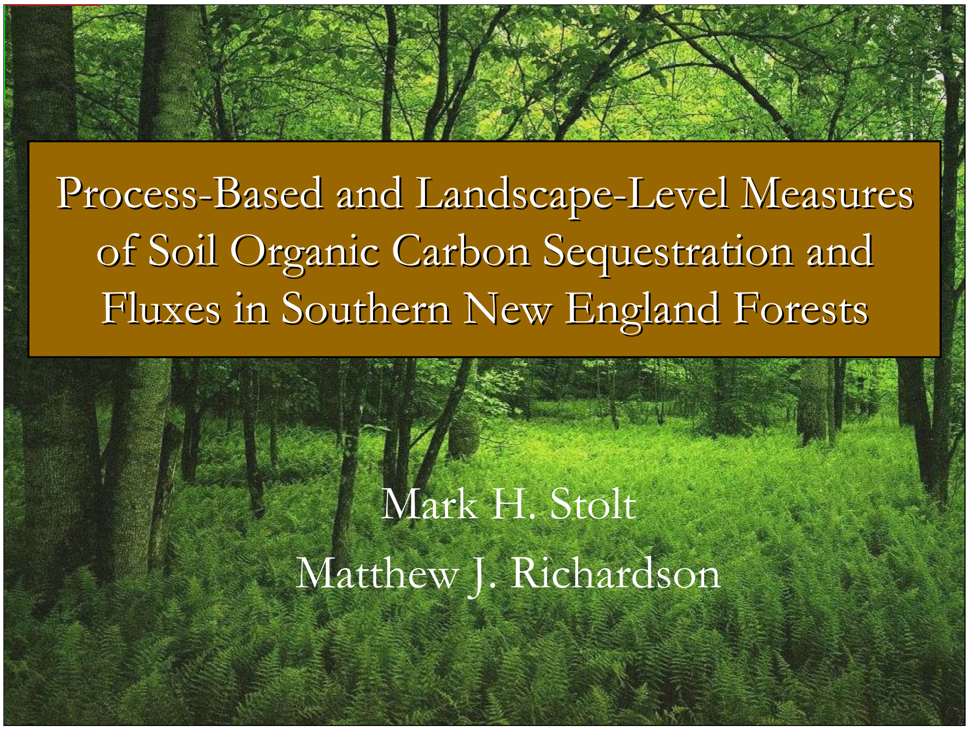
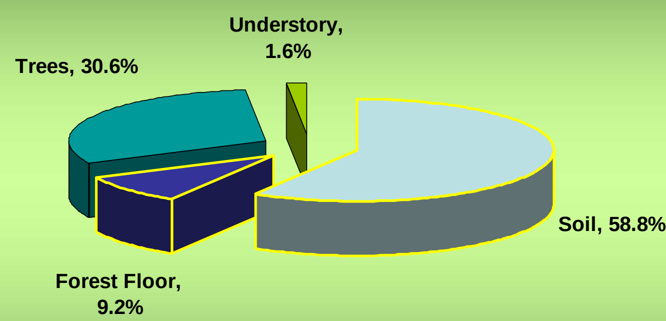



This work was done by my graduate student Matt Richardson at the University of Rhode Island. His thesis, having the same title as this presentation, is available from the university library.

# Forest Ecosystem Carbon Pools




In mature forests of temperate regions, soils comprise over 65% of the total carbon

It is important to note here that although we think of forests storing lots of carbon the soil actually stores much more.

# Land-Use and Carbon

- Land-use changes from agriculture clearing and plowing over past 200 years have resulted in the release of significant amounts of carbon to the atmosphere.
- In late 1800's 30% of New England was forested, now over 70% is forested.
- As these areas are reforested, carbon accumulates (until levels prior to disturbance are reached).

Aggrading (regeneration after a previous land use such as agriculture) forests accumulate carbon both in the vegetation and soil as they return. Understanding this is important in carbon cycle measures.

## Land-Use and Carbon

- How long do these aggrading forests in New England sequester significant carbon?
- Can forests be managed to accumulate carbon?
- Does land-use history affect accumulation rates?

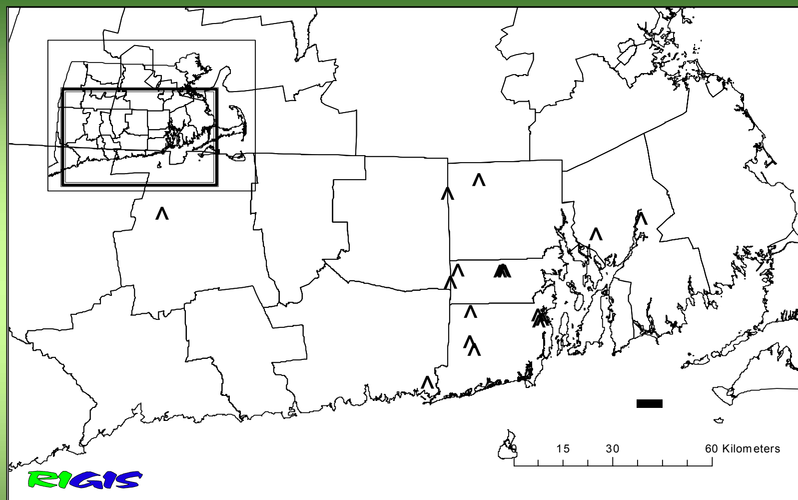
Not all of the carbon cycling effects within aggrading forests are understood. These are some of the commonly posed questions.

## Objectives (I)

- Measure soil organic carbon (SOC) pools and sequestration rates in aggrading southern New England forests
- Test the effects of forest type and soil type on SOC sequestration
- Compare results from two different approaches (paired site and chronosquence) to measure SOC sequestration

Our goal was to answer some of these questions using these research objectives.

# Site Locations




17 sites, ranging in age from 25 to 86 years.

We worked in southern New England, primarily in Rhode Island, but also had sites in Connecticut and Massachusetts.

# Soil Sampling

- Sampled to a depth of 1 m using split-core sampler
- Collected samples based on breaks in master horizons (A, B, and C)
- O horizons were sampled by cutting a 15 x 15 cm section of the forest floor

We sampled the soil to a meter using a split core sampler. Samples were divided based on master horizon breaks.

## Analyses

**Bulk Density**

- Determined based on weight and volume of samples.

**Carbon Content**

- Used C:N analyzer to determine percent carbon of each soil sample collected.

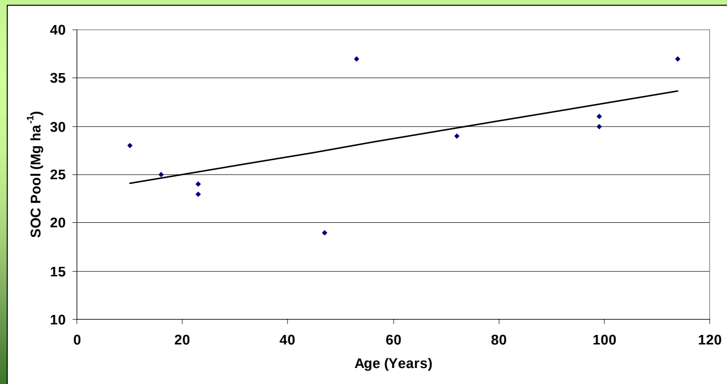
**Forest Age**

- Tree cores - dyed to enhance rings and counted to determine forest ages.

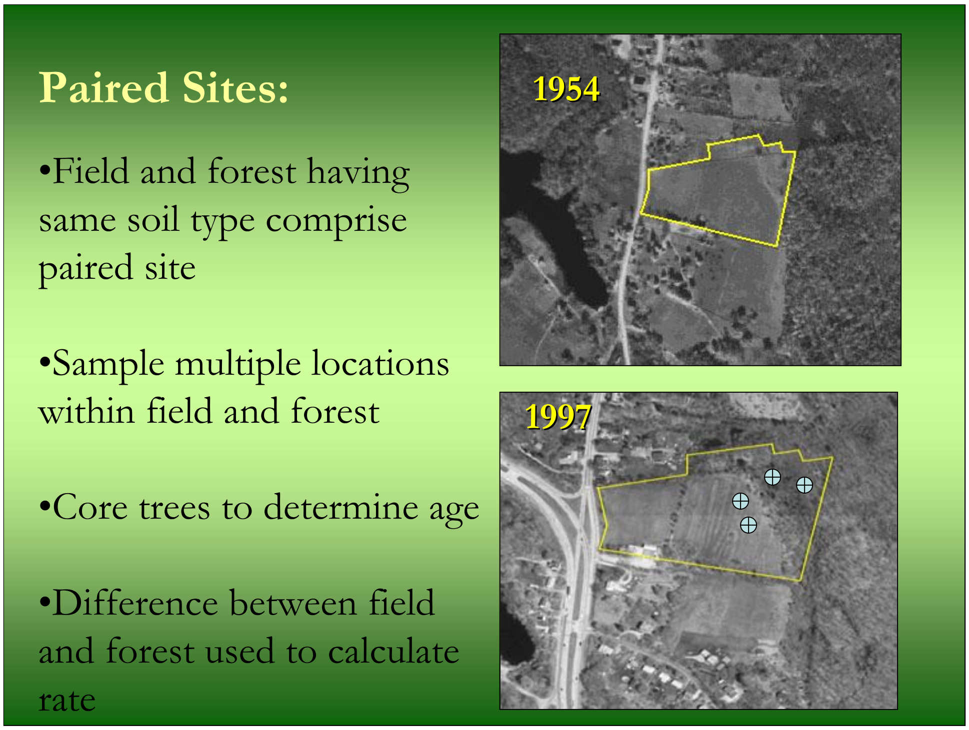
To calculate carbon accumulation on an area basis (Megagrams per hectare; Mg/ha) measures of bulk density, carbon content, and the age of the forest are necessary.

# Chronosequence Approach

Chronosequence – uses SOC pools from different aged forests to calculate a single sequestration rate.




The chronosequence approach is the most commonly used method in the literature to calculate carbon sequestration in aggrading forests.




We used the paired site approach to calculate carbon sequestration. A paired site includes a forest and an agricultural field that are adjacent and have been mapped the same soil type. In these photographs, the soils in the northeast corner of the field are in the Merrimac series. Photographs from 1939 and 1954 showed the cultivated field was approximately the same size. 1972 photographs suggest the northeast corner of the field is returning to forest. By 1997, the northeast corner has completely reverted to deciduous forest.

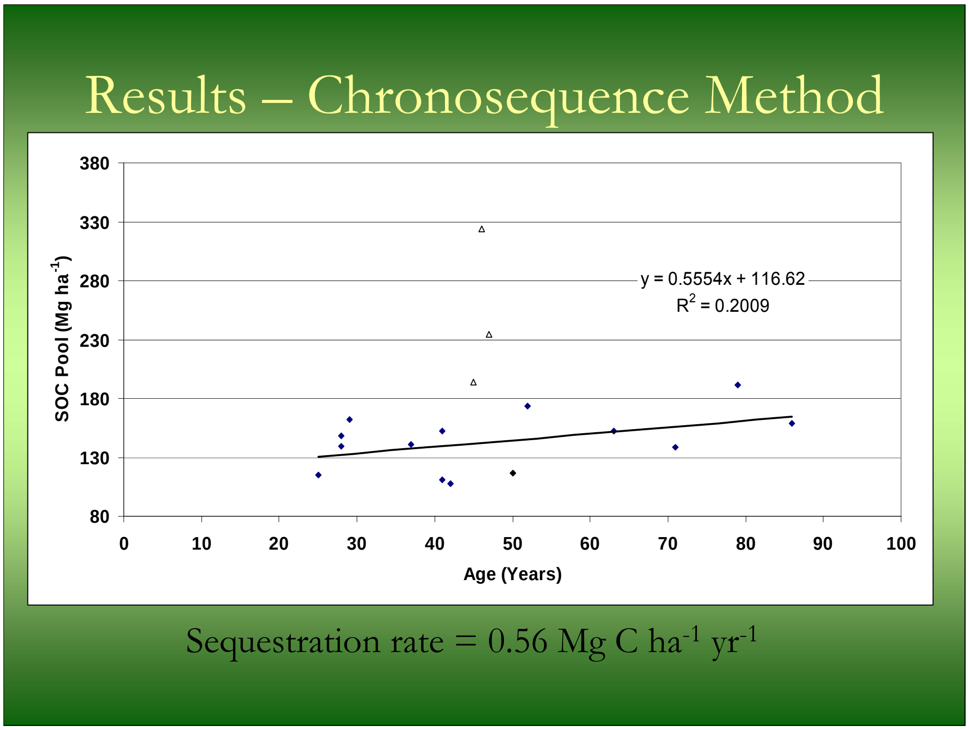
# Results – Site Ages and SOC Pools

| Soil or Vegetation Type | n | Mean Field Pool Size* (Mg C $ha^{-1}$)** | CV (%) | Mean Forest Pool Size* (Mg C $ha^{-1}$)** | CV (%) |
|---|---|---|---|---|---|
| Merrimac | 7 | 102[a] | 31 | 150[a] | 23 |
| Sudbury | 9 | 118[a] | 27 | 154[a] | 24 |
| Coniferous | 9 | 110[a] | 34 | 160[a] | 22 |
| Deciduous | 7 | 113[a] | 21 | 142[a] | 22 |
| Total | 16 | 111[†] | 28 | 152[†] | 22 |

** Means with different letters are significantly different based on a t-test at the $\alpha = 0.05$ level within field and forest types.

- Mean forest pools were significantly higher than mean field pools ($p<0.01$)

There was significant differences between field and forest C-pools, but there was not a significant difference in C-pools between soil types or forest types.




The chronosequence approach showed a 0.56 Mg of C per ha per year accumulation rate. The 3 data point shown by triangles were considered outliers and not used in the calculations.

# Results – Paired Site Method

| Site | Age (Years) | Forest Type | Difference Between Field and Forest Pools (%) | Whole Soil SOC Sequestration Rate (Mg C $ha^{-1}$ $yr^{-1}$) |
|---|---|---|---|---|
| St6 | 25 | Coniferous | 31 | 1.42 |
| SR1 | 28 | Coniferous | 19 | 0.92 |
| SNK2 | 28 | Deciduous | 12 | 0.61 |
| S3 | 29 | Deciduous | 34 | 1.91 |
| MC3 | 37 | Coniferous | 10 | 0.39 |
| SBurr1 | 41 | Deciduous | 8 | 0.22 |
| SC2 | 41 | Deciduous | 30 | 1.10 |
| Me1-MA | 42 | Deciduous | 13 | 0.34 |
| MNK2 | 45 | Deciduous | 18 | 0.79 |
| SG1 | 46 | Deciduous | 7 | 0.49 |
| SR2 | 47 | Coniferous | 18 | 0.90 |
| MNK10 | 50 | Deciduous | 22 | 0.52 |
| SWG1 | 52 | Coniferous | 27 | 0.90 |
| SC2-II | 63 | Coniferous | 29 | 0.71 |
| ME1 | 71 | Coniferous | 34 | 0.66 |
| MHC1 | 79 | Coniferous | 54 | 1.31 |
| MC2 | 86 | Coniferous | 60 | 1.11 |

- Mean sequestration rate = 0.84 Mg C $ha^{-1}yr^{-1}$.
- No significant differences among soil or forest type
- (but 8 of the 10 highest rates were for coniferous forests)

The paired site approach showed a higher sequestration rate than the chronosequence approach. Although our statistical comparisons indicated there was no significant differences between forest types and SOC pools, 8 of the 10 sites with the highest sequestration rates had coniferous vegetation suggesting that coniferous forests sequester carbon in the soils faster than deciduous.

## Results – Comparison of Approaches

| SOC Pool | Chronosequence Rate (Mg C ha$^{-1}$ yr$^{-1}$) | Paired Sites Rate (Mg C ha$^{-1}$ yr$^{-1}$) |
|---|---|---|
| Total Soil | 0.56 | 0.84 |
| Mineral soil | 0.36 | 0.23 |
| O Horizon | 0.19 | 0.61 |
| A horizon | 0.34 | -0.02 |
| Subsoil | 0.02 | 0.16 |

**Chronosequence Method:**

- **Lower rate**
- **Majority of sequestration occurring in mineral soil**
- **O horizon rate relatively low**
- **Subsoil rate negligible**

**Paired Site Method:**

- **Higher rate (50%)**
- **Majority of sequestration occurring in O horizon**
- **A horizon not sequestering SOC**
- **Subsoil rate more significant**

The comparison between the two approaches suggests considerable differences. The data suggest the chrosequence approach is underestimating carbon sequestration rates.

# Effects of Land-Use History

| Site | Forest Age (years) | Field Vegetation | Forest Vegetation | Soil Type | Field Pool (Mg C $ha^{-1}$) | Forest Pool (Mg C $ha^{-1}$) |
|---|---|---|---|---|---|---|
| SG1 | 46 | Hay | Deciduous | Sudbury | 301 | 324 |
| | | | | Mean | 111 | 152 |

- Much higher SOC pools could be due to previous land-use practices.
- In the chronosequence method, this site was considered an outlier.
- The paired site method showed a 7% difference between field and forest SOC pools. Rate = 0.49 Mg C $ha^{-1}yr^{-1}$.
- Data suggest paired site method is more effective at accounting for land-use history affects.

The paired-site approach offers a way to take into account land use history effects. Fields that have reverted back to forest have likely undergone the same land use history as the adjacent field that has not been converted. Therefore, effects of land use history on C-sequestration should be minimal. For example, the SG1 site had a filed pool of 301 and a forest pool of 324 Mg of C per ha. If the mean field pool was used as the starting point for this aggrading forest (which is essentially what is done in a chronosequenece approach), this 46 year old forest would accumulate C at a rate of 4.6 Mg per ha per year. This is 10 times the actual rate.

## Summary (I)

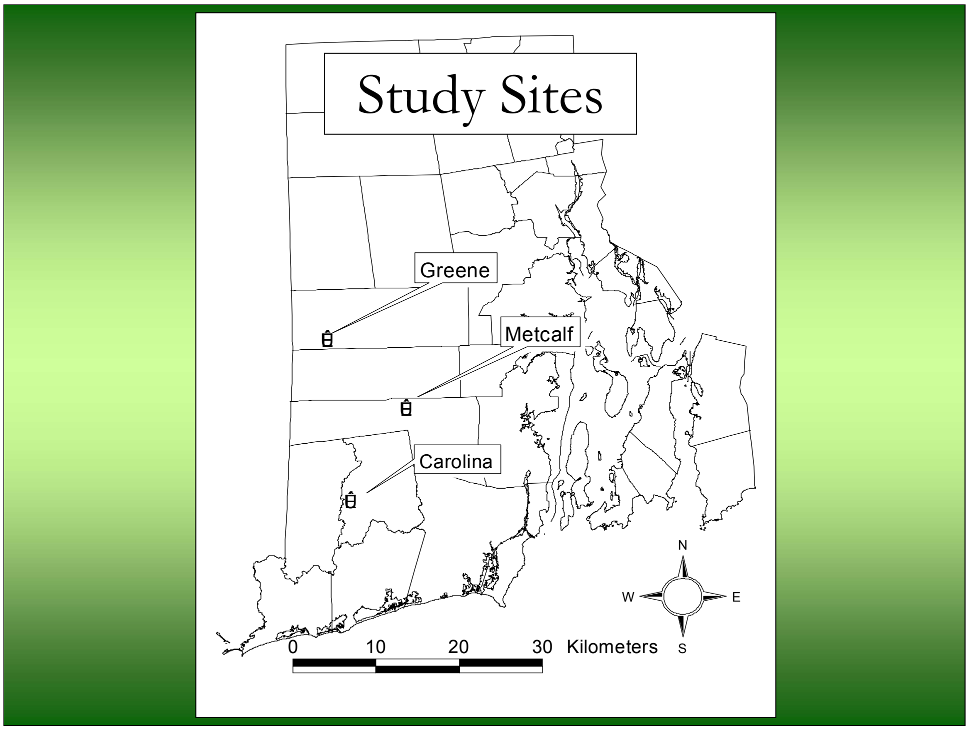
- SOC pools and sequestration did not differ significantly by soil or forest type
- Chronosequence method likely underestimating SOC sequestration
- Paired site method accounts for variability among sites due to land-use history

In general, our studies suggested that there are not significant differences between SOC pools of different forests or between well drained and moderately well drained soils. The results suggest the paired site approach may provide a more accurate estimate of C sequestration rates in temperate forests of southern New England and that land use effects can be accounted for using this approach.

# Objectives (II)

- Document SOC additions and losses in three forested watersheds
- Use these process-based measurements of SOC flux to develop annual SOC budgets
- Compare annual process-based fluxes to paired site sequestration rates

In the second part of the study we took a process based approach to examine C sequestration.




We worked in 3 small forest watersheds in Rhode Island.

# Watershed Characteristics

| Site | Size (ha) | Deciduous (%) | Coniferous (%) | Stream Type | Mean Daily Discharge ($m^3$ $day^{-1}$) |
|---|---|---|---|---|---|
| Carolina | 32 | 81 | 19 | Seasonal | 467 |
| Greene | 83 | 59 | 41 | Seasonal | 623 |
| Metcalf | 142 | 91 | 9 | Perennial | 900 |

Carolina

Metcalf

The 3 watershed differed in their size, daily discharge, stream persistence, and distribution of coniferous and deciduous vegetation.

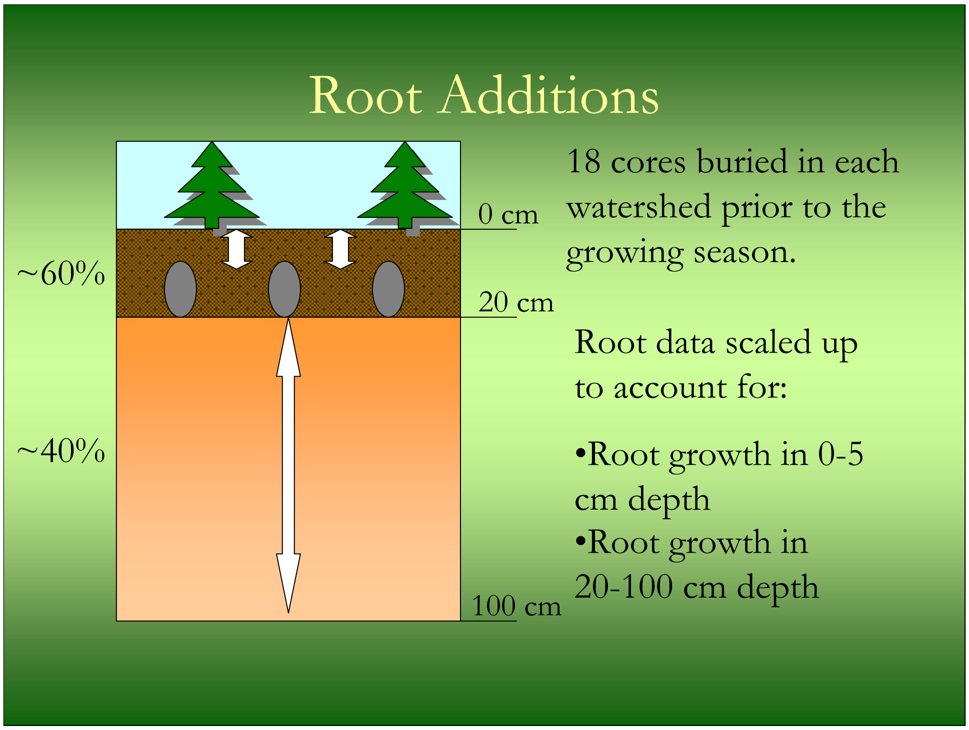
# Carbon Additions

**Leaf Litter** – collected bi-weekly to bi-monthly, depending on the season.

**Deadfall** – ½ meter square plots to determine yearly inputs.

**Roots** – fine roots measured using in-growth cores. Coarse roots estimated.

We measured C additions as leaf litter, deadfall, and roots.



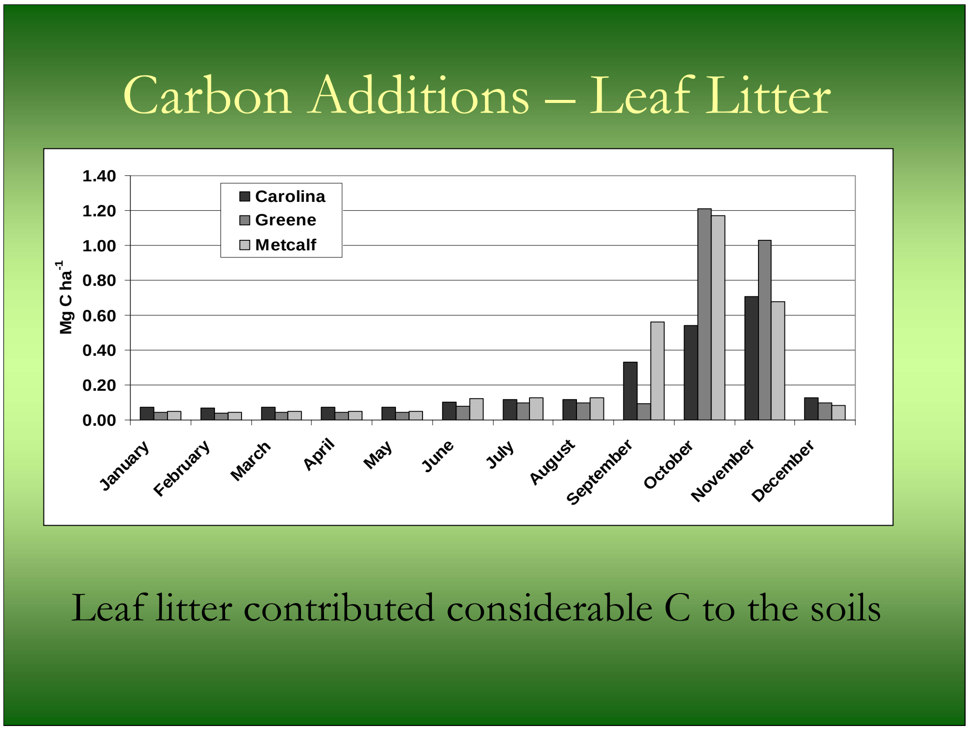

Fine root additions were measured within a depth of 5 and 20 cm from the soils surface using in-growth cores. These data were used to extrapolate coarse root additions and root additions from 0-5 and from 20 -100 cm. These extrapolations were based on published literature.

# Carbon Losses

**$CO_2$** – measured carbon lost through soil respiration. Collars in place in soil for repeated measurements from same locations

**DOC** – measured carbon lost through stream flow out of the watershed

We used the dynamic closed chamber approach to measure CO2 losses and DOC concentrations in the stream water times discharge rates to track DOC losses fro the watershed.




Most leave litter additions occurred in September, October, and November.

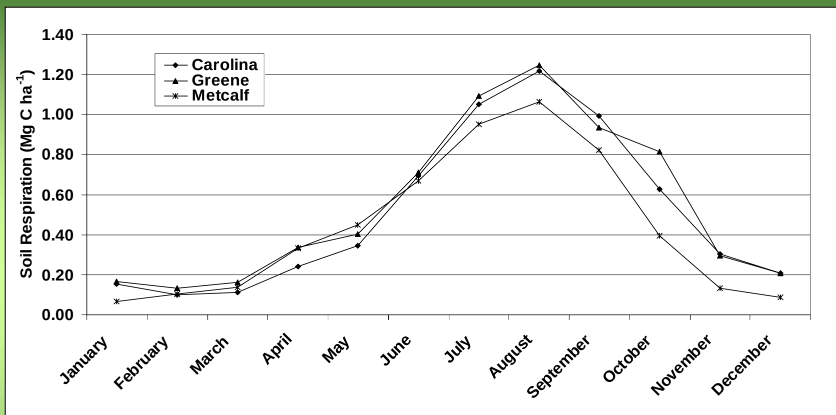
# Carbon Additions - Roots

Fine root additions averaged 2.3 Mg C $ha^{-1}$ $yr^{-1}$.

No significant differences among drainage classes.

The 15 cm core on the right was placed in the soil at a depth between 5 and 20 cm in March and removed at the end of the growing season. On average this approach estimated that 2.3 Mg of C per hectare per year is added as fine roots to the upper meter of these forest soils.

# Carbon Losses

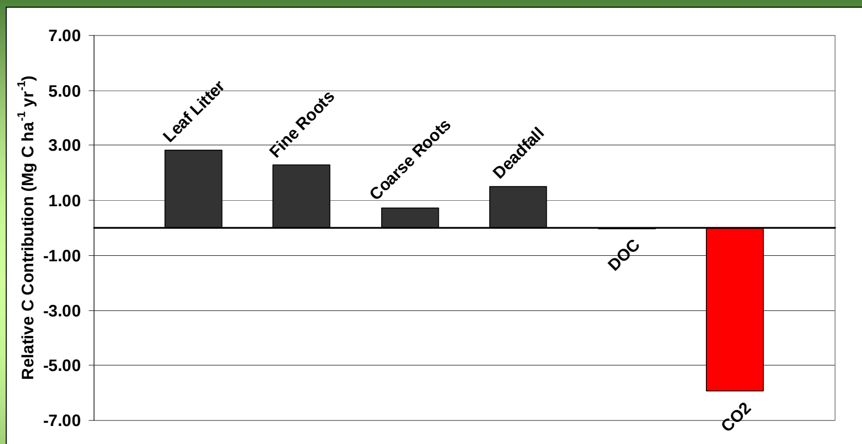



• Soil respiration varied with temperature.

• No significant differences were observed among drainage classes.

Carbon losses (CO2) related to respiration varied with temperature. Soil drainage class did not appear to effect respiration rates such that well drained soils had essentially the same CO2 losses as poorly drained soils.

# Overall Annual Fluxes




Annual fluxes ranged from 0.85 to 2.14 Mg C $ha^{-1}$ $yr^{-1}$, averaging 1.39 Mg C $ha^{-1}$ $yr^{-1}$.

Leave litter additions were essentially equivalent to estimate total root additions. Nearly all losses are from soil respiration. DOC losses are essentially irrelevant in watershed scale C flux mass balances.

# Summary (II)

- Leaf litter and fine roots most significant additions within watersheds.
- Soil respiration accounts for nearly all losses and DOC is negligible.
- Mean annual flux higher than paired site SOC sequestration rate, but within range of reported values.

# Conclusions and Implications

- Additional studies focusing on drainage class and $CO_2$ flux needed.
- Additional studies focusing on root production would help to solidify C flux budgets.
- SOC represents 35 – 40% of ecosystem C sequestration.
- Coniferous forests may be more efficient at sequestering SOC and forests could be managed to sequester C.
- Using the rates we measured, approximately 5 ha of forest sequesters enough carbon to offset the emissions of a typical person.