Total Belowground Carbon Allocation at Black Rock Forest

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Masters Research
February 15, 2008

In terrestrial ecosystems, soils are the largest component of the terrestrial carbon sink (Watson & Intergovernmental Panel on Climate, 2000) yet understanding of carbon (C) allocation patterns and controls on the C pools remains wanting (Giardina *et al.*, 2004; Ryan & Law, 2005; Litton *et al.*, 2007). Since the residence time of immobilized C varies among carbon pools, small alterations in allocation patterns can impact terrestrial C storage capacity (Friedlingstein *et al.*, 1999; Giardina *et al.*, 2004). The most productive way to examine belowground processes for the development of accurate models is to synthesize information about allocation patterns, mechanistic controls linking canopy and belowground processes, and responses of autotrophic and heterotrophic respiration to abiotic and biotic factors above and belowground (Ryan & Law, 2005). A first step in applying this integrative approach is to develop a carbon budget that reflects allocation patterns by quantifying the carbon pools. Research examining belowground C in northeast deciduous forests, such as Black Rock forest, is conspicuously scarce. Therefore the focus of this research is to provide a belowground C estimate for six experimental plots at Black Rock Forest.

Additionally, patterns of C allocation are malleable. Both natural cycles and anthropogenic disturbance can influence C allocation. Fertilization, ice storm damage, droughts (Palmroth et al., 2006), developmental stage (Coleman et al., 2004), and functional group (Coleman et al., 2000) have all been linked to differences in C allocation patterns. In order to assess the potential affect of disturbances on C allocation, both the loss of a foundation taxon through girdling and deer grazing through exclusion fences are examined.

The primary goal of this project is to quantitatively establish a baseline estimate of the total belowground carbon allocation (TBCA) for six experimental plots (in the Loss of a Foundation Taxon project). Secondary goals are to 1) Provide a preliminary assessment of the

potential effect of the loss of oaks on below ground carbon pools based on control and girdled plots from the pilot project area 2) Provide a preliminary assessment of how below ground carbon pools change in the presence or absence of deer, by using fenced and unfenced sub-plots in the control and pilot project area. Due to constraints on paper length, hypothesis, results, and a discussion of the secondary goals as well as results from additional experimental plots can be found in the appendix.

Study Site

Black Rock Forest is a 1,530 ha preserve located in the Hudson Highlands, Orange County, New York. The site is 400 m a.s.l. on the north slope of Black Rock Mountain (41.45° N, 74.01° W) (Ellison et al., 2007). The acidic and nutrient poor soils (Lorimer 1981) are classified as Chatfield and Rockway series (Ellison et al., 2007). The north slope is dominated by mature (120 yr old) Quercus rubra L., Q. prinus L. and Q. velutina Lam. (Ellison et al., 2007). Temperatures are seasonal ranging from −2.7 °C in January to 23.4 °C in July and the average annual precipitation is 1,200 mm (Xu & Griffin, 2006).

Methods

All measurements and soil cores were taken within a 25m x 25m center plot on eight established 75m x 75 m plots at Black Rock Mountain. Experimental plots (EP) refer to plots that have not received any treatment and are part of the Loss of a Foundation Taxon study. Pilot plots (PP) refer to plots situated in the pilot project area of the Loss of a Foundation Taxon project. These plots have received a combination of girdling and deer exclusion treatments (girdled unfenced, girdled fenced, control fenced, control unfenced).

Total belowground C allocation was determined using the methods described in Giardina and Ryan (2002). This method applies a mass balance approach to estimate total belowground carbon allocation (TBCA).

$$TBCA = F_S + F_E - F_A + \Delta [Cs+Cr+C_L]/ \Delta t \quad \text{Equation 1}$$

Where F_S = surface carbon dioxide [CO_2] efflux or "soil" respiration, F_E = C exported via erosion, leaching or CH_4 efflux, F_A = C in aboveground litterfall, C_S = C content of mineral soil, C_R = C content of root (coarse +fine) biomass, C_L = Carbon content of the litter layer.

Measurements: F_S was measured three times during the growing season (May-September) at ten locations within each center plot. PVC collars, 4 inches in diameter, were inserted 2-3 cm into the soil two days before measurements. A LiCor 6400 portable photosynthesis system adapted with a soil respiration chamber (LI-900, Li-Cor Inc., Lincoln NE) was placed on top of the collar before measurements. Collars remained in the soil throughout the growing season and were used for all Fs measurements. Fs was also measured using the soda lime method (Edwards, 1982) but due to inconsistencies between the two methods, LiCorr measurements are used for the TBCA calculation.

F_A was estimated for EP using litterfall measurements from 2006. Since treatments have not been applied to these plots, F_A should remain constant. This assumption is supported by the constant F_A observed over a four year period in a Eucalyptus plantation (Giardina & Ryan, 2002). Four litter baskets (0.36 m^2) were placed in each center plot and litter collection occurred three times during the year. Leaves and twigs were oven dried to a constant mass and weighted. The dry mass of acorns was not obtained and therefore not included in F_A. A 50% C content for the litter was assumed based measurements of leaf, twig, branch and bark material from Girarda and Ryan (2002) and (Carlisle et al., 1966). Plot F_A was calculated from the

combined litter mass from all litter baskets. Litterfall measurements for LP are being processed but are not completed. Consequently, estimates of TBCA can only be calculated for EP plots at this point in time.

ΔC_S ΔC_R, ΔC_L were assumed to be zero. Δ Cs, ΔCr, and ΔC_L are changes in carbon pools between two time periods. Soil cores and forest floor litter layer samples were only collected once during the year and therefore these C pools cannot be calculated. While it would be ideal to have these values, it is likely that TBCA would not drastically decrease if they were incorporated into the calculations. Annual changes in C_S and C_L appear to be relatively small, only altering the TBCA estimate for a *Eucalyptus* plantation made by Giardina and Ryan (2002) by 2.1%. C_R was found to be the most dynamic of the three C pools averaging 11% of TBCA (Giardina & Ryan, 2002). Therefore, the TBCA reported in this paper represents an overestimate and measurements in the summer of 2008 can be used to correct for this bias. Although these three C pools were assumed to be zero, they were either measured or estimated for all EP and PP because they will still be needed to calculate TBCA next year. In order to provide a full characterization of the allocation patterns in the six main EP plots, the C_S, C_R, and C_L data is presented in this paper. See appendix for more information (*) and additional EP and the PP data.

F_e was also assumed to be zero. Losses of dissolved organic C (DOC) and dissolved inorganic C (DIC) in closed canopy forests are very small ((Raich & Nadelhoffer, 1989; Giardina & Ryan, 2002). In temperate forests, losses of DOC are usually less than 0.01 kg $C/m^2/yr$ (Campbell et al., 2000). Erosion is also nominal because leaf canopy, forest floor litter, and root systems work to minimize the impact of rain on soil particle movement (Giardina & Ryan, 2002).

Three soil cores (0.00229 m^2, about 18 cm in length) from each of the 18 EP and two soil cores from each PP treatment were extracted in June 2007. A small amount of soil was removed from each of the cores for C_S analysis. Roots were hand picked by eye and then Loss on Ignition (LOI) was performed (Vitt, 2000). Organic soil carbon was estimated by assuming organic matter contained 52% carbon (Vitt, 2000). Inorganic soil carbon was measured on two samples from each plot, after LOI, with a Perkin Elmer CHNS/O series II elemental analyzer (Waltham, MA, USA).

Organic matter (including fine roots) was extracted from two and a half soil cores from each of the six main EP, and one and a half from each of the PP using a Kirchhof-Pender Do it Yourself Root Washer (described in the User Manual for the Delta-T Scan type DTS, pg 143). Cores were washed for 10 minutes, organic matter was collected, rinsed with DI water, and then oven dried at 60 ^{0}C for 48 hours. Fine root carbon was estimated using the point intercept method (Wenk et al., 2006)*. Biomass was doubled for coarse and fine roots determined from ½ cores. Root carbon was assumed to be 47% based on the average of three coarse root samples determined by CHN analysis. Fine root carbon was calculated as the product of fine root biomass and % C composition.

Sieves were used to isolate coarse roots (>2mm) (John *et al.*, 2001) from samples collected during root washing. Half of one soil core from each of the six EP and from each of the PP (on both sides of the deer exclusion fence) was oven dried for nutrient analysis*. Coarse roots (>2mm) were removed from these samples and reunited with coarse roots from the sister half. Roots were rinsed with DI water and oven dried at 60°C for 48 hours. Percent C was determined for three samples by CHN analysis. Coarse root C was measured as the product of dry weight and average % C of three samples (47%).

Prior to leaf fall, six forest floor litter samples ($0.008m^2$) per plot were collected from all EP and PP. Due to an unfortunate fire, most forest floor litter samples were lost but two samples from each of the 6 main EP and from all PP were unaffected. These bulk samples were oven dried at 60^0C to a constant mass, weighed, and %C was determined by CHN analysis. Forest floor carbon was calculated as the product of the dry weight and the % C. Replicate samples were averaged to obtain plot estimates of C_L.

Statistical Analysis

A model based on % change in measured monthly CO_2 efflux at Harvard forest (Davidson et al., 1998) was created to estimate monthly (October – April) soil CO_2 efflux at Black Rock Forest. At Harvard forest, respiration rates peaked in July while at Black Rock forest, rates increased into September. In order to account for this difference, the model was shifted by two months so that both peaks were aligned. For the growing season, where measurements were taken at Black Rock forest every other month, mean respiration rate was calculated based on respiration rate from the two nearest months. The last PP measurement was taken at the end of August but from the EP data it is clear that respiration rates should increase into September. Therefore, the measured % increase from July to September on the EP plots was used to estimate the September respiration on PP plots. Variation in measured soil CO_2 efflux as well as differences in carbon pools of EP and PP can be found in the appendix, as they do no address the primary goal.

At each of the 10 locations within the EP (and 5 locations in each PP), three soil respiration measurements were taken (30 measurements/plot). Outliers in the dataset were identified as being more than 1 umol from the mean of the two closest measurements. In each

case, this number was > 4 standard deviations from the mean and removed from the analysis (yielding 20-30 measurements/plot).

Results

Average TBCA for the six EP plots was 1.38 kg C m^{-2} yr^{-1}. In EP, modeled yearly soil CO_2 efflux ranged from 1.31-1.84 kg C m^{-2} $yr^{-1}$and averaged 1.55 kg C m^{-2} yr^{-1} (Figure 1). Growing season soil CO_2 efflux measurements in EP averaged 173.74, 276.35, 338 mg C m^{-2} hr^{-1} in May, July, and September respectively. Measured seasonal plot variation is shown in Figure 2. Please see appendix for modeled monthly estimates of respiration rates in EP and PP plots and seasonal respiration measurements of PP plots.

Average litter input in EP was 0.16 kg C m^{-2} yr^{-1} (Figure 1). Individual plots ranged from 0.15-0.18 kg C m^{-2} yr^{-1}. Organic C in EP plots was 2.5-6% and inorganic carbon was < 0.09% for all plots (Table 1). See appendix for % organic carbon in individual samples and plot level estimates from EP and PP. On EP, total root C average 0.36 kg C m^{-2} (Table1). EP plot average forest floor litter C ranged from 0.19-0.63 kg C m^{-2} (Table 1). For individual measurements and plot averages for PP and EP C_S , C_R, and C_L please see the appendix.

Discussion

TBCA at Black Rock Forest (1.38 kg C m^{-2} yr^{-1}) is higher than most other TBCA measurements; 0.438–0.510 kg C m^{-2} yr^{-1}in mature *Eucalyptus pauciflora* in Australia, 0.554 kg C m^{-2} yr^{-1} in *P. ponderosa* in Oregon, 0.710–0.733 kg C m^{-2} yr^{-1}in *Pseudotsga menziesii* and 1.880 kg C m^{-2} yr^{-1}in plantations of *Eucalyptus* in Hawaii (*cited within* (Litton et al., 2004). Some of this overestimate is due to assuming F_E, C_S, C_R, C_L to be zero but a large part of this is due to the overestimate of soil CO_2 efflux. Annual soil CO_2 efflux at Black Rock Forest (1.31-1.84 kg C m^{-2} $yr^{-1)}$ is 30-85% greater than reported estimates for Harvard forest (0.46-0.99 kg

C m^{-2} yr^{-1}) (Davidson *et al.*, 1998; Savage, 2001; Davidson *et al.*, 2002). In a global review of CO_2 flux, the mean soil respiration rate for temperate deciduous forests (including mixed broad leaved and needle leaved forests) was 0.647 kg C m^{-2} yr^{-1} (Raich, 1992). A slightly higher rate was measured at the Duke FACE site using the soda lime method, 1.06 kg C/m2/yr (Andrews, 2001). The annual respiration modeled for Black Rock Forest is more similar to rates observed in moist tropical forests (1.260 kg C m^{-2} yr^{-1}) than to temperate ecosystems.

This apparent inconsistency could be related to the Harvard forest dataset that was chosen for the model. The model was developed from respiration rates observed during the 1995-1996 year because that particular dataset was the least ambiguous and measured peak respiration values from Black Rock forest were within one standard error from the mean peak efflux value. Soil respiration measurements over a five year period at Harvard forest revealed that mean summer and spring time respiration, onset of spring, month of peak summer respiration, and mean peak summer respiration rate are all variable (Savage, 2001). The 1995-1996 dataset that was used differed from the measured Black Rock forest dataset in almost all of the above variables (Table 2). Adjustments such as aligning the peak growing season were applied to the model but the differences governing fundamental processes of these two growing seasons would increase the model error. The Harvard dataset from 1998 appears to be a better match for Black Rock forest (Table 2) and will be used to recalculate the yearly soil efflux.

Additionally, there was a 30% difference from the peak summer CO_2 efflux between the1995-1996 Harvard forest dataset and Black Rock forest data set (Table 2). This difference would carry through each successive month in the model because no adjustment for peak respiration rate was made. Another model that is likely to be more accurate would be one based on measured relationships of soil moisture and soil temperature that were taken concurrently

with respiration measurements. This model was not created because of time constraints. Independent of model parameters, growing season respiration rates at Black Rock forest are within the upper range of those measured at Harvard forest. The measured soil CO_2 efflux at Black Rock forest could represent interannual variation that is undetectable with one year of observations or it could indicate a higher basal rate of soil respiration for this forest.

Litter influx values for Black Rock forest (0.160 kg C m^{-2} yr^{-1}) are similar to those reported for Howland forest in Maine (0.158 kg C m^{-2} yr^{-1}) and slightly lower than observations at Harvard forest (0.219 kg C m^{-2} yr^{-1}) (Davidson et al., 2002). They are also consistent with observations of a *Quercus –Pinus* stand (0.337 kg C m^{-2} yr^{-1}) in New York (Raich & Nadelhoffer, 1989). The litter influx is an underestimate because the C input from acorns was not incorporated into the calculations.

Comparison of litterfall and soil respiration in 14 mature temperate hardwood forests reveal a relatively small range of litterfall (0.150-0.275 g C m^2 yr^{-1}) and soil respiration values (0.500-1.000 g C m^2 yr^{-1}) (Davidson et al., 2002). One atypical stand had exceptionally high soil respiration rates in comparison to litterfall input. Interestingly, this 90 year-old Aspen hardwood forest, on acidic soils (pH 4.8), in Michigan had litterfall (0.148 g C m^2 yr^{-1}) and respiration (1.160 kg C m^{-2} yr^{-1}) values comparable to those observed at Black Forest.

Soil C is hard to assess because most studies report the carbon/unit area. Unfortunately, my calculations are missing the area component but this can easily be adjusted once LOI (on a consistent volume of soil) is preformed on soil cores taken from the additional EP plots. Other work at Black Rock forest found 49.5% organic C at the litter layer and 37.5% at the O horizon. The measurements in this study, 2.1-6.77% (Table 3 in appendix) align with values from the B and C horizons (Personal communication with D. Peteet). The lower organic C composition in

my samples is likely due to differences in soil depth. Soil samples in my study were not taken from a specific soil horizon and they are more representative of organic carbon in the deeper soil rather than surface soils. The low contributions of inorganic C found in the Black Rock forest soil is likely because the geologic bedrock is composed of gneiss and granite (Barringer & Clemants, 2003), neither of which contain very much C in their chemical composition.

For comparison to other scientific studies, root biomass distribution is used as a proxy for root carbon stocks, in this discussion. Average EP root biomass at Black Rock forest (0.80 kg C m^{-2}) is approximately five times lower than the global average root biomass of temperate deciduous forests (4.2 kg C m^{-2}) (Jackson et al., 1996). Fine root biomass for a temperate deciduous forests is 0.78 kg m^{-2} (Jackson et al., 1997) while at Black Rock it was estimated to be 0.33 kg m^{-2}. In contrast to the findings of Jackson et al. (1997), fine root biomass in three forest stands dominated by *Quercus* ranged from 0.270 –0.341 kg m^{-2} (Nadelhoffer et al., 1985) which indicates a wide variance among fine root biomass in temperate deciduous forests that could be related to dominant tree species.

Possible errors associated with root estimations stem from estimating fine root biomass from the 1-2 mm diameter size fraction. Limiting estimation of the roots by size fraction might have excluded a large portion of fine roots present because fine roots smaller than 1mm in diameter could represent the majority of fine roots for some forests (Jackson et al., 1996). Additionally, 26% roots in a temperate deciduous forest are found in the top 10 cm of soil and 60% in top 30 cm (Jackson et al., 1996). Since soil cores were approximately18cm in length it is possible that they would have only extracted around 50% of the roots present. However, the study site is very rocky and the difficulty in finding sites where a 16.5 cm core could be taken indicate that the soil profile is very shallow and therefore most roots would be restricted to the

surface soil. In order to minimize disturbance on plots, soil cores were not taken very close to trees. Doing this may have unintentionally avoided coarse roots in the soil sample but if the soil profile is shallow coarse roots should be distributed throughout the plot.

In summary, it was found that the estimated belowground C allocation could be up to 1.38 kg C m^{-2} yr^{-1}. If the total ecosystem C at Black Rock forest is estimated at 17.5 kg C m^{-2} (Schuster *et al.*, 2008) then belowground C allocation can account for up to 7.9 % of ecosystem C each year. This is important in understanding the carbon budget this forest, and similar forests in the northeast, which impact the global carbon cycle.

Acknowledgements

I gratefully thank the Ernst C. Stiefel Foundation for providing funding for this research, Kevin Griffin, Bill Schuster, and Dorothy Peteet for their guidance and support, and Christopher Burdette, Teo Cruz, Marlene Robles, Mia Lewis, Yasmine Koukaz, and Joshua Varon for field assistance.

Figures and Tables

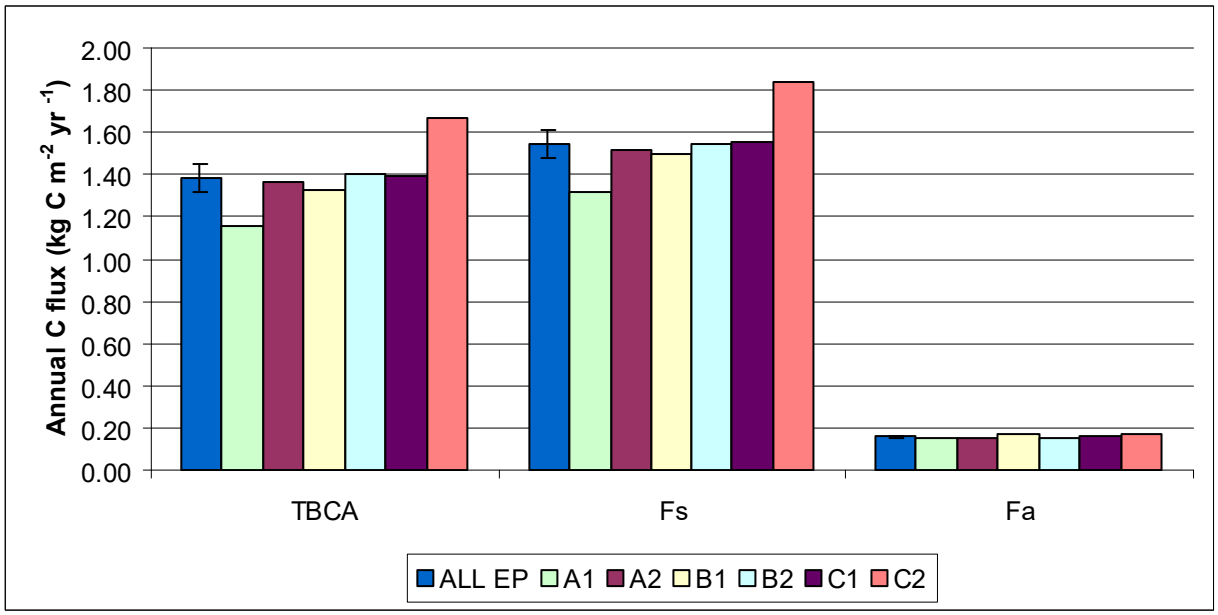

Figure 1. TBCA, soil CO2 efflux (F_s), and aboveground litterfall (F_A) for six EP plots (A1-C2) (n=1) and the North Slope (ALL) (n=6) at Black Rock forest. F_s is based on a model using three growing season measurements from 2006 and F_A is based on littterfall collected from 2005. Error bars are standard errors of means (SEM).

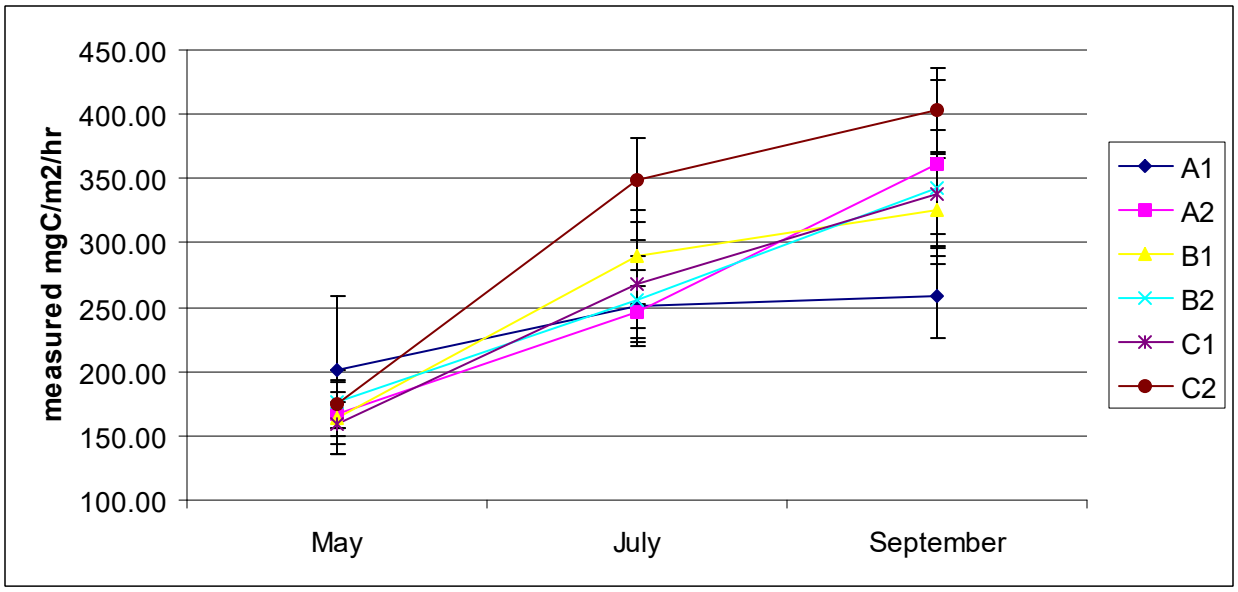

Figure 2. Monthly respiration rates on six EP plots (n = 20-30) at Black Rock forest. Measurements were taken during 2006. Error bars equal one standard error.

Table 1. Plot average coarse root, fine root, total root biomass and C (n=2), soil organic and inorganic C (n=3) and forest floor litter C (C_L) at Black Rock Forest.

	Average g C m^{-2}				Average g m^{-2}			Average Soil C	
Plot	Coarse Roots	Fine Roots	Total Root	C_L	Coarse Roots	Fine Roots	Total Root	Organic C (%)	Inorganic C (%)
A1	289.09	192.86	481.95	271.62	609.90	406.88	1016.78	2.5	0.07
A2	247.69	113.17	360.87	555.84	522.56	238.76	761.32	4.33	0.07
B1	73.14	196.18	269.31	352.96	154.29	413.88	568.17	3.1	0.03
B2	76.59	135.46	212.05	190.73	161.57	285.78	447.36	3.14	0.04
C1	563	185.06	748.07	417.95	1187.77	390.43	1578.20	5.99	0.08
C2	26.22	107.95	134.17	627.04	55.31	227.74	283.05	4.19	0.06

Table 2. Mean summer and spring respiration rate, onset of spring, month of peak summer respiration, and mean peak summer respiration at Harvard forest in 1995 and 1998 and at Black Rock forest in 2007.

	Black Rock Forest	Harvard forest 1995	Harvard forest 1998
Mean spring respiration (mg C m^{-2} hr^{-2})	179.13	125.00	180
Mean summer respiration (mg C m^{-2} hr^{-2})	266	235.17	280
Mean peak respiration (mg C m^{-2} hr^{-2})	334	257.5	330
Month of peak summer respiration	September	August	September
Onset of spring	Not enough information	Middle of May	Late May

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Appendix

Secondary goals:

▪Provide a preliminary assessment of the potential effect of the loss of oaks on below ground carbon pools based on control and girdled plots from the pilot project area

▪Provide a preliminary assessment of how below ground carbon pools change in the presence or absence of deer, by using fenced and unfenced sub-plots in the control and pilot project area

Hypothesis for secondary goals:

It is hypothesized that there will be a net loss of below ground carbon in the girdled and unfenced pilot plots. The girdled trees will have a compromised transport system that will eventually lead to the death of the tree. When this happens, leaf production can be expected to decrease and therefore reduce the amount of carbon entering the below ground system through the reduction in above ground leaf litter. Autotrophic respiration by the root system should also decrease with the tree mortality and, in response, the heterotrophic respiration by the microbial community should increase once it starts to decompose the root system.

The unfenced portions of the pilot plots will likely experience greater rates of herbivory by deer. The herbivory will reduce the phytosynthetic capacity of understory plants and, consequently, photosynthate production will diminish. This decline will prompt changes in C allocation patterns. As observed in a northern boreal forest, soil C mineralization rates will decrease in response to herbivory (Stark et al., 2003), thus reducing the plant input of C below ground.

Elaboration on Methods:

Point Intercept method for fine root biomass estimation (Wenk et al., 2006). Organic matter (>1mm, diameter) was evenly distributed on a plastic tray containing a grid of 57 spots. The tray was passed under a microscope and the first object in the pointers path was categorized as fine roots, soil organic matter, and aboveground detritus (larger than 1 mm in any direction). Fine root biomass was calculated as the product of the fraction observed and the sample dry weight.

Nutrient analyses has been completed on half of the samples from the six main experimental plots and four from the pilot plots by Matthew Brown from the Central Park

Conservancy Soil Science lab but the results have not been forwarded to me and are therefore not available for this paper.

Data Analysis:

Differences in C_L, C_S, C_R, and F_S between the mean of the main EP plots and plot average of each PP plot were assessed using Z (normal distribution) tests. This test compares the mean of multiple measurements (EP plots) to a mean of one measurement (PP). Following the advice of a statistical consultant at Columbia University, results were considered to be statically significant when $p < 0.001$. When $p < 0.05$ values were indicated because they may be suggestive of a trend. This test assumes a normal distribution among the six plots and although it may indicate relationships the results cannot be considered a robust evaluation due to the small sample size.

Analysis of variance (ANOVA) was used to assess differences in monthly measured soil CO_2 efflux in the experimental plots as well as differences in monthly soil CO_2 efflux between each of the pilot plot treatments and experimental plots. These tests used all measurements made on each plot (20-30 for each EP and 10-15 for each PP). ANOVA's were computed with SPSS statistical software (SPSS, Chicago, IL, USA).

Results for Pilot Plots:

Mean soil CO_2 efflux on control fenced, control unfenced, girdled fenced, girdled unfenced plots were estimated to be 1.38, 1.31, 1.46, and 1.20 kg C $m^{-2}yr^{-1}$ respectively. Girdled unfenced PP had a lower yearly soil CO_2 efflux than EP ($p<0.05$) and was the only PP plot to differ from the EP. This is based on modeled monthly efflux measurements (Figure 1). Modeled monthly soil respiration on experimental plots is shown in Figure 2. In May, soil respiration was the same between EP and all four of the PP. There was also no difference among any of the four PP. In July, soil respiration was the same between EP and all four of the PP however the girdled unfenced treatment was the only one to indicate a trend towards a lower respiration rate ($p=0.054$). All PP had similar respiration rates. EP (September measurements) and PP (August measurement) were the same and there was no difference among the PP.

Pilot plot control fenced, control unfenced, girdled fenced, girdled unfenced had 2.88, 4.53, 6.02 and 6.77 % organic C respectively and all had < 0.07% inorganic C (Table 2).

Neither PP plot average % organic C content nor % inorganic C was different from EP plots. There was no difference between mean EP coarse root, fine root, or total root Cm^{-2} and any of the PP plots (Table 3). Mean EP forest floor litter (kg m^{-2}) as well as % C composition of the litter did not differ from PP plots. In PP plots, C_L ranged 0.22-0.66 kg C m^{-2} (Table 4). Mean F_A in EP plots was similar to mean control all (fenced and unfenced combined), and different from mean girdled (fenced and unfenced combined) ($p=0$) in 2006. Each month of measured soil respiration in EP (May, July, August) had a different soil CO_2 efflux ($p<0.05$).

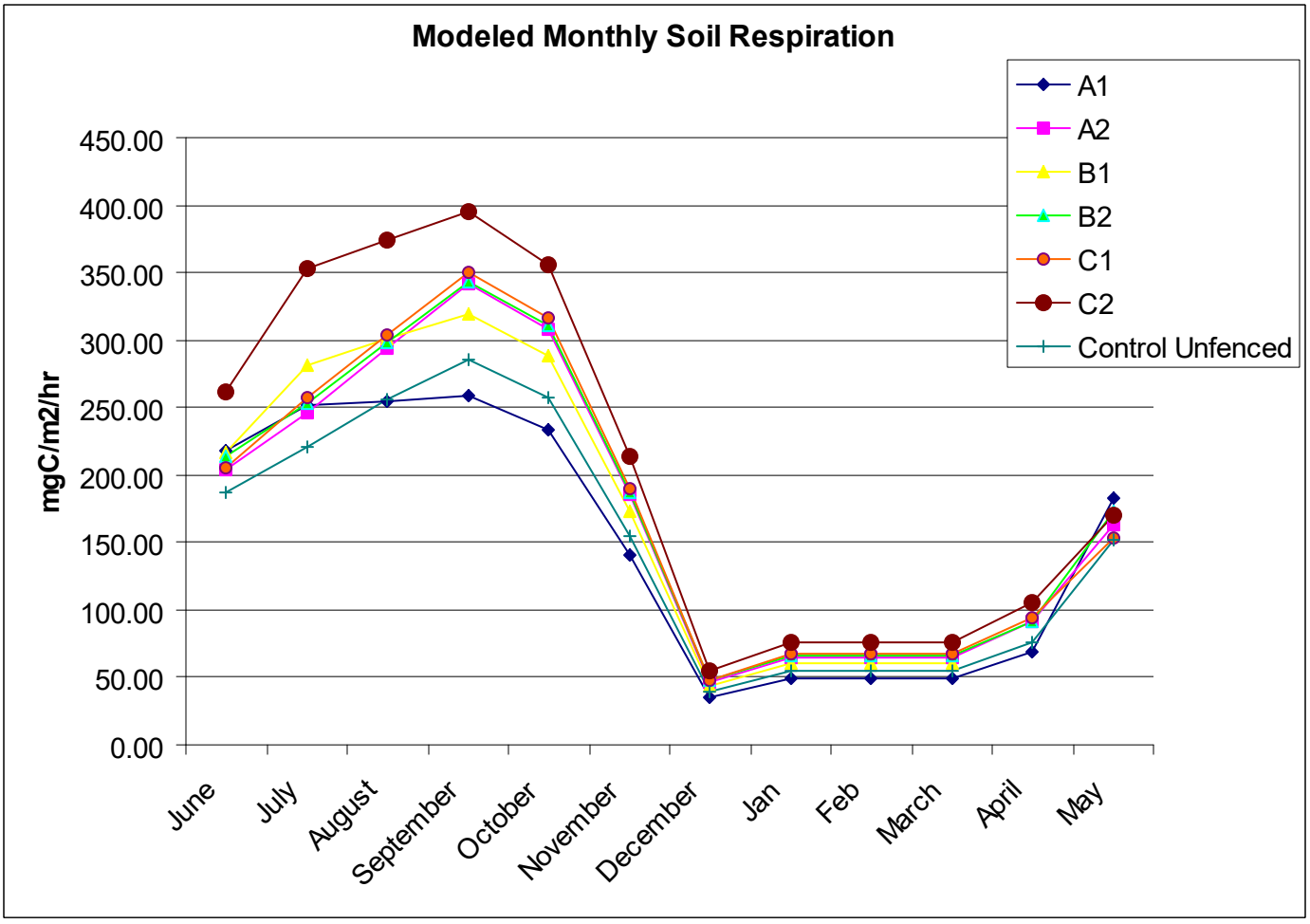

Figure 3. Modeled monthly soil respiration for six EP plots and control unfenced PP at Black Rock forest for 2007. Measured values for May, July, and September are based on 20-30 efflux measurements within 10 locations inside the plot.

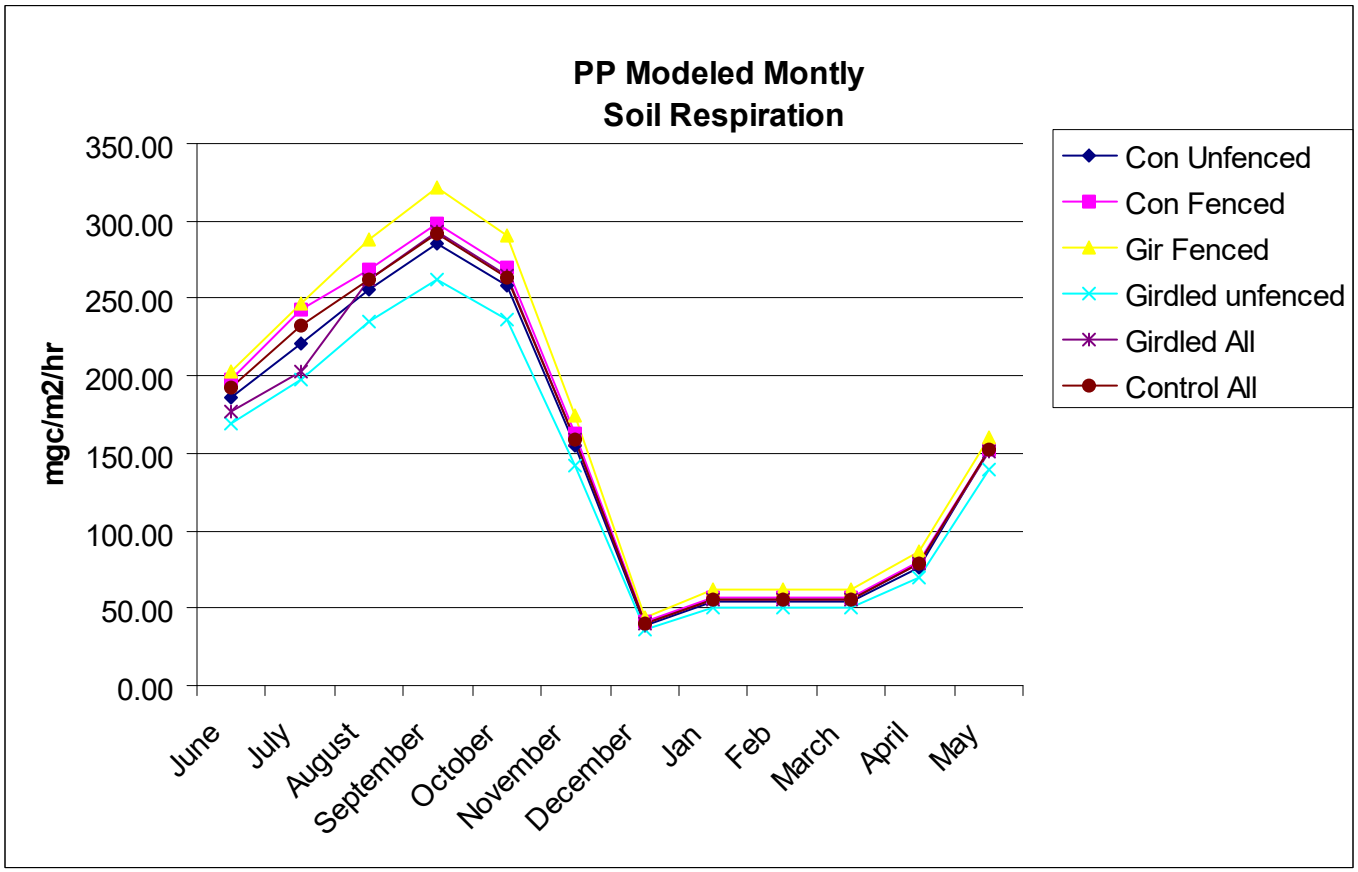

Figure 4. Modeled monthly soil respiration for four pilot plots, average of control plots (fenced and unfenced), and average of girdled plots (fenced and unfenced) at Black Rock forest for 2007. Measured values for May, July, and August are based on 20-30 efflux measurements within 10 locations inside the plot.

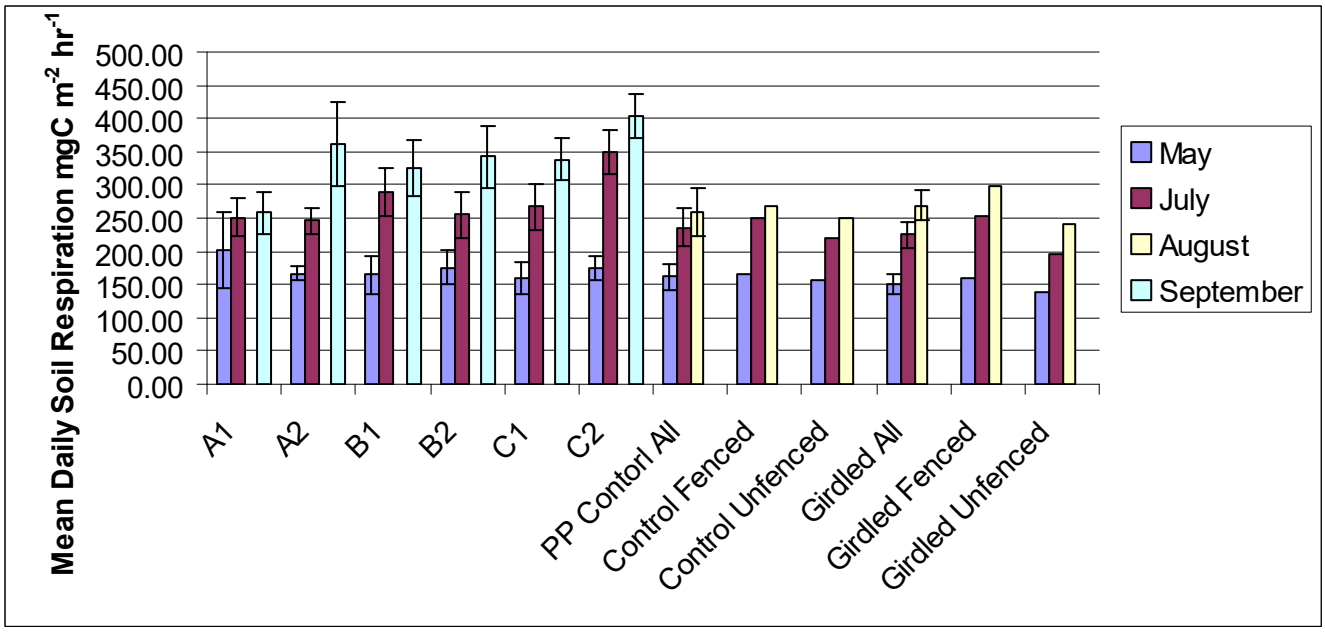

Figure 4. Mean monthly soil respiration on the six main experimental plots (A1-C2) and the pilot plots (Control and Girdled, fenced unfenced) at Black Rock forest in 2007. Means are based on fluxes measured once each month (EP n=20-30, PP n=10-15) at 10 locations within each experimental plot and at five locations within each pilot plot. Error bars are one standard error.

Table 3. Average percent organic and inorganic composition determined for each soil core (n=1) and average plot level percent organic (n=3) and inorganic (n=2) soil carbon based on soil core measurements. Samples are from plots in the "loss of a foundation taxon" study at Black Rock Forest in the summer of 2007.

		Individual Soil Core Measurements		Plot Average	
Plot	Soil core	% Organic C	% Inorganic C	% Organic C	% Inorganic C
A1	1			2.50	0.07
	2	2.58	0.07		
	3	2.42	0.06		
A2	1	4.39	0.05	4.33	0.07
	2	5.71	0.08		
	3	2.90			
B1	5	3.00	0.03	3.10	0.03
	2	3.00			
	4	3.29	0.04		
B2	1	2.50	0.06	3.14	0.04
	2	2.88	0.02		
	3	4.03			
C1	1	3.75	0.08	5.99	0.08
	2	6.96	0.07		
	3	7.26			
C2	1	3.30	0.07	4.19	0.06
	2	5.63	0.04		
	3	3.65			
Control unfenced	1	3.61	0.07	4.53	0.06
	2	5.45	0.05		
Control fenced	1	3.21	0.04	2.88	0.04
	2	2.55	0.04		
Girdled unfenced	1	5.74	0.07	6.02	0.06
	2	6.30	0.05		
Girdled fenced	1	8.80	0.05	6.77	0.04
	2	4.74	0.04		
A3	1	5.64		5.72	
	2	3.63			
	3	7.89			
A4	1	1.78		2.11	
	2	2.41			
	3	2.15			
A5	1	4.09		3.88	
	2	3.91			
	3	3.63			
A6	1	4.15		4.36	
	2	5.02			
	3	3.91			

Table 3 (continued)

	Soil	Individual Soil Core Measurements		Plot Average	
Plot	Sample	% Organic C	% Inorganic C	% Organic C	% Inorganic C
B3	1	3.71		2.73	
	2	2.21			
	3	2.26			
B4	1	2.97		4.54	
	2	4.36			
	3	6.31			
B5	1	8.03		5.19	
	2	3.50			
	3	4.05			
B6	1	3.27		5.70	
	2	7.80			
	3	6.04			
B7	1	6.29		4.31	
	2	3.61			
	2	3.03			
C3	1	2.28		2.48	
	2	2.68			
	3	3.19			
C4	1	4.70		4.24	
	2	2.53			
	3	5.50			
Z5	1	3.09		3.85	
	2	5.12			
	3	3.34			

Table 4. Average coarse root biomass (CR), Fine root biomass (FR), total root biomass (TR), Carbon in coarse roots (CCR), Carbon in fine roots (CFR), Carbon in all roots (CTR) for individual cores (n=1) and plots (n=3). Samples are from plots in the "loss of a foundation taxon" study at Black Rock Forest in the summer of 2007.

		Root biomass (g)			Root biomass (g/m2)			g C/m2			Plot Average g C/m2		
Plot	Core	CR (g)	FR (g)	TR (g)	CR	FR	TR	CCR	CFR	CTR	CCR	CFR	CTR
A1	1.00	0.75	1.35	2.10	327.51	587.46	914.97	155.24	278.45	433.70	289.09	192.86	481.95
	2.00	0.52	1.05	1.57	227.07	460.33	687.41	107.63	218.20	325.83			
	3.00	2.92	0.40	3.32	1275.11	172.85	1447.96	604.40	81.93	686.33			
A2	1.00	3.21	0.60	3.81	1401.75	262.86	1664.60	664.43	124.59	789.02	247.69	113.17	360.87
	2.00	0.18	0.43	0.61	78.60	188.50	267.10	37.26	89.35	126.61			
	3.00	0.20	0.61	0.81	87.34	264.92	352.26	41.40	125.57	166.97			
B1	5.00	0.54	1.50	2.04	235.81	655.75	891.56	111.77	310.83	422.60	73.14	196.18	269.31
	2.00	0.00	0.54	0.54	0.00	236.54	236.54	0.00	112.12	112.12			
	4.00	0.52	0.80	1.32	227.07	349.34	576.42	107.63	165.59	273.22			
B2	1.00	0.14	0.34	0.48	61.14	149.44	210.58	28.98	70.84	99.81	76.59	135.46	212.05
	2.00	0.60	0.97	1.57	262.01	422.13	684.13	124.19	200.09	324.28			
C1	1.00	0.39	0.50	0.89	170.31	219.86	390.16	80.72	104.21	184.94	563.00	185.06	748.07
	2.00	7.20	0.76	7.96	3144.10	332.79	3476.89	1490.31	157.74	1648.05			
	3.00	0.57	1.42	1.99	248.91	618.63	867.54	117.98	293.23	411.21			
C2	1.00	0.03	0.34	0.37	13.10	148.47	161.57	6.21	70.38	76.59	26.22	107.95	134.17
	2.00	0.33	0.74	1.07	144.10	322.23	466.34	68.31	152.74	221.04			
	3.00	0.02	0.49	0.51	8.73	212.52	221.25	4.14	100.73	104.87			
Control unfenced	1.00	0.50	0.71	1.21	218.34	312.11	530.45	103.49	147.94	251.43	148.00	142.27	290.27
	2.00	0.93	0.66	1.59	406.11	288.21	694.32	192.50	136.61	329.11			
Control fenced	1.00	0.20	0.59	0.79	87.34	256.19	343.52	41.40	121.43	162.83	81.76	140.75	222.51
	2.00	0.59	0.77	1.36	257.64	337.70	595.34	122.12	160.07	282.19			
Girdled unfenced	1.00	0.12	0.68	0.80	52.40	298.52	350.92	24.84	141.50	166.34	26.91	115.71	142.62
	2.00	0.14	0.43	0.57	61.14	189.71	250.85	28.98	89.92	118.90			
Girdled fenced	1.00	0.10	0.59	0.69	43.67	255.82	299.49	20.70	121.26	141.96	25.87	106.81	132.69
	2.00	0.15	0.45	0.60	65.50	194.87	260.37	31.05	92.37	123.42			

Table 5. Forest floor litter. Average % carbon (n=3) and biomass of each bulk sample collected, calculated carbon content in the bulk sample and in a m^2, plot level averages (n=2) of floor litter C m^2 and % C in litter. Samples are from plots in the "loss of a foundation taxon" study at Black Rock Forest in the summer of 2007.

Forest Floor Litter Components

Plot	Sample	%C	Biomass(g)	G C	G C/m^2	Plot average g C/m^2	Plot average %C
A1	1	36.05	2.74	0.99	123.46	271.62	34.87
	2	33.68	9.97	3.36	419.78		
A2	1	44.71	11.86	5.30	662.80	555.84	46.78
	2	48.86	7.35	3.59	448.89		
B1	1	44.93	6.5	2.92	365.07	352.96	46.30
	2	47.67	5.72	2.73	340.85		
B2	1	43.18	1.52	0.66	82.05	190.73	45.54
	2	47.91	5	2.40	299.41		
C1	1	49.91	5.88	2.93	366.87	417.95	50.73
	2	51.54	7.28	3.75	469.02		
C2	1	48.97	6.37	3.12	389.92	627.04	44.30
	2	39.64	17.44	6.91	864.15		
Control unfenced	1	42.16	12.13	5.11	639.31	417.35	35.72
	2	29.27	5.34	1.56	195.40		
Control fenced	1	44.79	3.46	1.55	193.71	382.50	46.71
	2	48.62	9.4	4.57	571.29		
Girdled unfenced	1	32.61	5.06	1.65	206.28	223.62	41.21
	2	49.81	3.87	1.93	240.96		
Girdled fenced	1	50.00	10.21	5.11	638.15	662.86	48.13
	2	46.26	11.89	5.50	687.56		

Discussion:

The control unfenced plot appears to be representative of the 6 EP plots. It does not differ in C_S, C_R, C_L, F_A or F_S. However, F_S measurements were based on a small sample size so the results for F_S are not statistically robust. The deer exclusion fence did not statically alter any of the carbon pools but visual comparison suggests that higher rates of soil CO_2 efflux are found in fenced portions of both the control and girdled plot. With an increased sample size, this observation may be more apparent. If so, it would support my hypothesis that herbivory would decrease autotrophic C input to soil. Additionally, although the understory vegetation is not very dense on either side of the fence, in the control plot, there appears to more understory plants in the fenced portion of the plot. These plants would normally be consumed by herbivores such as deer but instead they should be contributing to the belowground C pool.

If there is no affect of herbivory on soil respiration, as the results suggest, this may be because there is not enough understory plants present in the control unfenced plot to have a noticeable affect on soil CO_2 efflux. This could be reflected in the findings that forest floor litter quantity, in both of the control and girdled plots, was not different from the EP plots. If herbivory did not influence soil respiration, it would also indicate that the understory contribution to soil CO_2 efflux, in the control fenced plot, is minimal. This might be related to the understory density or species composition. Differences in soil respiration rate have been observed among different functional groups (Raich & Tufekciogul, 2000) as well as among species found along a *Populus* hybridization gradient (Fischer *et al.*, 2007). Since plant contribution to soil respiration is seen between 2-14 days after the production of photosynthates (Knohl *et al.*, 2005), changes in long term belowground C allocation induced by herbivory should have been detectable. If plant response to herbivory is transient than perhaps my sampling dates could not provide the temporal resolution needed to detect a change.

The results fail to support the hypothesis that there would be a net loss of below ground carbon from the girdling treatment. The girdled unfenced plot did not differ from EP in C_S, C_R, C_L, or F_S. The girdling treatment decreased the aboveground litterfall in 2006 but, in comparison to the six EP, it did not alter the quantity of litter found on the forest floor. This is not surprising because EP plots exhibited a relatively wide range of forest floor litter biomass. All of the measured % organic C values fall within the expected range of the B and C soil horizon.

Soil CO_2 efflux was expected to diminish in the girdled plots because the autotrophic contribution, which accounts for 50-65% of total soil respiration (Hogberg *et al.*, 2001; Bhupinderpal-Singh *et al.*, 2003), was arrested from the dominant genera (*Quercus*). Although not significant, the girdled unfenced plot had the lowest average soil CO_2 efflux in all treatments for all measured months. The low sampling size and spatial coverage for girdled plots (5 locations, 10-15 samples) may not be enough to elucidate the true effect of the treatment. A year after a girdling experiment in a Scots pine forest, soil respiration decreased by 65% (Bhupinderpal-Singh *et al.*, 2003). In contrast, the only girdling experiment in a temperate deciduous forest failed to confirm any difference in soil respiration between girdled and control plots (Edwards & Ross-Todd, 1979). In a Brazilian *Eucalyptus* plantation, a similar reduction occurred on plots where only half the trees were girdled or all were girdled (Binkley *et al.*, 2006) revealing that decreases in soil respiration may not be proportional to an individual trees contribution. Instead, there may be a feedback effect that amplifies the signal only once a tipping point is reached reduction of autotrophic derived C.

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