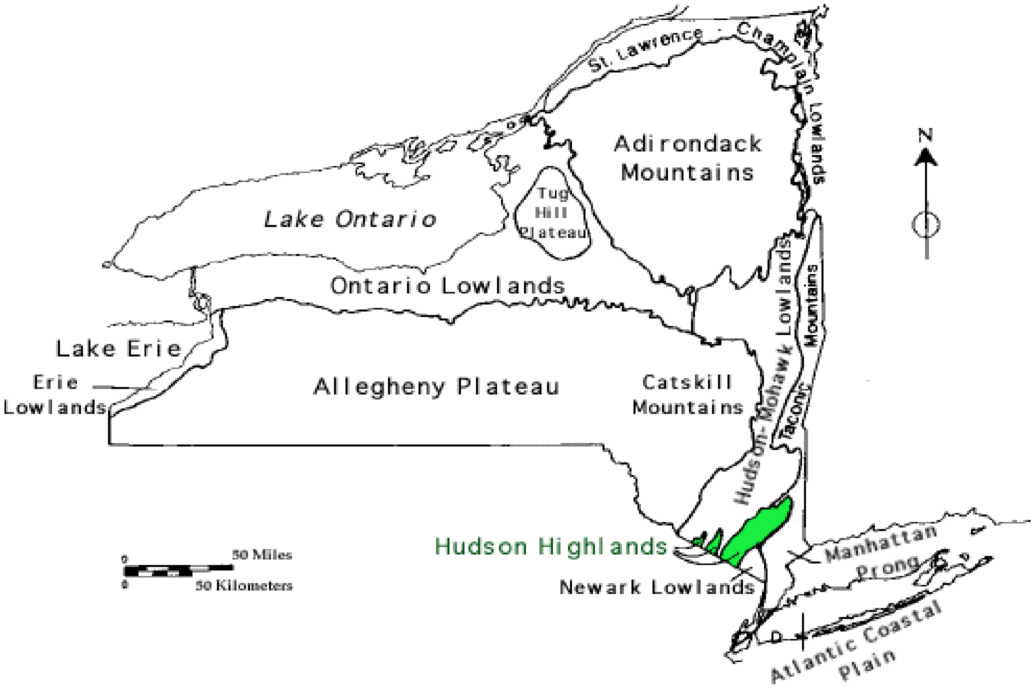

Figure 1. A map of New York State with the Hudson Highlands region shaded in.

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are needed to see this picture.

Figure 2. Map of Black Rock Forest.

The forest is becoming mature. An issue that coincides with this fact is how Black Rock Forest will function as a carbon sink in the future. Trees and other plants sequester carbon through photosynthesis and thus collectively can function as a carbon sink. However, they also give off carbon dioxide through respiration, so that an old-growth forest whose carbon pools are saturated would not take in more carbon than it gives off. A younger, not yet mature forest on the other hand could take in large amounts of carbon per year as its trees grow and woody debris accumulates. Black Rock Forest is in the latter category. Right now it is sequestering carbon at an average rate of 1.85 t/ha/yr (Schuster et al. 2003). Eventually it will reach its limit and be unable to sequester carbon at a net positive rate. Studies are being done at BRF to determine the yearly amount and rate of carbon being sequestered in order to know when they will start to decrease.

There are four pairs of long-term plots in the forest that have been allowed to grow without interference for at least seventy-five years (Figure 3). The four pairs are located

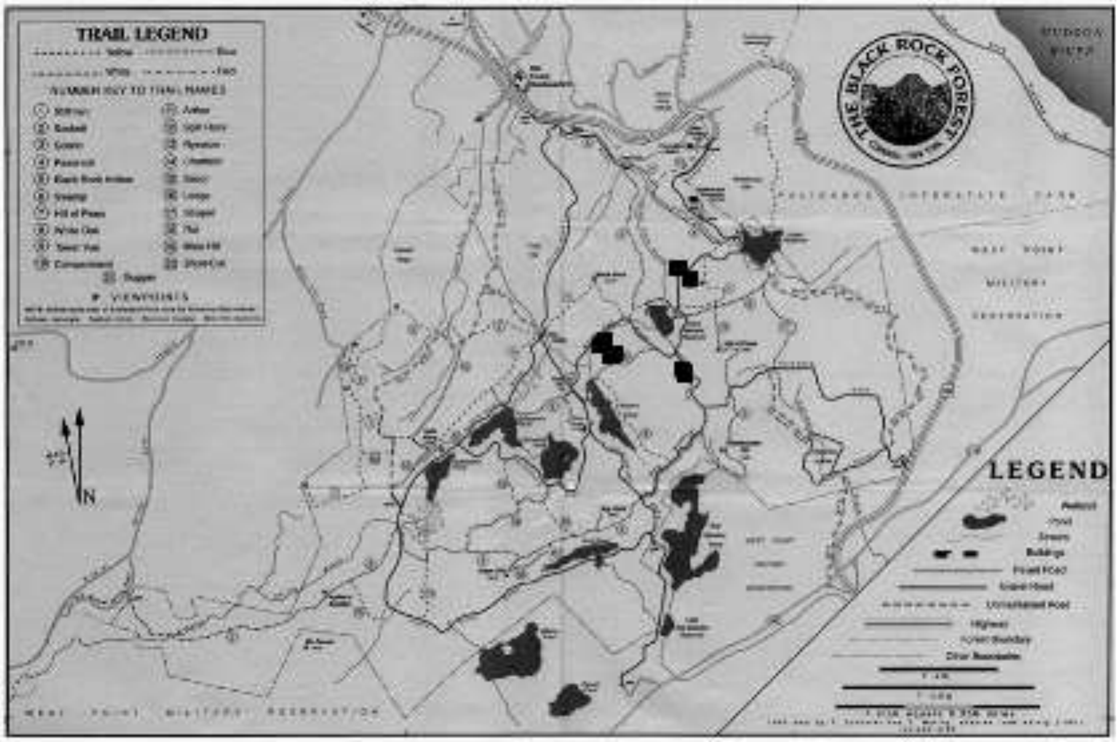

Figure 3. A map of Black Rock Forest with the eight long-term plots' approximate location marked with dark squares. They are not to scale.

on sites entitled Mount Misery, Bog Meadow, Arthur's Brook, and White Oak Trail (named for their proximity to these landmarks in BRF). The Mount Misery plots are 98 years old, Bog Meadow 93 years old, and the plots at Arthur's Brook and White Oak are all 118 years old. Every year since 1931, the diameter (in inches) at breast height (DBH) of the trees on each plot has been measured. One plot of each pair was thinned when the experiment began, and the other, the control, was left as it was in order to observe how fast and abundantly the trees grew over time under different conditions of competition. From the DBH measurements the above-ground-biomass (AGB) as well as the carbon of each tree have been calculated; from these numbers the yearly amount and rate of carbon sequestered on the plot has been determined, and then extrapolated to an average for the entire forest (Schuster et al., 2003). This is feasible because the plots are meant to represent the forest as a whole; presumably what is occurring on the plots is going on everywhere else in the forest (that shares the same ecosystem type). However, since only the aboveground parts of living trees have been studied, this is not a picture of the total carbon in the ecosystem. There are many carbon pools besides the aboveground living stems: “Much of the carbon stored by…temperate forests is not in trees, shrubs, or other aboveground vegetation…only about one third is in vegetation” (Moffat 1997). Thus in order to understand the amount of carbon that is held by the forest, these other pools must be considered, and they are slowly being incorporated into the study.

The carbon study at BRF needs to be extended to other parts of the forest ecosystem – so far the carbon contained in living trees is the only component of the ecosystem extensively studied, with the exception of one study of carbon in the forest soil (Paek 1998). Eventually, all significant carbon pools in the forest ecosystem, such as coarse and fine woody debris, as well as the roots of living trees, must be studied. The carbon pool this project was intended to focus on was woody debris. Relevant literature was provided by Professor Peter Bower, to give some background on how the biomass of living trees is measured, how carbon is measured in organic substances, and the history of Black Rock Forest. The guidelines presented in Harmon and Sexton (1996) was the piece of literature most heavily relied on; they suggested working with fine and coarse debris separately since they require different materials and methods. Due to the time constraint of one summer, it was decided that only one or the other could be measured. Coarse woody debris was settled upon, since it makes up a larger percentage of total ecosystem carbon than fine debris does (Harmon and Sexton 1996).

The carbon in a tree is approximately half of its biomass (Schuster et al. 2003), so in order to find the carbon in the coarse woody debris (CWD), we first had to find the biomass of each piece. Allometric biomass equations for living trees could not be used on CWD because as it decays it loses biomass and carbon, so that finding the equations for living specimens would result in an overestimate of biomass and carbon. In addition, the equations assume that the tree is whole and undamaged, and often CWD comes in the form of broken or not whole pieces of the original tree.

Since mass can be obtained by dividing density by volume, the mass of each piece could be found by calculating the volume and density separately for each specimen and then applying that equation. From the mass the carbon in each specimen could be calculated. The densities would have to be obtained with out using the specimens because the CWD on the long-term plots could not be removed or disturbed. Harmon and Sexton's (1996) guidelines gave three different formulas for calculating the volume of specimens; the one that required the most measurements was chosen since it would be the most thorough – for the reason that dead wood can come in many shapes and forms. Presented here are the study performed and the preliminary results of the analysis of the data that was collected.

Materials and Methods

By definition, coarse woody debris is any piece of dead wood 1.5 meters or larger in length/height and 10 centimeters or more in diameter at the large end (Harmon and Sexton 1996). Five decay classes were defined to classify each specimen, since as the wood decayed, it would lose biomass (Harmon and Sexton suggest this but do not provide any decay classes). The decay classes are as follows: Decay Class 1 specimens are mostly standing (snags), retain many fine twigs and branches and all the bark, have died within last 2 years, and resemble very closely live wood. Decay Class 2 specimens are mostly standing (snags), retain the main branches and most of the bark, and have been dead for approximately 2 - 5 years. Decay Class 3 specimens are mostly on the ground (logs), retain the cylindrical shape, have all or most branches gone, bark mostly gone, and the wood is mostly sound. Decay Class 4 specimens are found on the ground (logs), may have an irregular shape, have no branches or bark, and are mostly soft, fragmenting wood. Decay Class 5 specimens are by definition too decayed to measure: they are all soft, fragmenting wood, have a highly irregular shape that is indistinguishable from the soil in some parts. Thus none of the CWD specimens measured are classified as Decay Class 5, nor can those specimens that would have been classified as Decay Class 5 really be considered CWD anymore (although sometimes it was evident that it once had been). The class is there for completeness, that is it was important to be able to distinguish between what could be measured and what could not so that the most accurate data could be collected. Having the fifth decay class was like having a control to base others against. Later, these decay classes were compared with those of the USDA Forest Service's Forest Inventory and Analysis Program and the two sets were found to be very similar.

Measurements

Each of the eight plots was outlined with measuring tape in order to create an x-y axis to note the location of each specimen. The coordinates were plotted as charts on

Excel to function as maps with coordinates for each specimen, in case it was necessary to find specific specimens again. The maps proved to be very important as the plots had to be revisited several times to seek out specific specimens for various reasons. For each specimen the following information was recorded: specimen number, whether it was a log (at an angle of less than 45 degrees to the ground) or a snag (at an angle of 45 degrees or more to the ground) (Harmon and Sexton 1996), species, decay class, length or height, diameter at the base/large end, midpoint, and top/small end, DBH (if necessary), x- and y-coordinates, and any other pertinent information (Table 1). There was one equation for cylindrically-

shaped specimens that was used primarily (Harmon and Sexton 1996):

$$\text{Volume} = \frac{\text{length}(\text{area}_{\text{base}} + \text{area}_{\text{midpoint}} + \text{area}_{\text{top}})}{6}$$

There was another equation for cone-shaped specimens that was also used when necessary (Harmon and Sexton 1996):

$$V = \frac{\text{length}(\text{area}_{\text{base}} + (\text{area}_{\text{base}} * \text{area}_{\text{top}})^{0.5} + \text{area}_{\text{top}})}{3}$$

Plot:												
spec #	log/snag?	species	lth/ht	lg end D	mdpt D	sm end D	DBH	DC	x-coor (m)	y-coor (m)	Volume	notes

Table 1. Chart used in the field.

To obtain the area of the base, midpoint, and top of each specimen, the diameter of those respective points on each specimen were taken with either a caliper or diameter tape and then put into the equation for the area of a circle: area = πr^2. In the event of an elliptically shaped log, a formula to determine a

round diameter (Harmon and Sexton 1996) was used:

$$d_{round} = \sqrt{(d_{max} * d_{min})}$$

Measurements necessary for the equations were taken whenever possible, and when it was not, measurements that would result in an approximate volume were taken. For example, there were specimens that were not shaped in the usual cylindrical trunk-of-a-tree shape and there were standing specimens that were so tall that the top diameter and sometimes the midpoint diameter could not be reached. For the former situation, an equation for a shape that most resembled the specimen was used (i.e., if a specimen had the rough shape of a quadrilateral, the lengths of its three sides were multiplied). For the latter situation, methods had to be improvised. A sonic height-measuring device was sometimes used to obtain height. Sometimes a snag was leaning at an angle against another tree; for these the Pythagorean theorem was used to calculate the snag's length as the hypotenuse, or right-triangle relationships to estimate length, such as 30-60-90 or 45-45-90. For snags standing up on their own the DBH of the specimen was taken, and the allometric equations were used to calculate the biomass; later on in the experiment percentages of biomass were subtracted from these specimens depending on their decay class. If the specimen was a relatively whole snag and still had its tag number (from the living tree carbon study), only the number and decay class were recorded, and the tree's last living biomass was obtained from the BRF database. As with the specimens whose DBHs were recorded only, these biomasses were adjusted according to decay class.

After all the measurements were obtained and the volumes calculated, density values needed to be obtained for the specimens. Since samples could not be taken from the specimens on the plots, it was decided that a set of density values could be created for every decay class of every species encountered on the plots; this set of values could be referred to and also added to by anyone using these methods afterwards. Samples were taken from specimens in areas surrounding the plots so that they would be from the same environment.

To obtain density, the volume and dry mass of each sample taken had to be calculated. Firstly, the wet weight of each sample was taken. Next it was necessary to obtain the dry weight of each, but since these samples were too large to fit into the ovens in the science center's labs, sub-samples of each sample were taken, weighed wet, and then dried in an oven at the BRF science center's lab. The dry weight of each sample was calculated using the wet weights of both the sample and sub-sample and the dry weight of each sub-sample using the following ratio, where x is the dry weight of the original sample:

$$\frac{\text{wet weight}_{\text{subsample}}}{\text{wet weight}_{\text{sample}}} = \frac{\text{dry weight}_{\text{subsample}}}{x}$$

The volumes of both the samples and the sub-samples were also calculated, and the ratio of sub-sample to sample weight was used to measure the average error of all the volume calculations of the specimens on the plots, since the volumes of the samples and sub-samples had been calculated using the same methodology. This was done by plotting the percentages against each other (percentage meaning the percentage of the whole sample that the sub-sample is) and seeing how well the points fit a line with a slope of 1.

The volume and mass of each sub-sample were used to calculate density values using the following equation:

$$\text{density} = \text{mass} * \text{volume}$$

They were compared to some available values (Elert et al. 2000) and then applied to the original specimens' volumes to get the dry biomass of each specimen on the long-term plots. For those specimens mentioned earlier whose only available measurement was the DBH, their biomasses were adjusted according to decay class with numbers obtained by taking averages from other data (Whittaker et al. '74, Luxford and Trayer 1940). For those classified as Decay Class 1, no change was made, since they had not had enough time to lose a significant amount of biomass. For those classified as Decay Class 2, 1.5% was subtracted for the loss of fine twigs and leaves. For those classified as Decay Class 3, 34.2% was subtracted, and for those classified as Decay Class 4, 60% was subtracted to account for larger and larger amounts of biomass lost.

To obtain the amount of carbon in each specimen, 49.8% of the adjusted biomasses was taken, and then to get the total carbon in CWD on each plot, the specimens' carbon was added up (Schuster et al. 2003). The approximate total ecosystem carbon on each plot and the percentage that CWD makes up in the BRF ecosystem was calculated by assuming the living tree biomass made up a third of the ecosystem's carbon (Schuster et al. 2003, Turner et al. 1993). The carbon in living trees on each plot was multiplied by three to obtain an estimate of the total amount of carbon in the plot, and the percentage of that total that each plot's coarse woody debris accounted for was calculated.

At the end of the summer it was decided that a few more plots of different ages should be studied to see better how the age of a plot affects the amount of CWD and the carbon it contains. In November, two plots, one 39 years old, the other 140 years old, were studied using the same methods created and employed during the summer (Figures 4, 5, and 6).

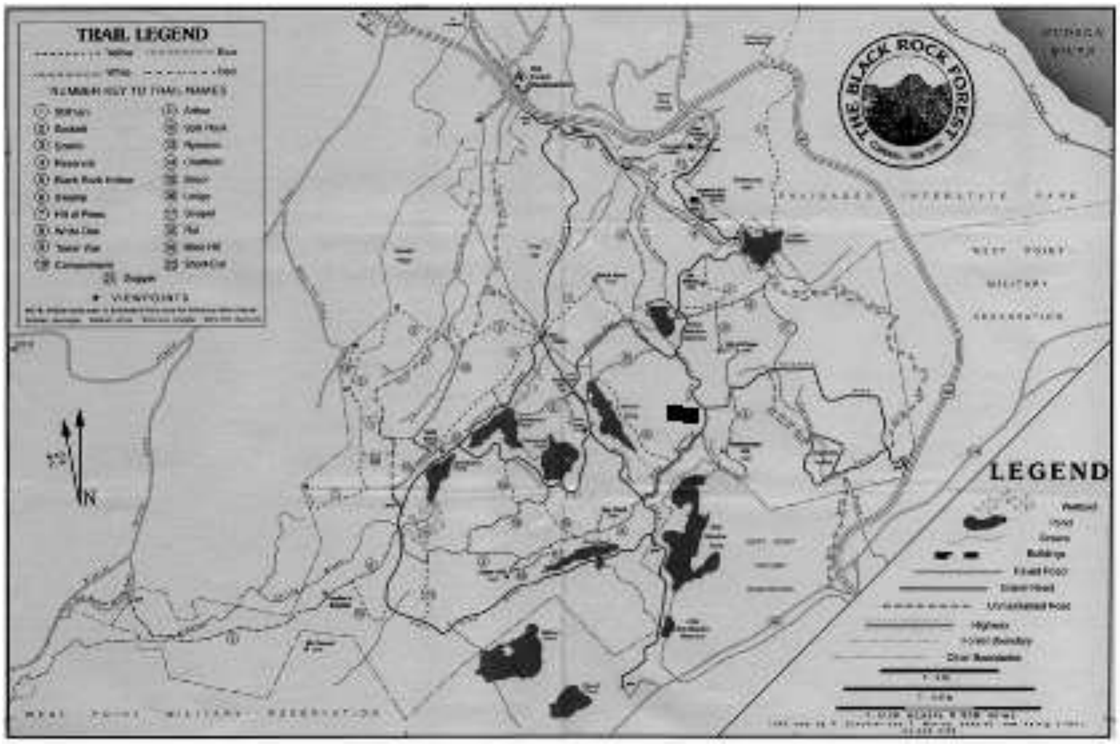

Figure 4. A map of BRF showing the approximate locations of the last two plots studied, marked as dark squares. They are not to scale.

Figures 5 and 6. Maps of the 39-year-old plot (A) and the 140-year old plot (34a) respectively, from Black Rock Forest.

The older plot was discovered to have been thinned at some point in its history after it was measured. These plots were larger compared to the other plots and not evenly shaped, so that a center point had to be randomly chosen and a square marked off in which to work in. This was done by finding something to throw (a stick or rock for example), spinning around a few times with eyes closed, throwing the object up in the air, seeing where it fell. The point where it fell was to be the center of the marked-off square. For these two plots, CWD carbon as a percentage of the total plot carbon could not be calculated because no data on the carbon in the living trees was available.

Results

The coordinates recorded for each specimen (1 point for snags and 2 or more for logs) were used to create maps of each of the eight paired plots with the location of all CWD specimens (Figures 7 through 14). Coordinates were not recorded for the two other plots, so there are no maps for them.

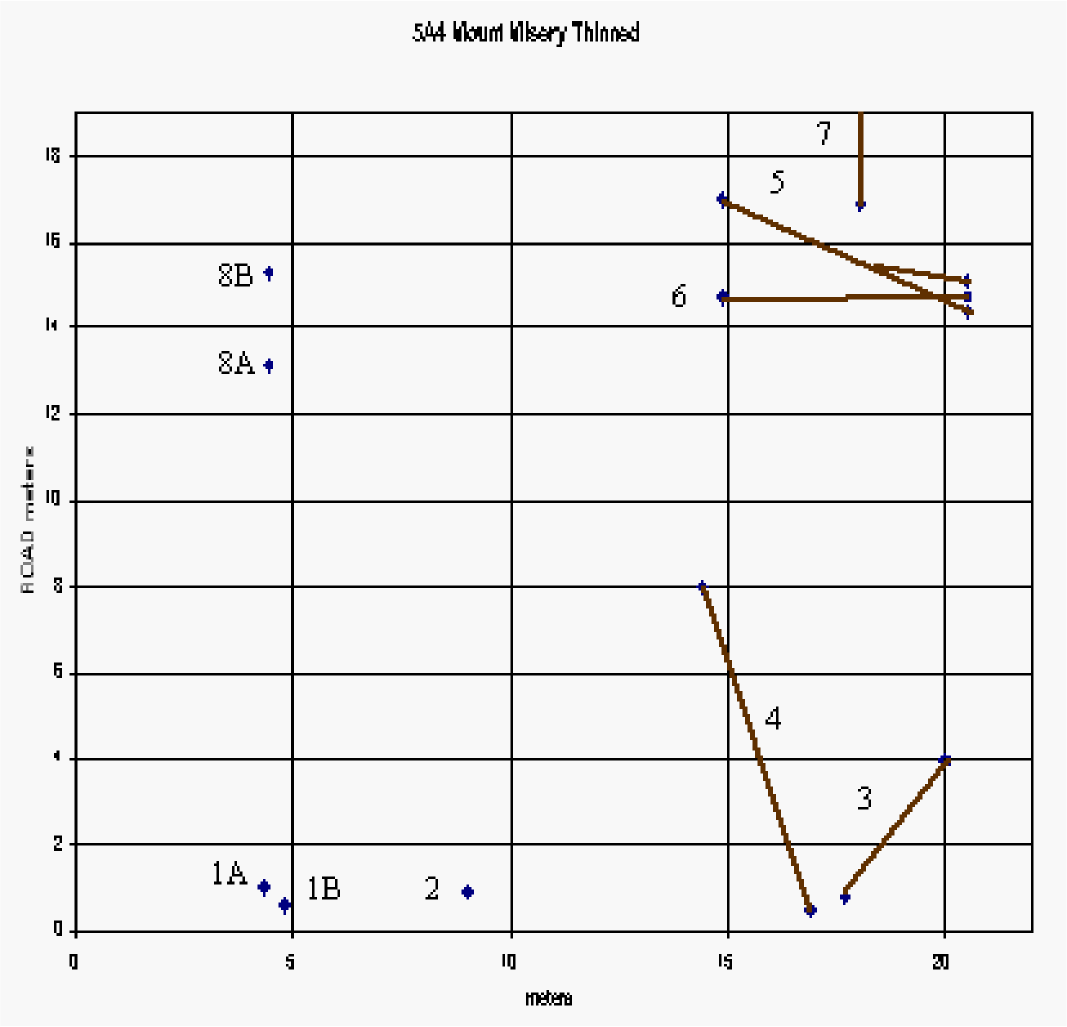

Figure 7. A map of plot 5A4, Mount Misery thinned, with the location of each specimen.

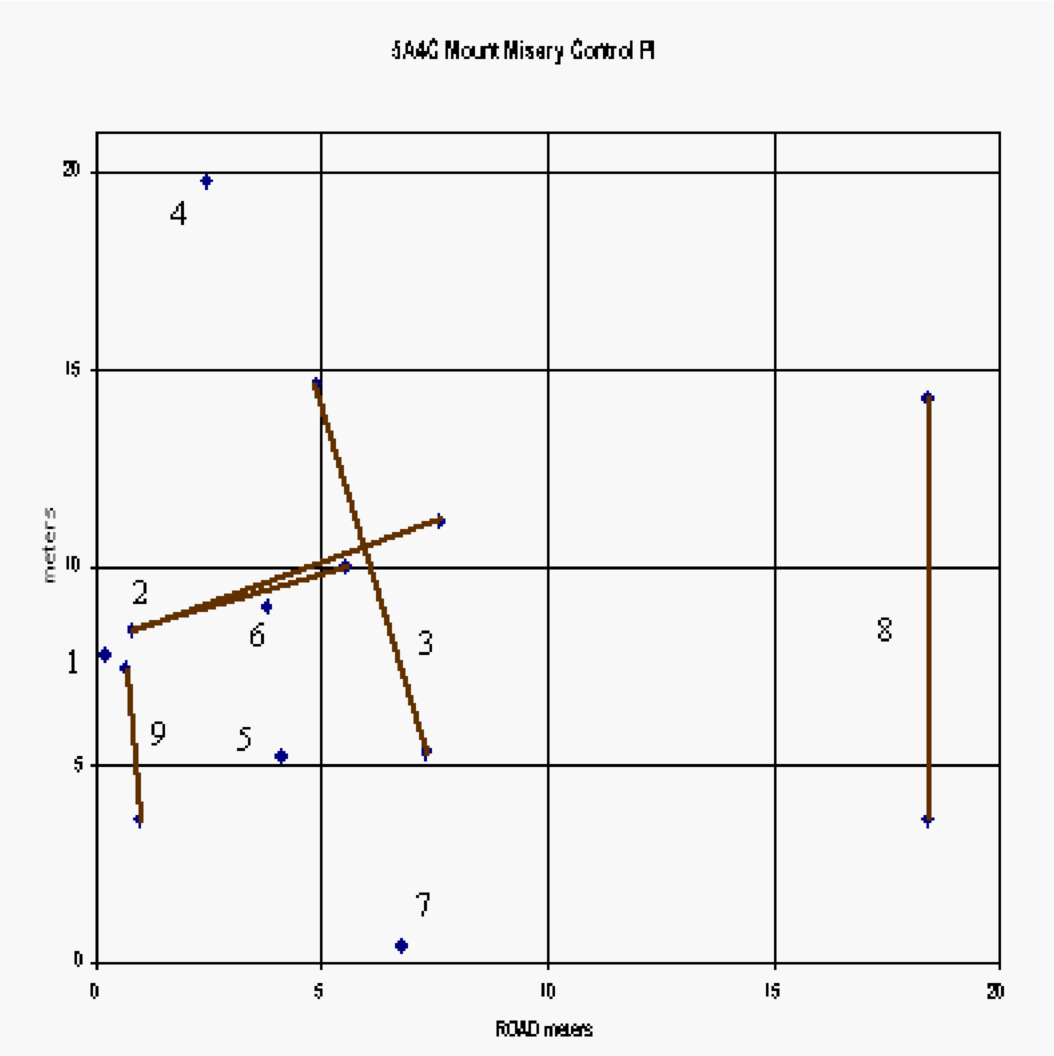

Figure 8. A map of plot 5A4C, Mount Misery control, with the location of each specimen.

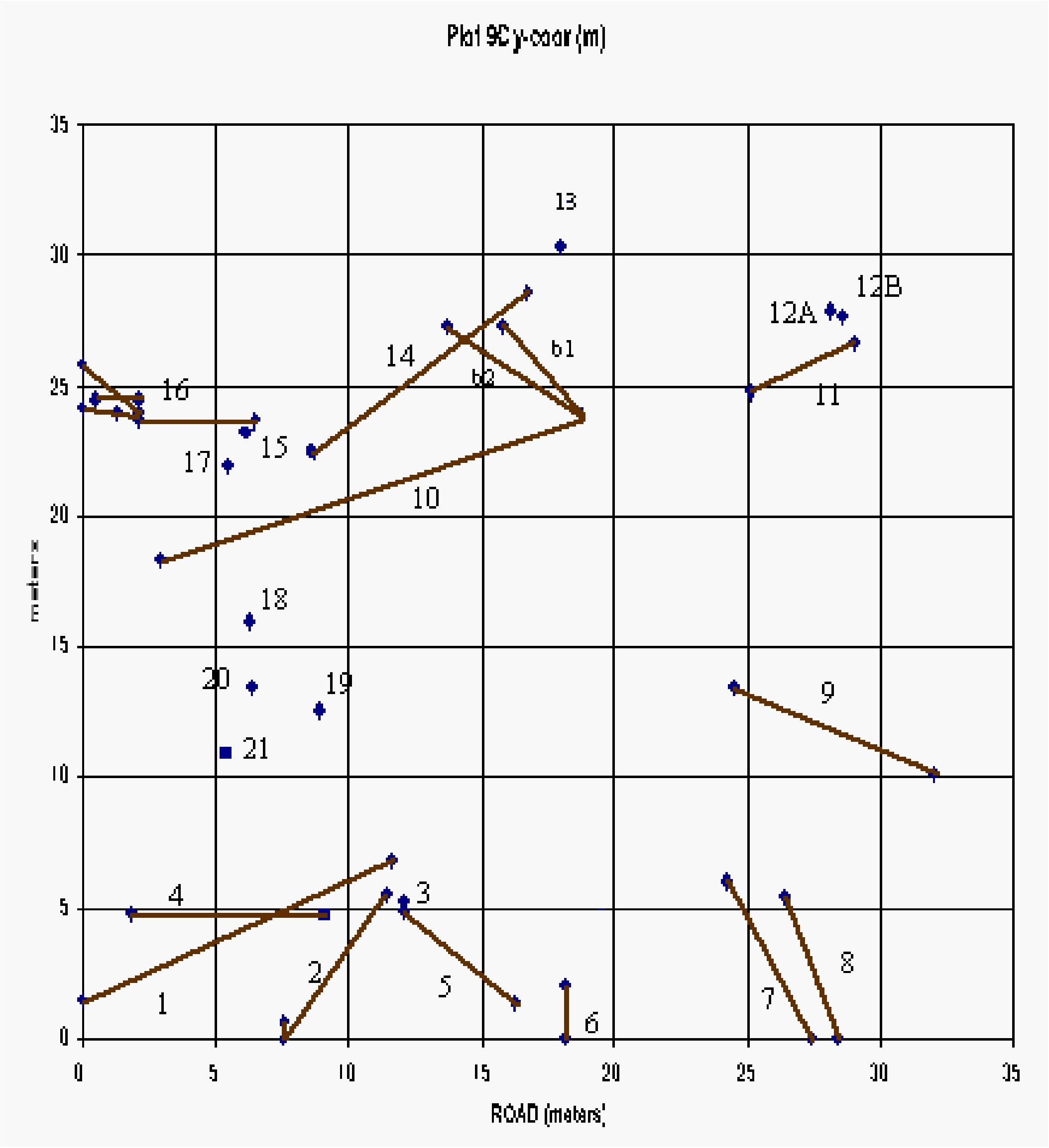

Figure 9. A map of plot 9C1, Bog Meadow thinned, with the location of each specimen.

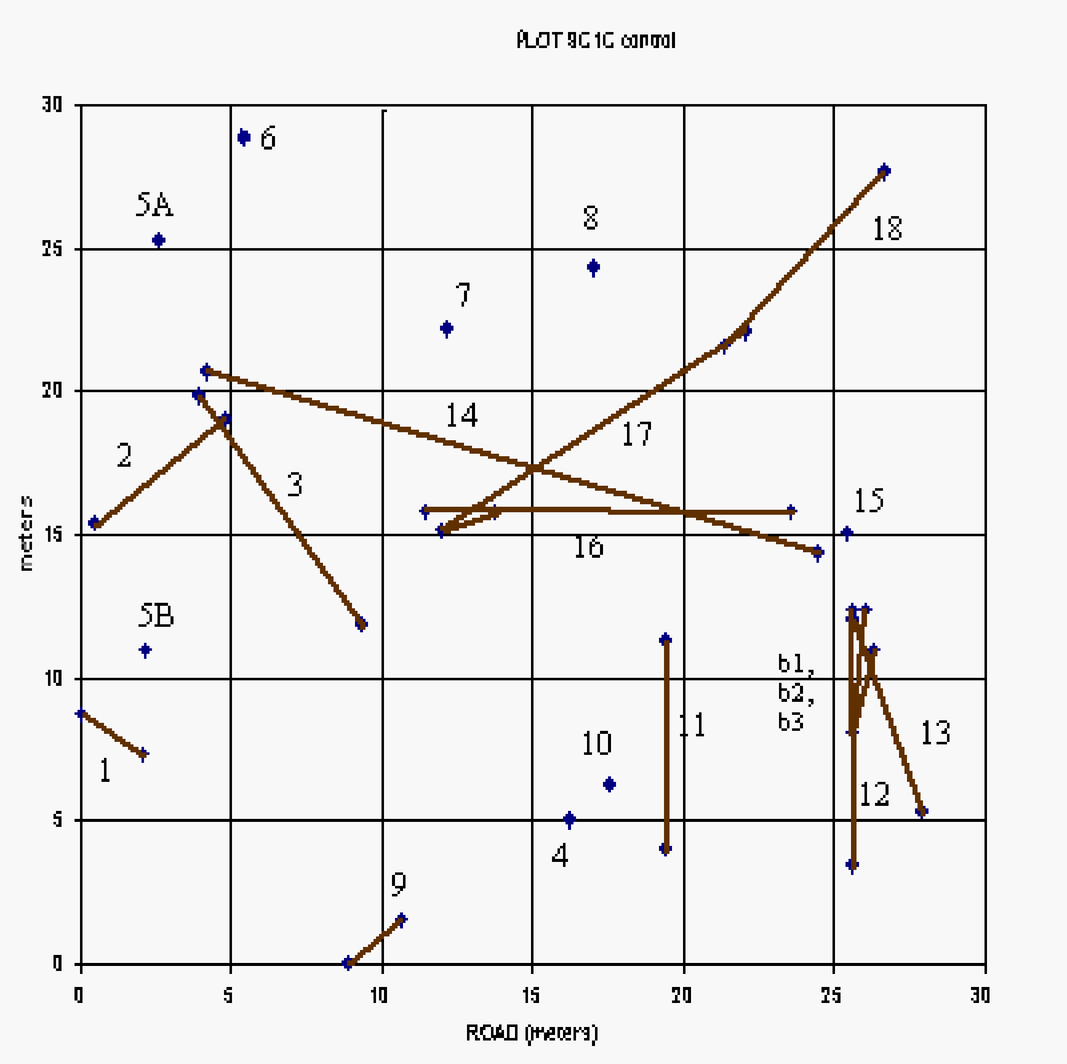

Figure 10. A map of plot 9C1C, Bog Meadow control, with the location of each specimen.

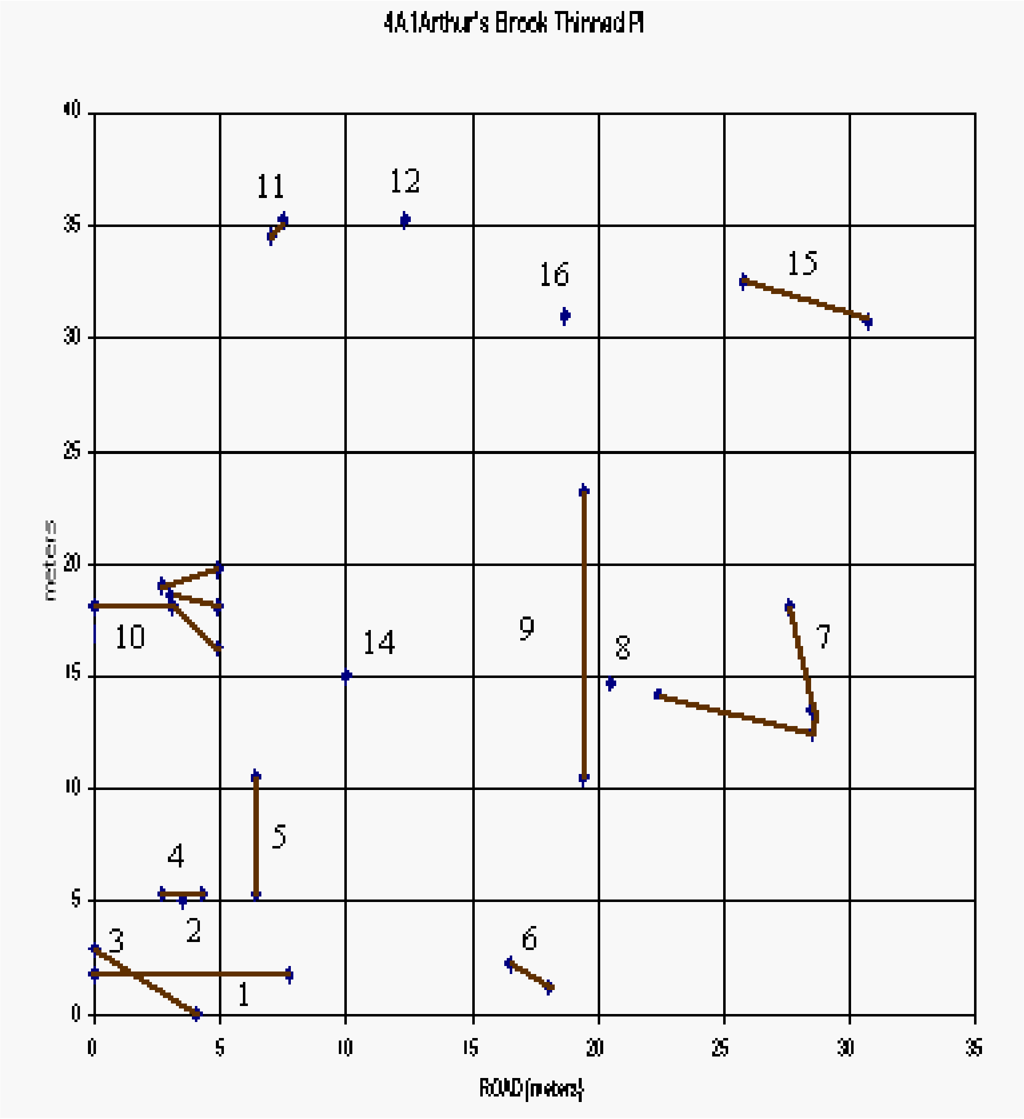

Figure 11. A map of plot 4A1, Arthur's Brook thinned, with the location of each specimen.

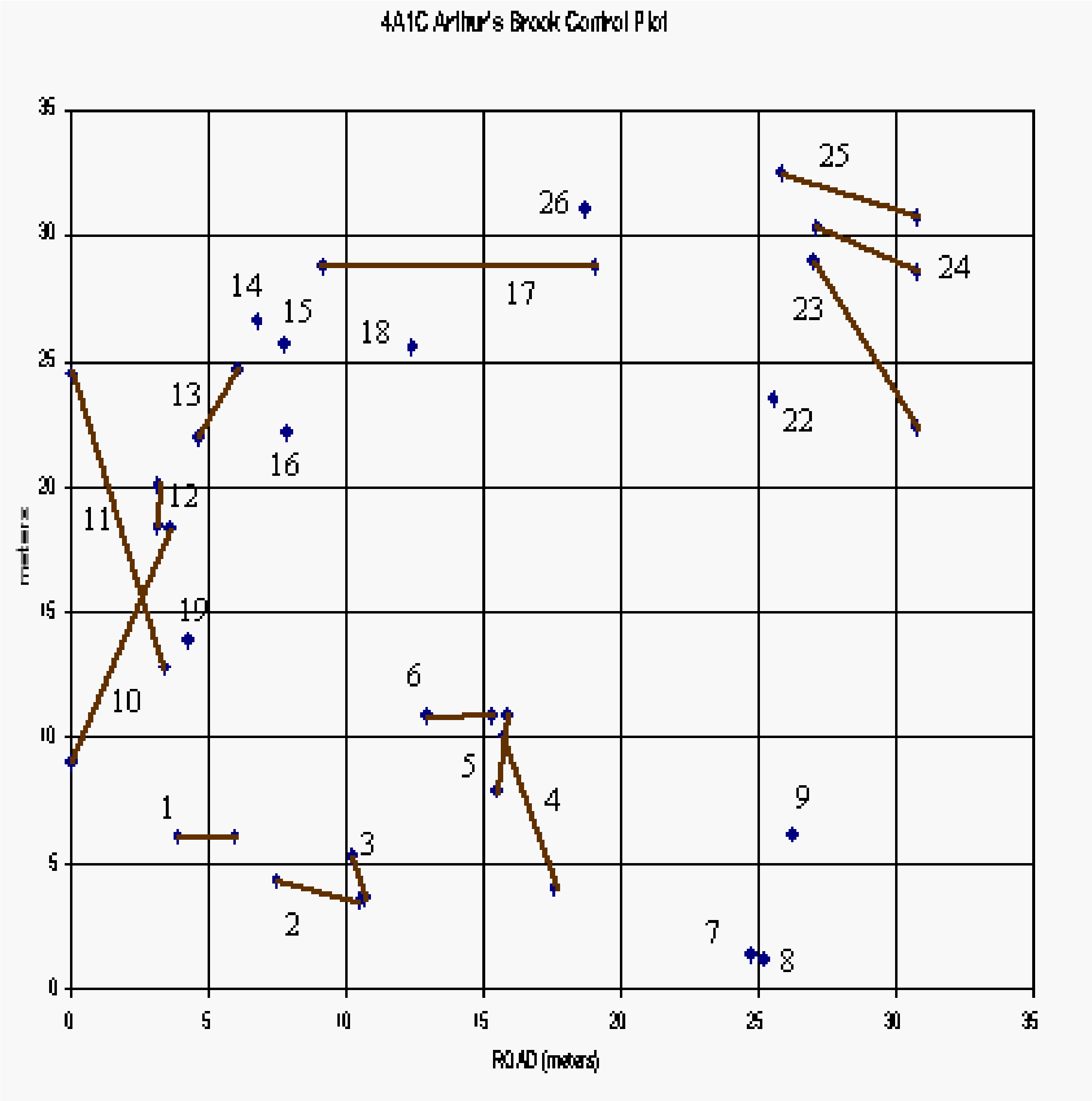

Figure 12. A map of plot 4A1C, Arthur's Brook control, with the location of each specimen.

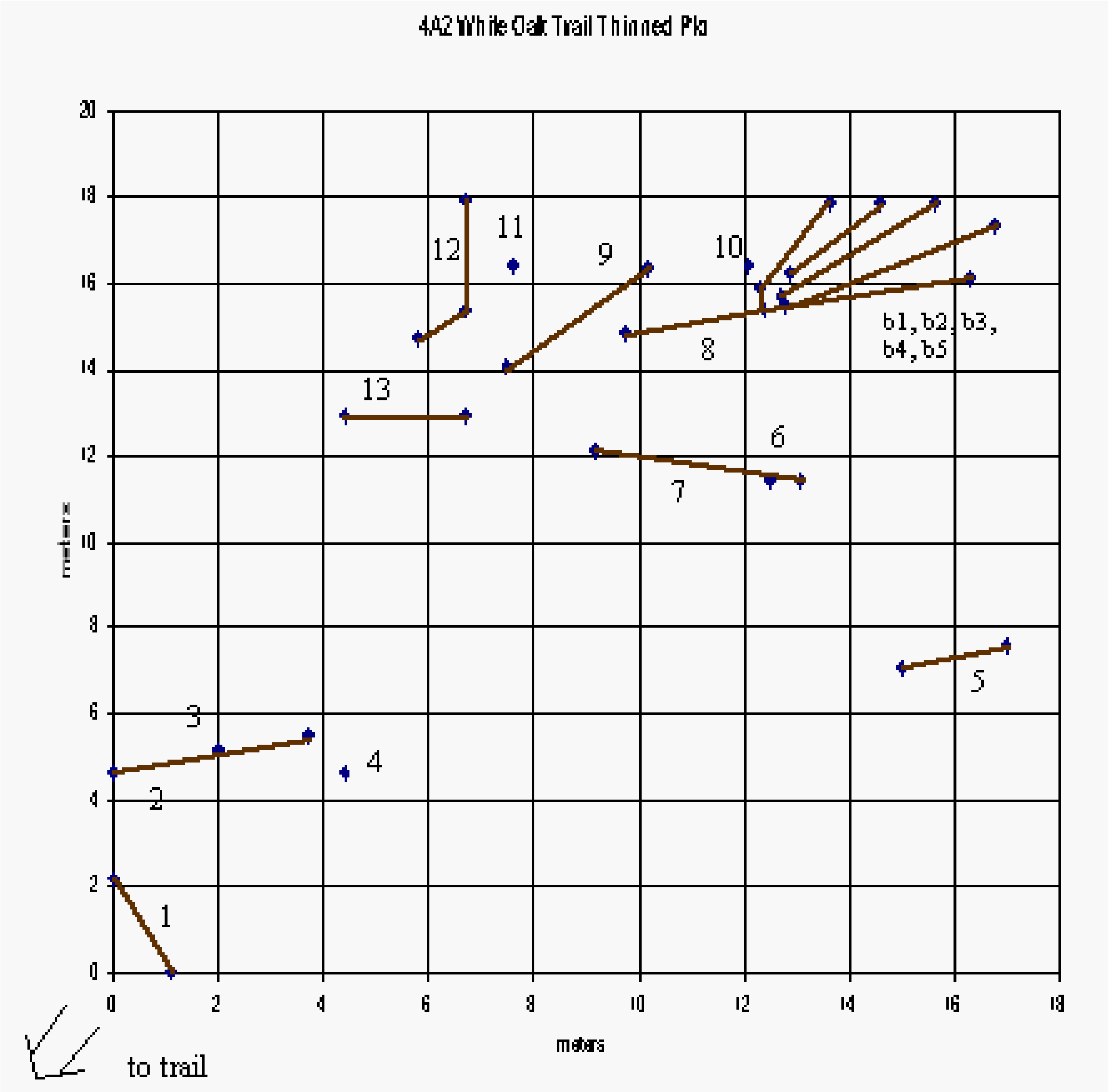

Figure 13. A map of plot 4A2, White Oak Trail thinned, with the location of each specimen.

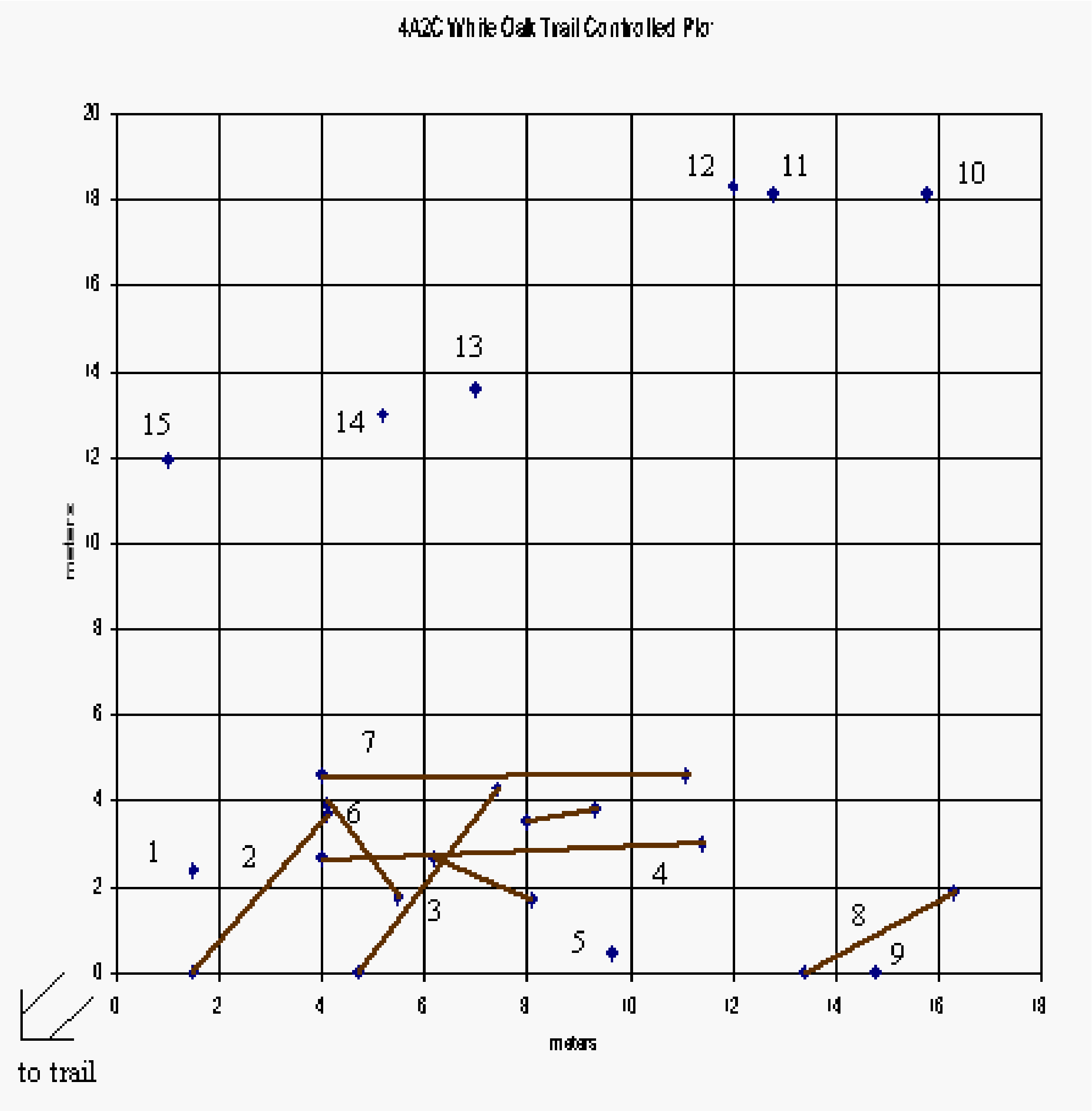

Figure 14. A map of plot 4A2C, White Oak Trail control, with the location of each specimen.

The densities obtained during the second part of the experiment cover every decay class of every species encountered on all ten plots studied, ranging from an average of 0.63 for decay class 1 to 0.2 for decay class 4. Values for each species vary depending on the species (Table 2).

Species	**Decay class 1**	**Decay class 2**	**Decay class 3**	**Decay class 4**
Red Oak	0.62	0.56	0.43	0.23
Chestnut Oak	0.66	0.54	0.44	0.30
Unidentified Oaks	--	--	0.44	0.27
Black Birch	0.61	0.46	0.35	0.12
Yellow Birch	--	0.58	0.46	--
Red Maple	--	0.47	0.35	0.15
Others, Partial IDs	--	0.52	0.41	0.20
Unidentified	--	--	--	0.11

Table 2. Average Densities Calculated from Samples and Sub-samples.

On all ten plots, carbon in CWD ranged from 199.8 to 1791.3 kg (Table 3). Carbon per hectare ranged from 4995 kg/ha to 32580.3 kg/ha (Table 3, Figure 15). The average was 15545.43 kg/ha. Overall, carbon per hectare in CWD on the plots increases with time with an r-value of 0.48 (Figures 16 and 17).

Table 3. Data calculated from the measurement of biomass and carbon in CWD, as well as from data provided by the BRF database.

plot	**plot age (yrs)**	**AGB (kg/ha)**	**Total C in AGB (kg)**	**Total C on plot (kg/ha)**	**Total BM of CWD (kg)**	**Total C in CWD (kg)**	**Total BM of CWD (kg/ha)**	**Total C in CWD (kg/ha)**	**% of Total Carbon in CWD**
young plot	39				401.20	199.8	10030.00	4995.00	n/a
BM C	93	222637.56	110873.51	332620.52	1508.32	751.14	16169.14	8052.23	2.42%
BM T	93	212135.38	105643.42	316930.26	1343.00	668.82	13456.88	6701.53	2.11%
MM C	98	309822.99	154291.85	462875.55	620.80	309.16	15122.62	7531.07	1.63%
MM T	98	226557.66	112825.71	338477.15	2181.97	1086.62	53720.20	26752.66	7.90%
AB C	118	293279.27	146053.08	438159.23	3596.92	1791.26	40465.31	20151.72	4.60%
AB T	118	324531.76	161616.82	484850.45	2367.58	1179.05	33075.06	16471.38	3.40%
WO C	118	176058.77	87677.27	263031.8	2498.94	1244.47	65422.20	32580.25	12.39%
WO T	118	221085.33	110100.49	330301.48	1651.36	822.38	40805.21	20321.00	6.15%
old plot	140				955.60	475.9	23890.00	11897.50	n/a

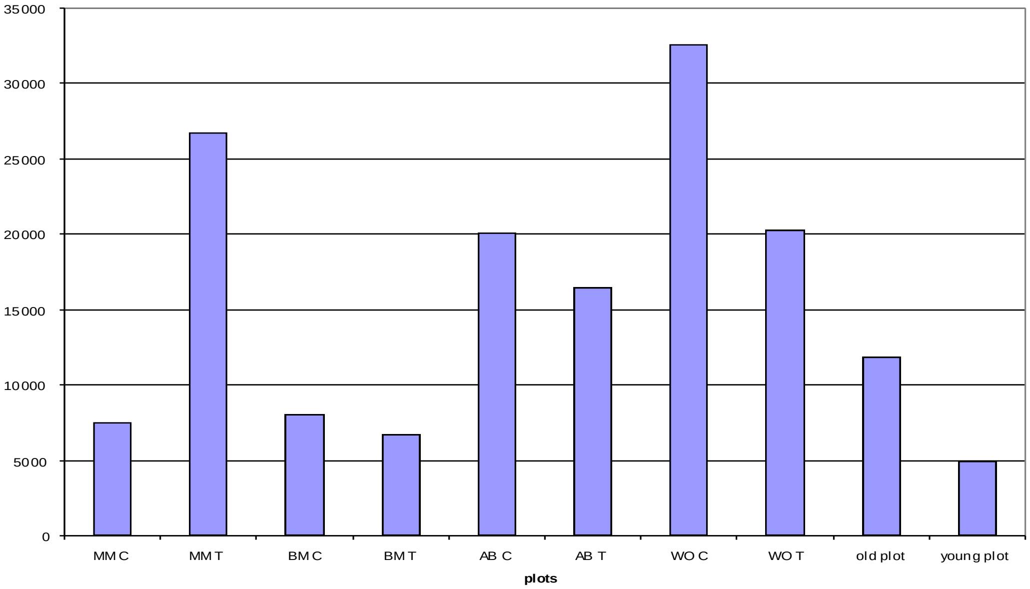

Figure 15. Amount of carbon per hectare in kilograms found in coarse woody debris on the ten plots studied. The plots are not in age order.

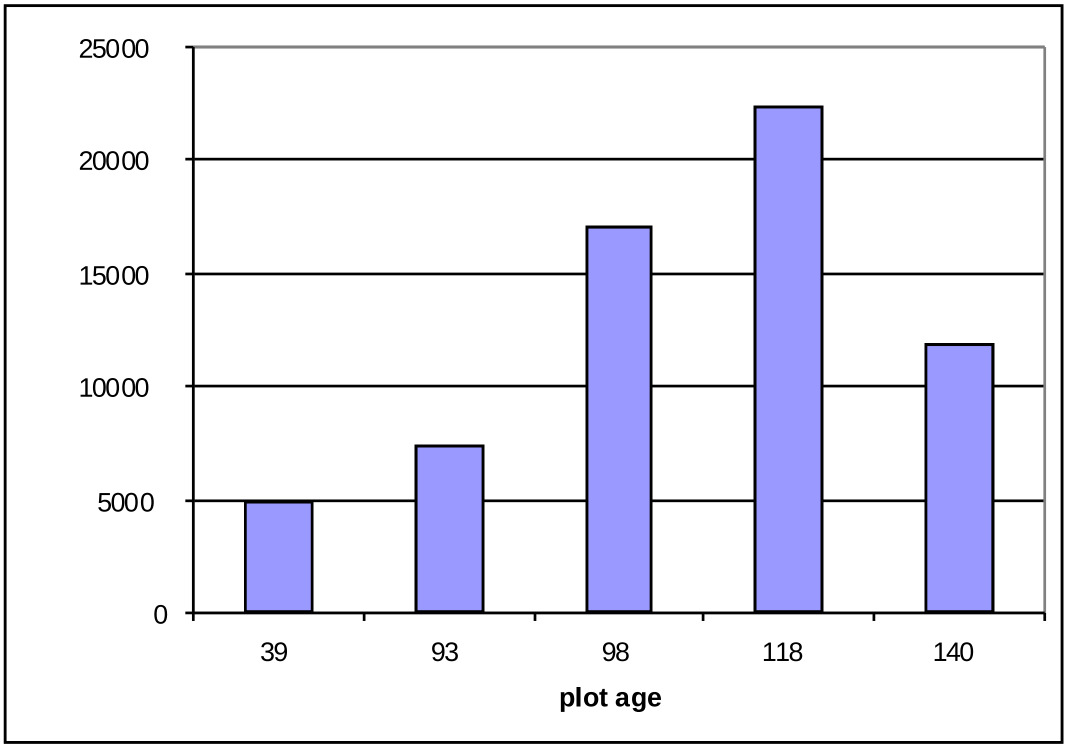

Figure 16. Average carbon per hectare plotted against plot age.

On the eight paired long-term plots percentage of total ecosystem carbon in the coarse woody debris ranged from 1.63% to 12.39%, and the average was 5.08% (Table 3, Figure 18). The average carbon percentage of the four younger plots (Mount Misery and Bog Meadow) was 3.52% and the average of the four older ones was 6.64% (Arthur's Brook and White Oak).

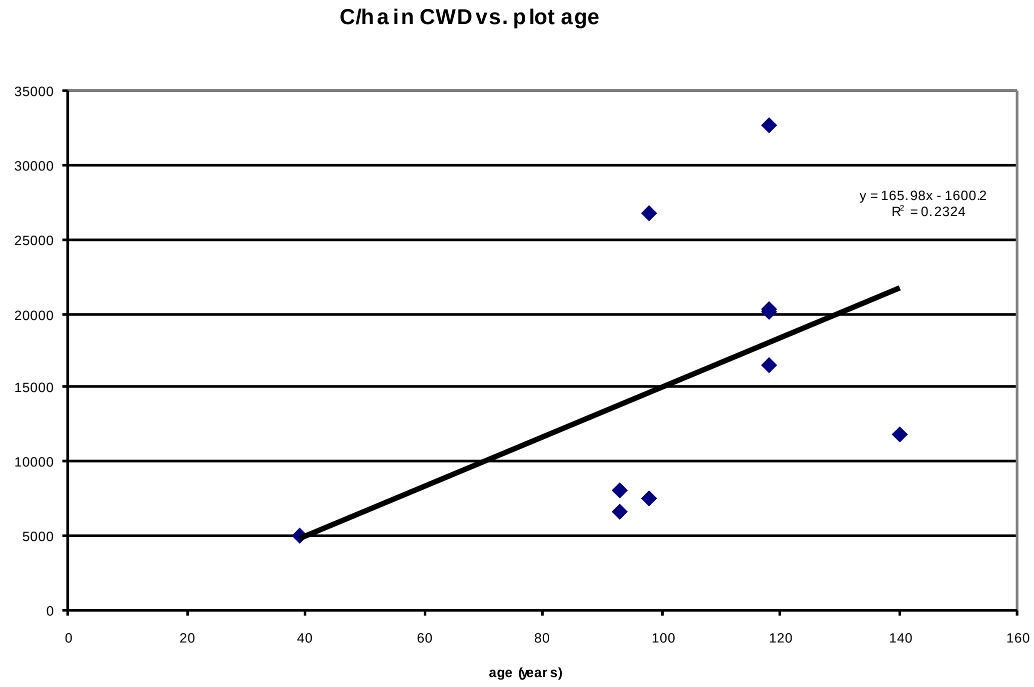

Figure 17. Carbon accumulation in kilograms per hectare on the plots over time.

Figure 18. Average percentage plotted against age. The percentages of the eight paired plots of the same age are averaged. The other two plots are not included because no percentage of total plot ecosystem was calculated.

The proportion of snags versus logs (calculated as snags/logs) on the plots decreases over time and has an r-value of 0.9 (Figure 19).

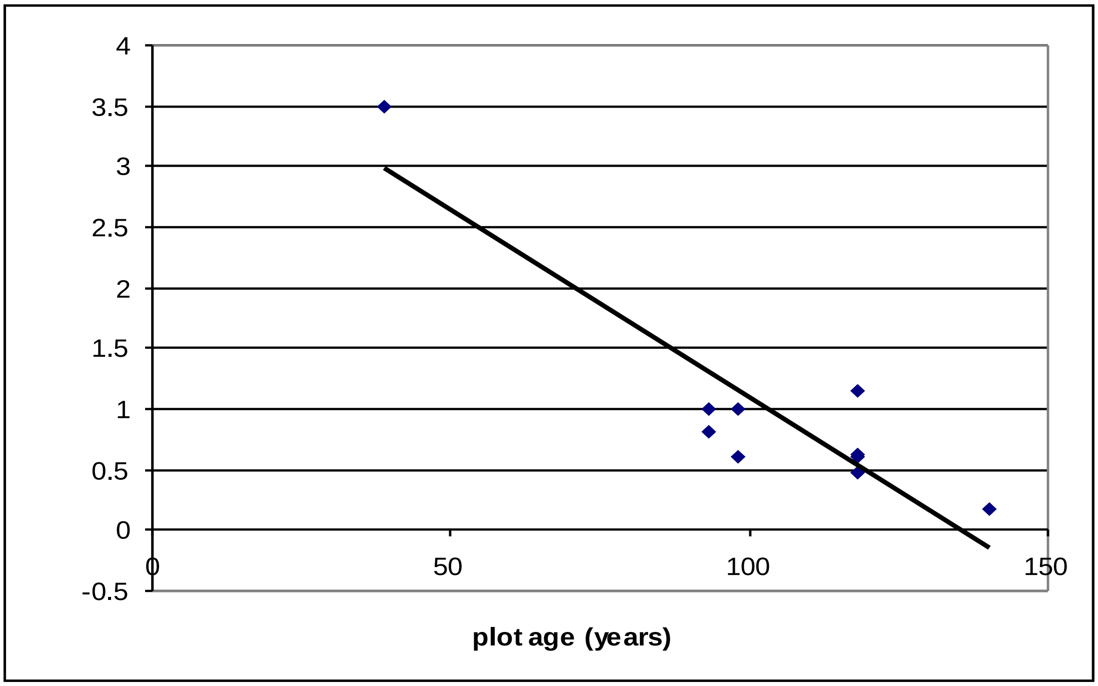

Figure 19. The snags to logs ratio (the number of snags divided by the number of logs) plotted against time.

The sub-sample volumes and weights when plotted against each other fit relatively well against a line of equation y = x; for the most part the volumes are very close to the masses or slightly less (Figure 20).

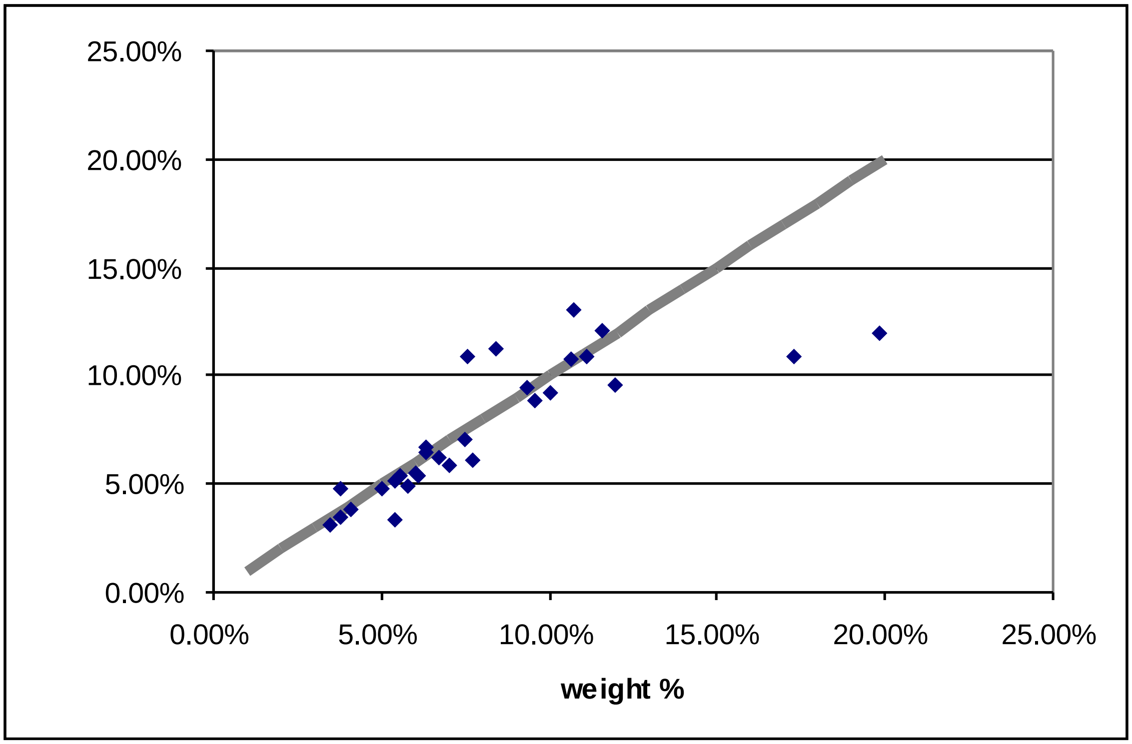

Figure 20. Sub-sample weight percentages of the sample weights plotted against sub-sample volume percentages of the sample volumes with a line y = x (slope = 1) superimposed.

Discussion

Coarse woody debris and the carbon it contains are increasing with time on the plots; the older plots for the most part have much more debris than the younger plots. Although there is a lot of variation between the plots, especially between those four that are the same age, there is a clear increase in carbon as the plots increase in age. This is the result of accumulation over time; trees die or lose branches over the years and these pieces of coarse woody debris pile up on the ground (usually) and slowly release their nutrients. As trees die they are not losing their carbon at all; it remains in the forest for a long time afterwards. Thus we can expect that a plot older than the ones studied here, one from an old-growth forest perhaps, would have a greater amount of CWD on its floor, and would be in balance with all the other carbon pools. However, there must be a saturation point where no more coarse woody debris can accumulate without taking away from other carbon pools, i.e. if a living tree dies its carbon is transferred from the living tree pool to the woody detritus pool. Until the stage of old-growth forest is reached, the carbon pools are not in balance; the woody debris pool will take more and more carbon from the living tree pool until they have achieved a balance. A forest's woody debris should make up 11% (Turner et al, 1993) of the total ecosystem's carbon, yet on average, Black Rock's plots' coarse woody debris only makes up about 5%. Since much of BRF is only about a hundred years old or less (although plots and different areas range), it is only now reaching the status of a mature forest, and still has not reached the status of an old-growth forest. As BRF ages, the amounts of coarse woody debris will increase and come to account for a greater percentage of the carbon in the forest ecosystem.

Amounts of carbon and percentages disagree because of the plots' sizes and number of living trees. Some of the plots were approximately 20 by 20 meters, and others were 30 by 30 meters, so that the larger plots would have greater amounts of carbon simply because they were larger. For this reason, the results and figures presented concern carbon per hectare. The carbon as percentages of total plot ecosystem were dependent on the number of living trees on each plot, since they were calculated using the amount of carbon in living trees on each plot. Thus, if any plot had a very low number of living trees, it could have made the percentage higher than it should have been, and vice versa as well. However, the difference in number between the controlled and thinned of each pair does not seem to be a large one. The difference in number of trees between sites is unknown.

A dead tree that is standing is known as a snag, and one on the ground is a log. When a tree first dies it is a snag (unless the cause of its death was being cut or knocked down), and as it decays and becomes less and less sound it will eventually fall over and become a log. When trees in an area recovering from a clear-cut begin to grow, competition is high and many die out in a small space of time. Thus there will be a high number of snags in the area, and few logs. After several decades the trees have thinned out and competition is not as intense. Those trees that have died will have most likely fallen to the ground. Those trees that have died during this time may or may not be standing, but there will be few of them since the competition has lessened considerably. Thus in an older area there should be many logs and few snags. This explains the decreasing ratio of snags to logs on the plots that were studied, and would be a useful too for estimating the age of a forest, or more specifically, one area of a forest.

There are several errors or potential errors within the project – most of these can be fixed with repeated use of the guidelines and the collection of more data. Firstly, the calculations of volume are not very accurate. Those coarse woody debris specimens on the plots and samples in the lab that did not have a regular shape to fit Harmon and Sexton's equations had to be estimated with other equations. Thus there is a large possibility of either under- or overestimating these volumes. The comparison of the sub-samples' volume and mass percentages were important in estimating the approximate accuracy of the specimen volumes, both with Harmon and Sexton's equations and with estimations. The results show that there is some degree of error in the volumes, but for the most part they are on-target.

The density table was created based on too few specimens. There are only 1-3 specimens per entry, and that is not enough to create really reliable values, although they compared well with another set of density values (Elert et al. 2000). Those who use these guidelines to measure coarse woody debris in the future should sample more specimens to make the density table more reliable. At least 10 or 20 specimens are suggested for each entry. There are also entries that have not been filled in; due to time constraints on the project, only the species encountered and only the decay classes these species were found in were sampled. As a result, there are some gaps in the set, which need to be filled in for future research. There are some things that may have increased or decreased the amounts of coarse woody debris on some plots; it is important to know about these things since they may have skewed the data to a certain extent. The area in which the Arthur's Brook plots are located had an ice storm during the winter before that brought down a lot of extra coarse woody debris. The thinned Mount Misery plot had two large scarlet oaks that recently died; this plot is one of the smaller plots, so that the addition of two very large trees would increase the coarse woody debris amount significantly. The 140-year-old plot was thinned in the 1930s for grey birch, aspen, and dead, dying, or diseased trees. Thus many potential pieces of coarse woody debris may have been removed, which would account for the low amount of coarse woody debris found on the plot. It is very likely the collection of data from undisturbed plots of a similar age would yield higher amounts of CWD and carbon from that pool.

Conclusion

Those using the guidelines in the future should be aware of the possible errors and try to avoid them. It is recommend that these methods be used again in order to add to and improve them, as many of them can be solved simply by use and practice. Also, in order to make the data more reliable, much more data will have to be collected. The data collected showed certain trends but they cannot be considered significant unless more research is done on other plots and samples to support the results that are presented here. The methods and data from this project will become much more reliable if they are used and collected for several years and errors are weeded out. This process will begin this summer (2004) when these methods will be applied to many more plots around BRF.

The implications of this experiment are quite important. As more and more fossil fuels are burned and forests are cut down, more and more carbon dioxide is being put into the atmosphere. The increasing carbon dioxide may be connected to increasing global temperature (Turner et al. 1993). Thus it is in the interest of our planet's health to try and find solutions to lowering the amount of carbon dioxide in the air. "Our understanding of the global carbon cycle…suggests that managing terrestrial ecosystems, especially forests, to sequester and conserve carbon may contribute to moderating the rise in atmospheric CO_2" (Turner et al. 1993). Forests offer the solution of a carbon sink that keeps carbon from becoming a greenhouse gas in the atmosphere: "Regrowing northern temperate forests are a globally significant sink for atmospheric carbon dioxide" (Compton and Hooker 2003). Northern temperate forests have been recognized as potential long-term carbon sinks because they were farmland approximately a century ago, and now they are becoming the mature forests they once were before they were cut down. The majority of Black Rock Forest is approximately a century old and takes in an average of 1.85 tons of carbon per hectare per year (Schuster et al. 2003). Its coarse woody debris makes up an average of 5% of total ecosystem carbon, while an old-growth forest's woody debris makes up approximately 11% (Turner et al. 1993). "[F]orest biomass approaches levels found in undisturbed forest within 50-70 yr…[but] in order for these regrowing forests to serve as important long-term C…sinks, significant accumulation must occur in pools with relatively long residence times, such as wood and humus" (Compton and Hooker 2003). Thus, the coarse woody debris carbon pool may continue to grow for a long time and keep Black Rock functioning as a carbon sink for many years to come, although its living trees may reach their full size and capacity in the near future if they have not already. Knowing how much carbon the forest contains and continues to sequester is important because it tells us how long a forest will continue to take in more carbon than it gives off and how much, as well as how much it can contain. The last bit of information is an important argument for existing older forests; although they may not be taking in a net positive amount of carbon, they still contain a lot of already sequestered carbon that is being held out of the atmosphere.

The creation and utilization of a set of methods for measuring the carbon in coarse woody debris at Black Rock is the next step in a large-scale carbon study. After many years of measuring the amount of carbon the forest sequesters in its live trees, scientists working there will be able to add another significant carbon pool to their numbers. Eventually other carbon pools such as soil will be studied so that a more complete picture can be drawn up of how much carbon the entire forest as an ecosystem contains.

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Literature Cited

1. Elert, Glenn, ed. and Students. "Density of Wood." The Physics Factbook. http://hypertextbook.com/facts/2000/ShirleyLam.shtml

2. Forest Inventory and Analysis Program website, USDA Forest Service. www.ncrs.fs.fed.us/4801/dwm

3. Harmon, M.E. and J. Sexton. "Guidelines for Measurements of Woody Detritus in Forest Ecosystems." US LTER Network Office Publication, no. 20. University of Washington, Seattle, Washington, USA. 1996.

4. Hooker, T. and J. Compton. "Forest Ecosystem Carbon and Nitrogen Accumulation During the First Century After Agricultural Abandonment." Ecological Applications. Vol. 13, 2003. pgs 299-313.

5. Luxford and Trayer, Wood Handbook, USDA 1940.

6. Maher, Neil, "Black Rock's Hidden Past: A History of Land-Use Practices Prior to the Creation of Black Rock Forest." Doctoral candidate in American History, New York University: 1995-6.

7. Moffat, Anne Simon, "Resurgent Forests Can Be Greenhouse Gas Sponges." Ecology. Vol. 277, July 18, 1997. pgs 315-316.

8. Paek, Woonji Lisa, "Organic Carbons in Soils from Black Rock Forest, Cornwall, N.Y." Undergraduate thesis, Department of Environmental Science, Barnard College: May 11, 1998.

9. Schuster W.S. F., K.L. Griffin, K.J. Brown, M.H. Turnbull, D. Whitehead, and D.T. Tissue. "Changes in Tree Biomass and Carbon Content Over Seven Decades (1930 – 2000) in an Aggrading Deciduous Forest." in review, Canadian Journal of Forest Research. 2003.

10. Turner D.P., J.J. Lee, G.J. Koerper, J.R. Barker. "The Forest Sector Carbon Budget of the United States: Carbon Pools and Flux Under Alternative Policy Options." EPA, May 1993.

11. Whittaker, R. H., F. H. Bormann, G. E. Likens, and T. G. Siccama. "Hubbard Brook Ecosystem Study: Forest Biomass and Production." Ecological Monographs 44: 233-252. 1974.

Appendix

Plot Data
Sample/Sub-sample Data