



# Coastal Forest Monitoring Report, Cape Cod National Seashore

## *Comparison of 2003 and 2013 Data*

Natural Resource Technical Report NPS/CACO/NRTR—2014/876



**ON THE COVER**

Photograph of forest canopy by: Stephen Smith, 2012.

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## Abstract

Forests and woodlands occupy the largest area within Cape Cod National Seashore (CACO) and are largely a reflection of the harsh coastal environment and past land-use history. Forest ecosystems in CACO are, and will continue to be, influenced by a number of different natural and anthropogenic factors. These include groundwater withdrawal, fragmentation, introduction of exotic species, disease and plant pests, and various aspects of climate change. Documenting changes in forest structure and function is an important priority for the Seashore in terms of understanding the resource and ultimately managing it.

In 2003 and 2013, forest vegetation was surveyed in permanent plots situated in the different forest types across CACO. Comparisons of the 2003 and 2013 tree data show that secondary succession within the forest overstory, as would be manifested in changes in tree species composition, has not occurred to any significant extent. Instead, existing trees are still growing and filling in open space rather than being outcompeted by other species. This is reflected in the total number of live trees which decreased for most species, suggesting that intraspecific competition and the continued growth of fewer, but hardier trees is occurring.

Of all tree species within the CACO forest monitoring sites, *P. rigida* and *Q. velutina* are growing the most rapidly. There has been a 12% average increase in canopy cover between 2003 and 2012. This has resulted in a shift to more shade-tolerant species such as *Carex pensylvanica* (Pennsylvania sedge; sedge), *Trientalis borealis* (starflower; forb), and *Mianthemum canadense* (Canada Mayflower; forb). *Q. velutina* and *Q. alba* both increased in frequency in the understory by 11% and 5%, respectively. Tree seedling densities actually decreased quite dramatically between 2003 and 2012. Understory species richness generally exhibited an increasing trend at the sites – another indicator of early successional processes. However, while a number of new species appeared between 2003 and 2012, overall plant community composition did not change significantly. In contrast, the proportion of the various growth forms did, with shrub species exhibiting large decreases compared to forb vegetation (the latter increasing at most sites). This makes sense given that there are many more herbaceous species that are shade-tolerant than there are shrub species. In general, the forests in CACO are young and many of the processes typical of older growth forests are not yet evident (e.g., significant community-level change; replacement of tree species). The next survey scheduled for 2022 will shed more light on the rate at which this processes is occurring.



# Introduction

Although Cape Cod National Seashore (CACO) may be best known for its ocean beaches, the interior forests and woodlands are the most prominent ecological feature of this coastal landscape. In the period before European settlement, Cape Cod was covered largely by pine-oak forests, interspersed with smaller areas of hickory (*Carya* spp.), beech (*Fagus grandifolia*), red maple (*Acer rubrum*), and birch (*Betula* spp.) (Motzkin et al. 2002). By the 18<sup>th</sup> and 19<sup>th</sup> centuries, much of Cape Cod had been transformed into wide open heathlands and grasslands that were created and maintained by agricultural practices of early settlers, including cutting, grazing, and burning (Eberhardt 2001, Eberhardt et al. 2003). The cessation of these activities by the mid-1800s allowed trees to re-invade the landscape (Patterson et al. 1983, Motzkin et al. 2002, Parshall et al. 2003), and forests now occupy the largest land-surface area and biovolume of any vegetation community.

The independent and interactive effects of human history and the coastal environment have resulted in a unique mosaic of forest types, each with the potential to follow a different trajectory of change. Scientifically monitoring and understanding this change has become an important priority for the Seashore because it can be used as a tool with which to manage forest resources. Currently, the dominant tree species within CACO is pitch pine (*Pinus rigida*), followed closely by black oak (*Quercus velutina*) and white oak (*Quercus alba*). Various mixtures of the above comprise most of the forest habitat, but this is broken up by smaller areas of exotic black locust (*Robinia pseudoacacia*), beech (*Fagus grandifolia*), red maple (*A. rubrum*), and Atlantic white cedar (*Chamaecyparis thyoides*) (Sneddon et al. 2000). Stands of *R. pseudoacacia*, most of which were planted by humans, exist as scattered, isolated patches throughout the middle and southern portion of CACO, whereas *F. grandifolia* predominates within a single, unfragmented stand of mature forest at the northern tip of the peninsula. *A. rubrum*, and to a lesser extent and *C. thyoides*, occur in a number of flooded depressions in the landscape.

At CACO, forest monitoring has taken place in various forms over the years with the first quantitative fieldwork occurring in 1981. To provide the audience of this report with some context on this and subsequent monitoring, the following text has been excerpted from the Forest Monitoring Protocol (Smith et al. 2011).

“Dr. William Patterson (University of Massachusetts, Amherst) established 21 sampling sites in forest habitat within the boundaries of CACO in 1981 (Patterson et al. 1983). The primary objective of this study was to collect data on forest structure and composition for modeling fire regimes (Patterson et al. 1983). The sites themselves were defined by a network of rebar stakes (hereafter known as “fire stakes”) representing points at which data were collected. The number and arrangement of stakes varied among sites and were based on subjective determinations of stand boundaries as inferred by various structural and compositional commonalities (Patterson et al. 1983).

Trees were sampled in two ways: At each fire stake, an angle gauge (“Cruz-all” type) was used to estimate basal area and tree densities, which yields data within circular areas of variable-radius depending on tree size and distance away from the sample point. In addition, tree cover was recorded within 20×20-m

subjectively placed relevé plots, which varied in number according to stand size. Estimates of percent cover of near-ground (i.e., shrubs, saplings between 0.5 and 2 m in height) and ground (<0.5 m in height) vegetation were recorded as ordinal ranks in 1-m<sup>2</sup> fixed-area circular plots (the center of each plot being the fire stakes).

In 1992, Unna Chokkalingam (Dr. Patterson's graduate student) re-located and re-surveyed 13 of the original fire-stake arrays to analyze changes over the previous decade (Chokkalingam 1995). As in 1981, trees were sampled in variable-radius plots. Shrub vegetation, however, was assessed in a different manner, by enumerating stems within 4-m<sup>2</sup> circular plots centered on each stake. Similar to 1981, herbaceous cover was recorded within 1-m<sup>2</sup> circular plots.

In 2002-2003, 13 sites surveyed in 1981 (Patterson et al. 1983) and 1992 (Chokkalingam 1995) were revisited and sampled by both the original method (variable-radius point-sampling) and a new method that used a fixed-area (modular) design (Barrett 1999, Hubbard 2001)."

In 2003 and 2012, the revised monitoring protocol suggested by Hubbard (2001) (see above excerpt) was implemented. Some of the 2003 data is discussed in Smith et al. (2011). However, this report provides a more extensive analysis of 2003 and makes comparisons with 2012 data to assess temporal changes in forest structure and composition.

## Methods

Methods for data collection follow Smith et al (2011) and are described in detail in that document. Monitoring was conducted in thirty-eight 0.04 ha fixed-area plots (20m x 20m sites) that were originally placed within different forest types (based on the dominant tree types) pine, pine-oak, oak, black locust, red maple, beech, Atlantic white cedar) (Figure 1). Absent from Figure 1 are sites CC04 (pine-oak), CC10 (pine-oak), and CC27 (oak), which are currently not monitored since the first two were established in 1981 and could not subsequently be found and CC27 was deleted from monitoring network due to human disturbance.

Each site is subdivided into smaller, nested plots for sampling different strata of forest vegetation (Figure 2; Smith et al. 2011). Because the 1981 and 1992 surveys were conducted in a different manner (Patterson et al. 1983, Chokkalingam 1995) than they were in 2003 and 2012, comparisons of variables for all four datasets could not be done, with the exception of diameter at breast height. Even analysis of the latter variable is somewhat compromised by differences in the number of sampling points and spatial scale between 1981/1992 and 2003/2012. Apart from this variable, this document is entirely focused on more recent changes between 2003 and 2012.

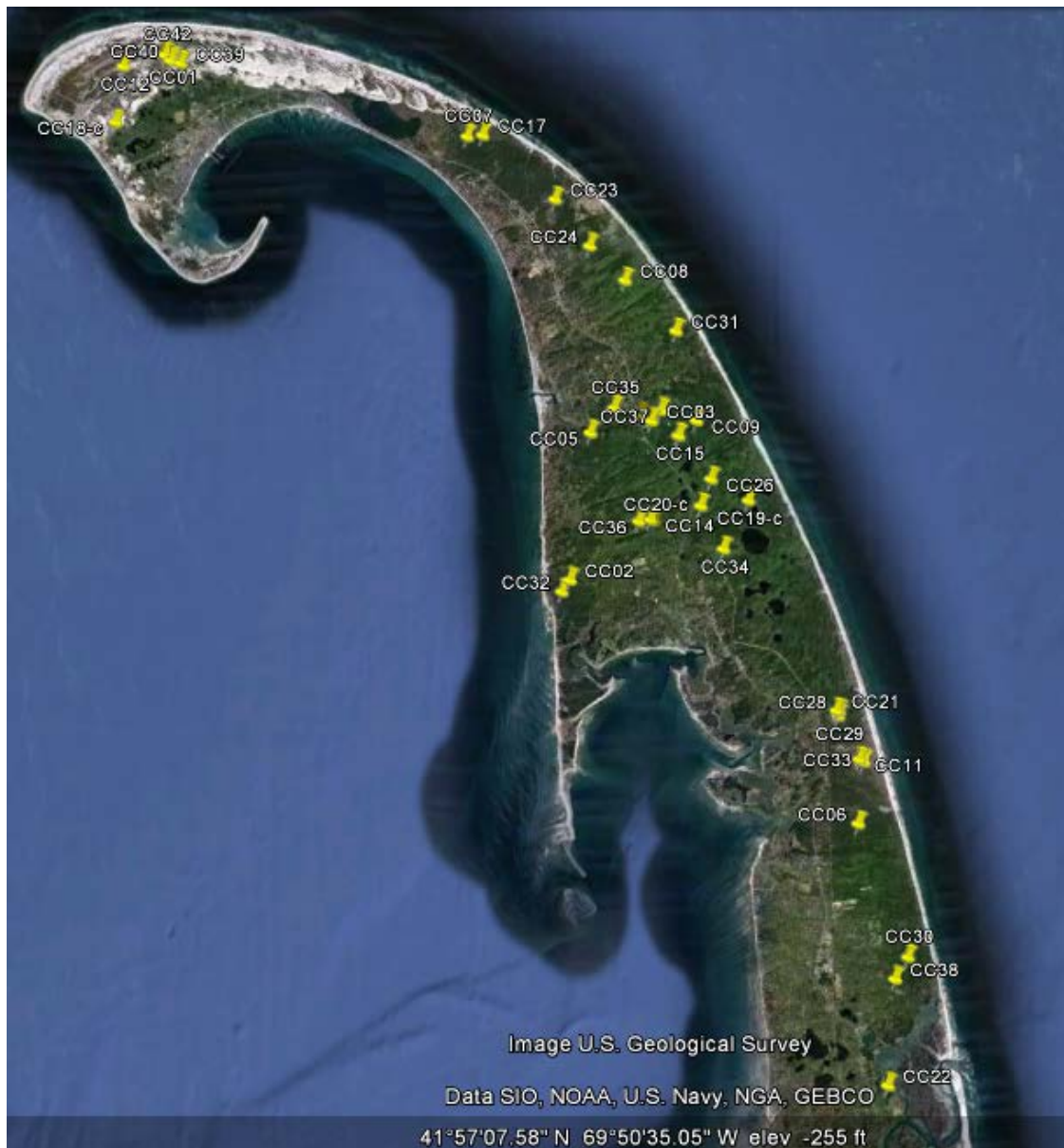


**Figure 1.** Map of CACO forest monitoring sites (2003 and 2012).

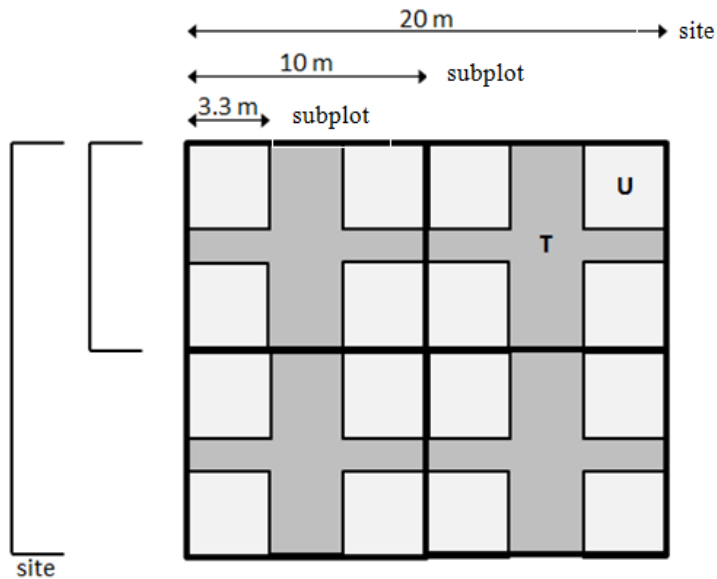


**Figure 2.** Diagram of fixed-area sampling plots (2003 and 2012) (T=tree layer scale of monitoring in 10 x 10m modules; U=understory scale of monitoring in 3.3 x 3.3 m subplots).

## Additions to monitoring in 2012

### *Soil and leaf litter sampling*

In 2012, soils were collected from the monitoring sites for the first time. Within each module (4 per site; Figure 2) an appropriate sampling location (i.e., no trees or dense roots) was selected and the loose organic debris cleared away by hand until the consolidated soil surface was reached. A butyrate tube (20-cm long, 10-cm diameter) was then inserted into the ground to a depth of 15 cm and the soil sample pushed out by plunger into a Ziploc bag. Leaf litter depth was determined at the time of soil sampling by measuring from the top of the litter layer to the surface of the consolidated soil. All samples were transported back to the North Atlantic Coastal Laboratory (NACL) where they were dried at 105°C to a constant weight and stored until they could be processed for particle size fractionation and organic matter content.

For organic matter content, soil samples were thoroughly dried and homogenized by breaking up the large clumps by mortar and pestle. Weight loss after combustion of the organic matter was then determined by placing the small subsamples of the homogenized material (~10 g) in a muffle furnace at 550°C for 5 hours. Particle size fractionation was accomplished by sieving the samples through multiple sieves corresponding to 1-2mm, 0.5-1mm, 0.25-0.5mm, 0.1-0.25mm, 0.05-0.1mm, and <0.05mm grain-sizes. The different fractions were then weighed and their relative contribution to the total sample weight calculated.

### *Elevations*

General elevations of the forest sites were determined in ARCGIS (ver. 10) using LIDAR coverage (2010) of CACO provided by the Army Corps of Engineers (ACOE). Forest site point data were overlaid on the LIDAR rasters and their corresponding elevations were extracted.

### ***Qualitative evaluation of aerial photography***

Aerial photographs available in Google Earth™ were used to conduct a qualitative assessment of changes in forest cover between 1995 and 2012 (1995 was the oldest date available). To do this, ten randomly-selected forest areas (Figure 3) of approximately 25 ha were examined for visually obvious changes in land cover. Since conifers (e.g., pitch pine) have dark signatures can easily be distinguished from deciduous trees (e.g., oaks) with light signatures, this kind of assessment, while qualitative only, can provide additional context for interpreting ground-level monitoring data and in assessing landscape changes over larger spatial scales.

Note: automated methods of mapping could not be used to conduct these assessments since the last vegetation classification within CACO was based on 2000 photography (there are no maps of more recent origin). CACO is currently working on a digital classification system to perform objective analyses of land cover changes over time using satellite imagery.

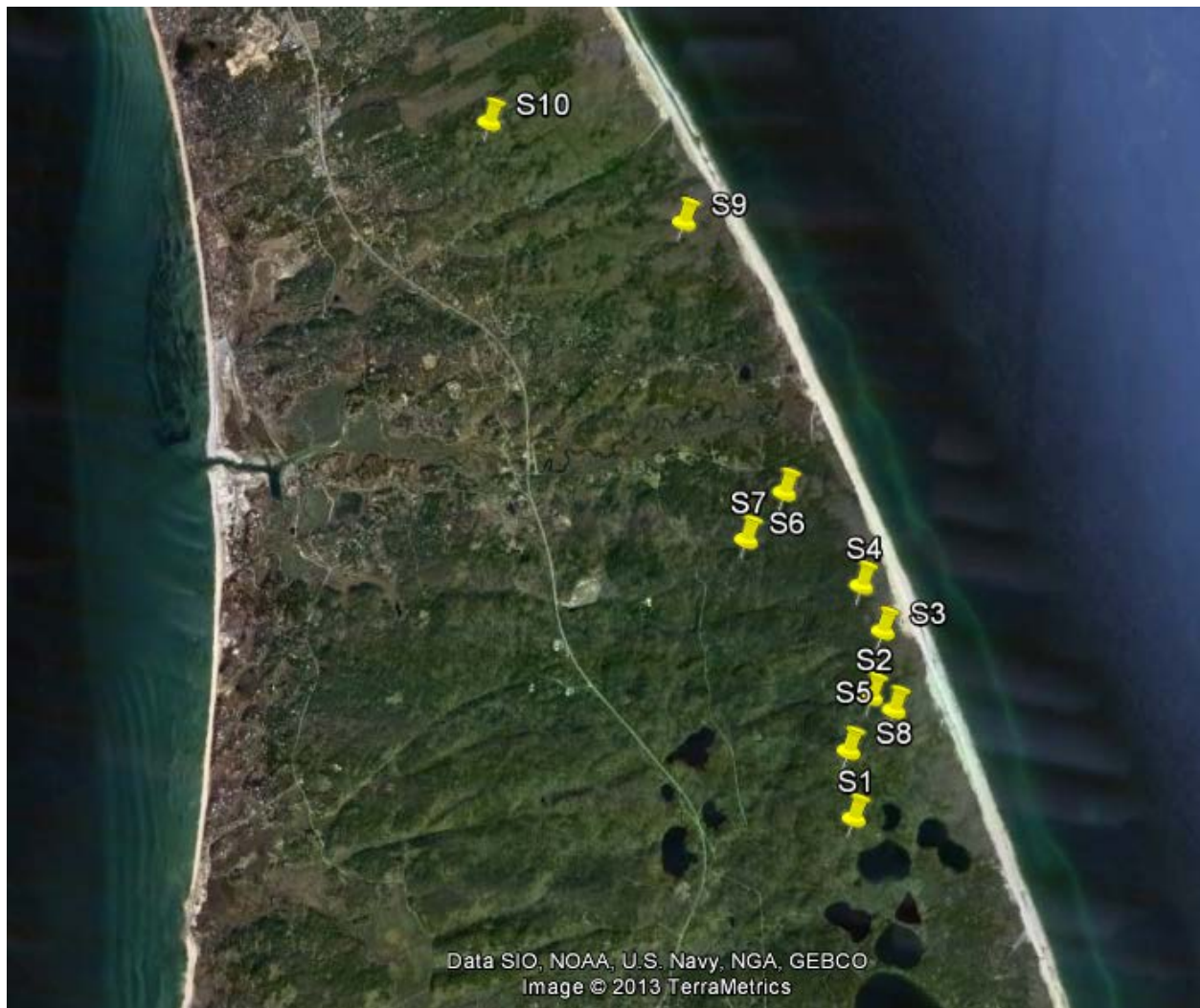


**Figure 3.** Map of locations for qualitative aerial photo analysis.

## Statistics

Statistical analyses followed standard methods outlined in Smith et al (2011), which are largely based on the concepts of Kent and Coker (1996). For parametric data, values were log-transformed to improve normality/heteroscedasticity and subjected to Analysis of Variance (ANOVA). Upon a significant ANOVA result, specific comparisons of means were conducted by Tukey's HSD tests (XLSTAT ver. 5.01). For non-parametric multivariate data, non-metric multidimensional scaling (NMDS) was used to illustrate differences in species composition among sites and survey years (Primer ver. 6.0). Principal components analysis (PCA) was also useful for visually depicting how different variables contributed to spatial patterns of sample distribution in ordinal space (Primer ver. 6.0). Analysis of similarities (ANOSIM) provided a means to test for significant differences among multivariate datasets and Analysis of Similarities (SIMPER) revealed which variables contribute most to dissimilarities among groups (Primer ver. 6.0). Spearman correlation was used to examine changes at individual sites between 2002 and 2012 (XLSTAT™).

For certain sites and variables, there were some missing data. For example, no data were collected for 1) understory cover in the nested subplots for CC01 (beech) in 2003 (unknown reason), 2) canopy cover (photos) at CC15 (pine-oak), CC16 (pine-oak), CC20 (red maple), and CC35 (black locust) in 2012 (field crew ran out of time), and 3) tree seedling counts at CC18 in 2003 (unknown reason). In addition, there are only data for the genus *Amelanchier* (shadbushes) because the field crew in 2003 did not record these shrubs to species. Based on our knowledge of CACO and the larger region, *Amelanchier* spp. likely consist of *A. canadensis*, *A. arborea*, and/or *A. laevis*.



# Results

## Trees

Note: overstory “tree” species were defined as those that have the potential to become part of the uppermost canopy layer species. Although some shrub species (e.g., *Ilex glabra* or inkberry) sometimes reached over 2 m in height, any species not conforming to the definition above, and that are defined as “shrubs” according to the USDA PLANTS database (<http://plants.usda.gov>) are not included in overstory analyses.

### **Tree densities in 2012**

In 2012, the total number of overstory tree species recorded was 14 (Table 1). For total numbers of trees (i.e., all sites), *P. rigida* was the most abundant taxon (> 500 total trees), followed by *Q. velutina* and *A. rubrum* (> 300 total trees). *Sassafras albidum* (Sassafras) and *Juniperus virginiana* (Eastern red cedar) occurred at the lowest densities ( $\leq 30$  total trees).

**Table 1.** Total tree densities (all sites) by species in 2012.

| Species                       | Total trees |
|-------------------------------|-------------|
| <i>Pinus rigida</i>           | 512         |
| <i>Quercus velutina</i>       | 341         |
| <i>Acer rubrum</i>            | 304         |
| <i>Quercus alba</i>           | 217         |
| <i>Prunus serotina</i>        | 217         |
| <i>Chamaecyparis thyoides</i> | 105         |
| <i>Robinia pseudoacacia</i>   | 104         |
| <i>Fagus grandifolia</i>      | 95          |
| <i>Nyssa sylvatica</i>        | 66          |
| <i>Amelanchier spp.</i>       | 41          |
| <i>Sassafras albidum</i>      | 30          |
| <i>Juniperus virginiana</i>   | 1           |

In terms of the average number of trees/site by species where they were present, *C. thyoides* occurred at the highest densities (> 50 trees/site), followed by *Q. alba*, *A. rubrum*, and *Prunus serotina* (black cherry) (> 20 trees/site) (Table 2). *J. virginiana* and *Nyssa sylvatica* (black gum) were the least dense, averaging 1 tree/site (site = 400m<sup>2</sup>).

**Table 2.** Average tree densities by species among sites where they were present in 2013.

| Species                       | Mean density (trees/site) | SE  | No. sites where present |
|-------------------------------|---------------------------|-----|-------------------------|
| <i>Chamaecyparis thyoides</i> | 52.5                      | 0.5 | 2                       |
| <i>Sassafras albidum</i>      | 30.0                      | -   | 1                       |
| <i>Prunus serotina</i>        | 24.1                      | 9.6 | 9                       |
| <i>Acer rubrum</i>            | 23.4                      | 6.8 | 13                      |
| <i>Pinus rigida</i>           | 22.3                      | 3.2 | 23                      |
| <i>Robinia pseudoacacia</i>   | 17.3                      | 4.1 | 6                       |
| <i>Nyssa sylvatica</i>        | 16.5                      | 6.1 | 4                       |
| <i>Fagus grandifolia</i>      | 15.8                      | 5.8 | 6                       |
| <i>Quercus alba</i>           | 14.5                      | 3.9 | 15                      |
| <i>Quercus velutina</i>       | 11.8                      | 2.0 | 29                      |
| <i>Amelanchier</i>            | 10.3                      | 8.9 | 4                       |
| <i>Quercus ilicifolia</i>     | 4.1                       | 0.9 | 14                      |
| <i>Crataegus sp.</i>          | 4.0                       | -   | 1                       |
| <i>Juniperus virginiana</i>   | 1.0                       | -   | 1                       |

**Basal area in 2012**

Basal Area is the cross-sectional area of a tree (over the bark) at breast height (=1.3 meters above the ground). It is calculated using diameter at breast height (DBH) measured in the field. By species, total basal area (all sites) was highest for *P. rigida* and *C. thyoides* ( $> 7 \text{ m}^2$ ) and lowest for *S. albidum* and *J. virginiana* ( $0.01 \text{ m}^2$ ) (Table 3). Mean basal area (only includes sites where species was present) was highest for *C. thyoides* and *P. rigida* and lowest for *S. albidum* and *P. serotina*.

**Table 3.** Total and mean tree basal area by species (all 39 sites).

| Species                       | Total ( $\text{m}^2$ ) | Species                       | Mean ( $\text{cm}^2$ ) |
|-------------------------------|------------------------|-------------------------------|------------------------|
| <i>Pinus rigida</i>           | 15.62                  | <i>Chamaecyparis thyoides</i> | 615                    |
| <i>Chamaecyparis thyoides</i> | 7.26                   | <i>Pinus rigida</i>           | 492                    |
| <i>Quercus velutina</i>       | 5.42                   | <i>Fagus grandifolia</i>      | 472                    |
| <i>Robinia pseudoacacia</i>   | 4.75                   | <i>Crataegus sp.</i>          | 455                    |
| <i>Acer rubrum</i>            | 4.08                   | <i>Robinia pseudoacacia</i>   | 343                    |
| <i>Quercus alba</i>           | 3.18                   | <i>Quercus velutina</i>       | 200                    |
| <i>Fagus grandifolia</i>      | 2.55                   | <i>Nyssa sylvatica</i>        | 167                    |
| <i>Prunus serotina</i>        | 1.21                   | <i>Acer rubrum</i>            | 149                    |
| <i>Nyssa sylvatica</i>        | 0.22                   | <i>Quercus alba</i>           | 118                    |
| <i>Crataegus sp.</i>          | 0.18                   | <i>Juniperus virginiana</i>   | 86                     |
| <i>Amelanchier spp.</i>       | 0.14                   | <i>Amelanchier spp.</i>       | 36                     |
| <i>Juniperus virginiana</i>   | 0.01                   | <i>Prunus serotina</i>        | 22                     |
| <i>Sassafras albidum</i>      | 0.01                   | <i>Sassafras albidum</i>      | 2                      |

When tree species composition based on basal area is plotted in ordinal space, there is a wide scattering of sites (Figure 4). Differences in the abundance (based on basal area) of *P. rigida*, *C.*

*thyoides*, and *R. psuedoacacia* (black locust) account for most of the spatial separation (Figure 4, 5, Table 4).

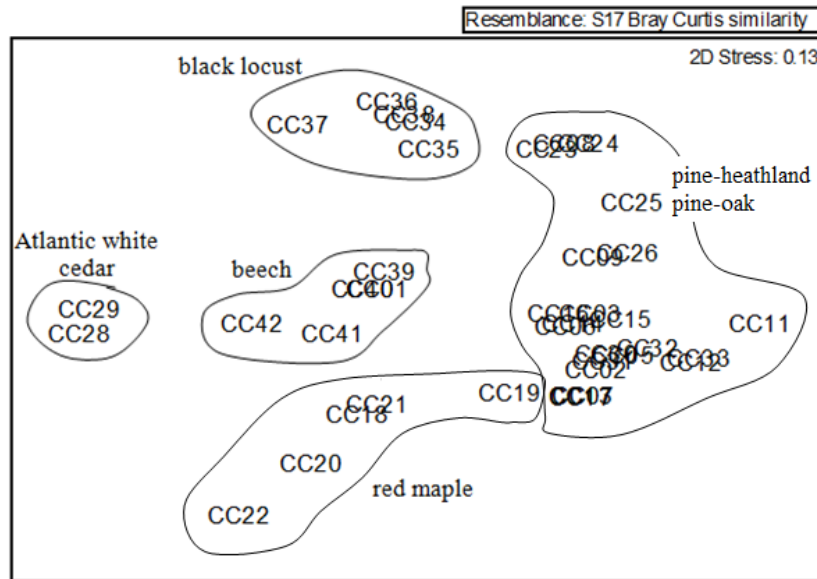


**Figure 4.** NMDS of basal area in 2012 (hand-drawn polygons show how sites of the same forest type cluster together).

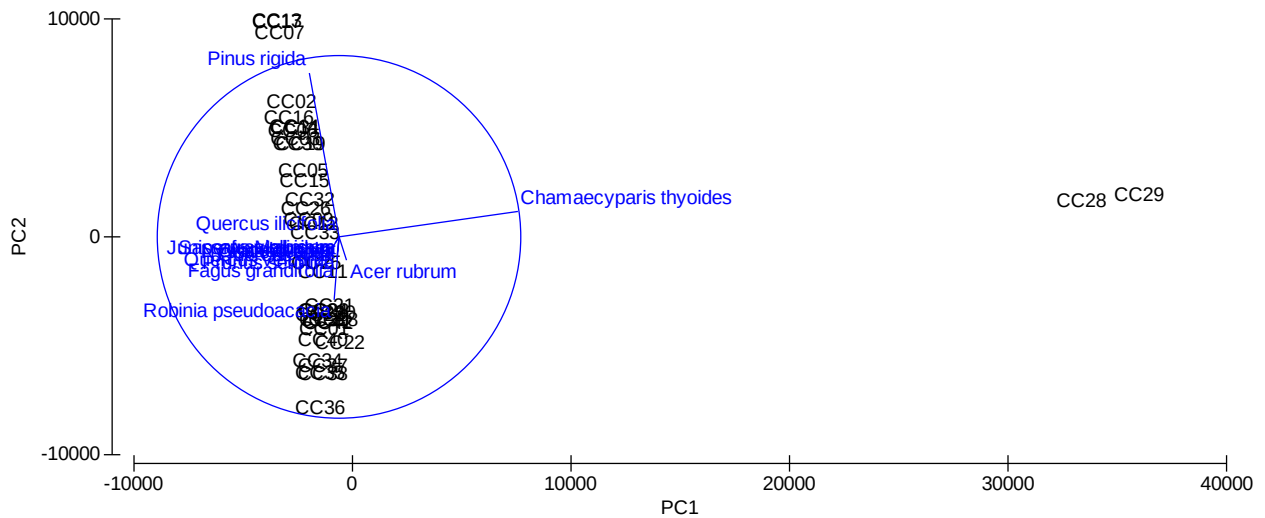


**Figure 5.** PCA of sites based on basal area (2012).

**Table 4.** Eigenvectors of PCA based on basal area in 2012 (highlighted rows indicate species contributing most to spread of data points in ordinal space by axis).

| Species                       | PC1    | PC2    |
|-------------------------------|--------|--------|
| <i>Acer rubrum</i>            | 0.041  | -0.129 |
| <i>Amelanchier</i> spp.       | -0.001 | -0.006 |
| <i>Chamaecyparis thyoides</i> | 0.984  | 0.140  |
| <i>Crataegus</i> sp.          | -0.001 | -0.012 |
| <i>Fagus grandifolia</i>      | -0.012 | -0.121 |
| <i>Juniperus virginiana</i>   | 0.000  | -0.001 |
| <i>Nyssa sylvatica</i>        | -0.003 | -0.018 |
| <i>Pinus rigida</i>           | -0.163 | 0.903  |
| <i>Prunus serotina</i>        | -0.007 | -0.081 |
| <i>Quercus alba</i>           | -0.022 | -0.034 |
| <i>Quercus velutina</i>       | -0.039 | -0.064 |
| <i>Robinia pseudoacacia</i>   | -0.027 | -0.347 |
| <i>Sassafras albidum</i>      | 0.000  | 0.000  |

### Changes between 2003 and 2012 (all sites)

#### *Tree density changes between 2003 and 2012*

Tree densities in 2003 and 2012 could not be compared to 1982 and 1992 data because of the variable radius plot design in the latter surveys (Patterson et al. 1983, Chokkalingam 1992). The 2003 and 2012 data were both collected within fixed, permanent plots (Smith et al. 2011) and thus could be compared for all variables.

Collectively (i.e., all plots pooled), substantial changes in the total number of trees per site between surveys were observed (Table 5). The largest changes occurred in *P. serotina* (black cherry), which decreased by 178 trees. Smaller changes occurred in *P. rigida*, which decreased by 41 trees, followed by *A. rubrum* (-26), *Amelanchier* spp. (-23), and *R. psuedoacacia* (-22). In contrast, *S. albidum* (+30) and *Nyssa sylvatica* (+23) increased.

**Table 5.** Changes (diff) in total tree numbers (all sites) between 2003 and 2012 by species

| Species                       | 2003 | 2012 | Diff |
|-------------------------------|------|------|------|
| <i>Sassafras albidum</i>      | 0    | 30   | 30   |
| <i>Nyssa sylvatica</i>        | 43   | 66   | 23   |
| <i>Quercus velutina</i>       | 340  | 341  | 1    |
| <i>Juniperus virginiana</i>   | 1    | 1    | 0    |
| <i>Quercus alba</i>           | 217  | 217  | 0    |
| <i>Fagus grandifolia</i>      | 96   | 95   | -1   |
| <i>Chamaecyparis thyoides</i> | 118  | 105  | -13  |
| <i>Robinia pseudoacacia</i>   | 126  | 104  | -22  |
| <i>Amelanchier spp.</i>       | 64   | 41   | -23  |
| <i>Acer rubrum</i>            | 330  | 304  | -26  |
| <i>Pinus rigida</i>           | 553  | 512  | -41  |
| <i>Prunus serotina</i>        | 395  | 217  | -178 |

**Frequency changes between 2002 and 2012**

Changes in frequency were much less pronounced than tree densities, with the largest changes occurring in *Q. velutina* (+10%) (Table 6). Despite a net loss of trees between 2002 and 2013 (Table 5), *P. serotina* increased in frequency by 8%. All other species exhibited changes of  $\leq 3\%$ .

**Table 6.** Changes in frequency by tree species between 2003 and 2012.

| Species                       | 2003 | 2012 | Change |
|-------------------------------|------|------|--------|
| <i>Quercus velutina</i>       | 64%  | 74%  | 10%    |
| <i>Prunus serotina</i>        | 15%  | 23%  | 8%     |
| <i>Sassafras albidum</i>      | 0%   | 3%   | 3%     |
| <i>Quercus alba</i>           | 36%  | 38%  | 3%     |
| <i>Pinus rigida</i>           | 56%  | 59%  | 3%     |
| <i>Crataegus sp.</i>          | 0%   | 3%   | 3%     |
| <i>Acer rubrum</i>            | 31%  | 33%  | 3%     |
| <i>Robinia pseudoacacia</i>   | 15%  | 15%  | 0%     |
| <i>Juniperus virginiana</i>   | 3%   | 3%   | 0%     |
| <i>Fagus grandifolia</i>      | 15%  | 15%  | 0%     |
| <i>Chamaecyparis thyoides</i> | 5%   | 5%   | 0%     |
| <i>Amelanchier spp.</i>       | 10%  | 10%  | 0%     |
| <i>Nyssa sylvatica</i>        | 13%  | 10%  | -3%    |

**Basal area changes between 2002 and 2012**

Basal area data from 1981 and 1992 could not be used for comparisons to more recent data because the sampling area and, therefore, numbers of trees in the former were vastly different. Between 2003 and 2012, there were some large differences in basal area (Table 7). The basal area of *P. rigida* increased by 2.15 m<sup>2</sup>, while *R. pseudoacacia* decreased by 1.23 m<sup>2</sup>. Considering that the total number of *P. rigida* trees actually decreased during this time period, this value

reflects a substantial change in the size of the remaining trees. All other changes were positive, indicating higher overall basal area of all species except for *Amelachier* spp. (shadbush).

**Table 7.** Mean basal area (m<sup>2</sup>) and change by species (all sites) between 2003 and 2012.

| Species                       | 2003   | 2012  | Change |
|-------------------------------|--------|-------|--------|
| <i>Pinus rigida</i>           | 13.47  | 15.62 | 2.15   |
| <i>Chamaecyparis thyoides</i> | 6.49   | 7.26  | 0.77   |
| <i>Quercus velutina</i>       | 4.77   | 5.42  | 0.65   |
| <i>Quercus alba</i>           | 2.85   | 3.18  | 0.33   |
| <i>Fagus grandifolia</i>      | 2.23   | 2.55  | 0.32   |
| <i>Crataegus</i> sp.          | 0      | 0.18  | 0.18   |
| <i>Acer rubrum</i>            | 4.01   | 4.15  | 0.14   |
| <i>Nyssa sylvatica</i>        | 0.48   | 0.57  | 0.09   |
| <i>Prunus serotina</i>        | 1.12   | 1.22  | 0.09   |
| <i>Sassafras albidum</i>      | 0      | 0.01  | 0.01   |
| <i>Juniperus virginiana</i>   | 0.0048 | 0.01  | 0.00   |
| <i>Amelanchier</i> spp.       | 0.16   | 0.14  | -0.02  |
| <i>Robinia pseudoacacia</i>   | 5.98   | 4.75  | -1.23  |

An NMDS plot of tree species composition by site (based on basal area) shows that only minor community-level changes occurred (Figure 6). Although ANOSIM results were not significant (Table 8), SIMPER revealed that *P. rigida* by far contributed most to dissimilarities among survey years.

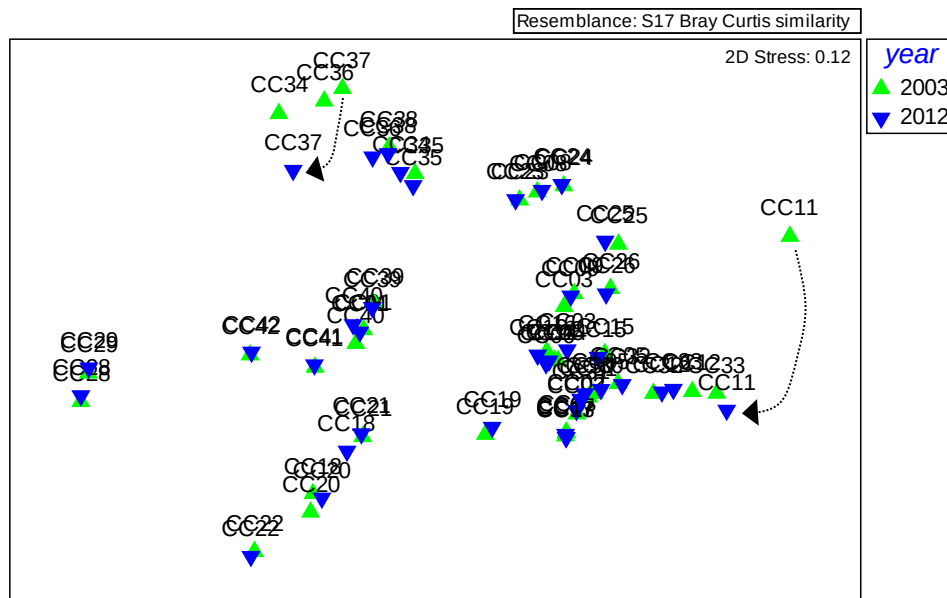


**Figure 6.** NMDS of Basal area by site in 2003 and 2012 (arrows show relatively large changes in ordinal space at two selected sites, indicating a larger change in species composition at these sites).

**Table 8.** ANOSIM and SIMPER analysis of changes in basal area between 2003 and 2012 (Contrib% indicates contribution of variable to dissimilarity between years)<sup>1</sup>.

| Species                       | Mean-03 | Mean-12 | Contrib% |
|-------------------------------|---------|---------|----------|
| <i>Pinus rigida</i>           | 0.34    | 0.40    | 31.32    |
| <i>Robinia pseudoacacia</i>   | 0.15    | 0.12    | 13.56    |
| <i>Quercus velutina</i>       | 0.12    | 0.14    | 12.16    |
| <i>Acer rubrum</i>            | 0.10    | 0.11    | 11.35    |
| <i>Chamaecyparis thyoides</i> | 0.17    | 0.19    | 9.51     |
| <i>Quercus alba</i>           | 0.07    | 0.08    | 9.21     |
| <i>Fagus grandifolia</i>      | 0.05    | 0.06    | 7.27     |

<sup>1</sup>ANOSIM R: -0.024, p= 0.99 (not significant)  
SIMPER

### Tree species richness

Very few changes in overstory tree species richness per site occurred between 2003 and 2012. In fact, the largest changes were +2 species at each of two sites, while many change values were  $\pm 1$  species or zero (Table 9). The sites that exhibited gains of two species were CC25 (oak), CC33 (pine-heathland). CC37 (black locust) gained 1 species while CC42 (beech) lost one species.

**Table 9.** Changes in species richness between 2003 and 2012 by site (AR = *A. rubrum*, NS = *N. sylvatica*, PS = *P. serotina*, PR = *P. rigida*, QA = *Q. alba*, QV = *Q. velutina*, SA = *S. albidum*).

| Site | Change  | Site | Change     | Site | Change        |
|------|---------|------|------------|------|---------------|
| CC01 | 0       | CC16 | 0          | CC30 | 0             |
| CC02 | 0       | CC17 | 0          | CC31 | 0             |
| CC03 | 0       | CC18 | +1 (QV)    | CC32 | +1 (QV)       |
| CC05 | 0       | CC19 | 0          | CC33 | 0             |
| CC06 | 0       | CC20 | 0          | CC34 | +2<br>(PR,QV) |
| CC07 | 0       | CC21 | 0          | CC35 | +1 (QA)       |
| CC08 | +1 (PS) | CC22 | 0          | CC36 | +1 (QV)       |
| CC09 | 0       | CC23 | 0          | CC37 | +1 (AR)       |
| CC11 | 0       | CC24 | +2 (PS,SA) | CC38 | 0             |
| CC12 | 0       | CC25 | +1 (PS)    | CC39 | 0             |
| CC13 | 0       | CC26 | 0          | CC40 | 0             |
| CC14 | 0       | CC28 | 0          | CC41 | 0             |
| CC15 | 0       | CC29 | 0          | CC42 | -1 (NS)       |

### Changes in the mean DBH of tagged trees between 2003 and 2012 (excludes dead and new trees)

The first tree tags were installed in 2003; thus no comparisons can be made prior to this survey. For tagged trees common to both the 2003 and 2012 surveys, all species increased in mean DBH (at sites pooled), with *J. virginiana* and *P. serotina* exhibiting the largest average changes of  $\geq 2.7$  cm (Table 10). No species exhibited decreases in mean DBH.

**Table 10.** Mean DBH change (cm) by species (all sites) between 2003 and 2012 (SE=standard error of the mean).

| Species                       | Mean change in DBH (cm) | SE   | No. trees |
|-------------------------------|-------------------------|------|-----------|
| <i>Robinia pseudoacacia</i>   | 1.67                    | 0.15 | 102       |
| <i>Nyssa sylvatica</i>        | 1.60                    | 0.16 | 38        |
| <i>Quercus velutina</i>       | 1.59                    | 0.08 | 254       |
| <i>Prunus serotina</i>        | 1.36                    | 0.22 | 155       |
| <i>Chamaecyparis thyoides</i> | 1.32                    | 0.11 | 102       |
| <i>Fagus grandifolia</i>      | 1.26                    | 0.12 | 88        |
| <i>Pinus rigida</i>           | 1.22                    | 0.08 | 420       |
| <i>Quercus alba</i>           | 1.17                    | 0.08 | 176       |
| <i>Amelanchier spp.</i>       | 0.41                    | 0.22 | 21        |

#### **Tree mortality between 2002 and 2012**

A number of tagged trees died between 2002 and 2012. These numbers varied substantially by species (Table 11). For example, 84 tagged *P. serotina* and 69 tagged *P. rigida* trees died whereas only two *F. grandifolia* died. By percentage, *P. serotina* and *Amelanchier spp.* exhibited the highest mortality, *F. grandifolia* the lowest.

**Table 11.** Mean DBH change (cm) by species (all sites) between 2003 and 2012 (SE=standard error of the mean).

| Species                       | Number dead | % Dead within species | % Dead of all trees |
|-------------------------------|-------------|-----------------------|---------------------|
| <i>Prunus serotina</i>        | 84          | 28%                   | 4%                  |
| <i>Pinus rigida</i>           | 68          | 12%                   | 3%                  |
| <i>Acer rubrum</i>            | 34          | 10%                   | 2%                  |
| <i>Quercus velutina</i>       | 30          | 8%                    | 1%                  |
| <i>Quercus alba</i>           | 19          | 8%                    | 1%                  |
| <i>Robinia pseudoacacia</i>   | 15          | 13%                   | 1%                  |
| <i>Chamaecyparis thyoides</i> | 14          | 12%                   | 1%                  |
| <i>Amelanchier spp.</i>       | 13          | 24%                   | 1%                  |
| <i>Fagus grandifolia</i>      | 2           | 2%                    | 0%                  |

By site, there was also a lot of variability in mortality (Table 12). CC35 (pine), CC37 (pine-oak), CC39 (pine-oak), and CC34 (red maple) had 48, 26, 19, and 18 trees die, respectively, between surveys. At all other sites the numbers were  $\leq 12$ . By percentage, CC35 (pine) and CC17 (pine) exhibited high mortality. CC07 (pine), C34 (black locust), CC37 (black locust), and CC39 (beech) also had relatively high percentages of tree death.

**Table 12.** Mean DBH change (cm) by species (all sites) between 2003 and 2012 (SE=standard error of the mean).

| Site | No. dead,<br>tagged trees | Total trees<br>w/in site | % dead | Site | No. dead,<br>tagged<br>trees | Total trees<br>w/in site | % dead |
|------|---------------------------|--------------------------|--------|------|------------------------------|--------------------------|--------|
| CC01 | 5                         | 42                       | 12%    | CC23 | 6                            | 52                       | 12%    |
| CC02 | 7                         | 42                       | 17%    | CC24 | 0                            | 86                       | 0%     |
| CC03 | 1                         | 27                       | 4%     | CC25 | 7                            | 82                       | 9%     |
| CC05 | 2                         | 46                       | 4%     | CC26 | 6                            | 60                       | 10%    |
| CC06 | 6                         | 48                       | 13%    | CC28 | 12                           | 62                       | 19%    |
| CC07 | 12                        | 45                       | 27%    | CC29 | 3                            | 63                       | 5%     |
| CC08 | 0                         | 55                       | 0%     | CC30 | 5                            | 76                       | 7%     |
| CC09 | 3                         | 29                       | 10%    | CC31 | 10                           | 63                       | 16%    |
| CC11 | 0                         | 53                       | 0%     | CC32 | 2                            | 36                       | 6%     |
| CC12 | 0                         | 43                       | 0%     | CC33 | 0                            | 32                       | 0%     |
| CC13 | 2                         | 33                       | 6%     | CC34 | 18                           | 83                       | 22%    |
| CC14 | 4                         | 36                       | 11%    | CC35 | 48                           | 77                       | 62%    |
| CC15 | 14                        | 76                       | 18%    | CC36 | 1                            | 29                       | 3%     |
| CC16 | 2                         | 56                       | 4%     | CC37 | 26                           | 97                       | 27%    |
| CC17 | 17                        | 44                       | 39%    | CC38 | 5                            | 54                       | 9%     |
| CC18 | 6                         | 37                       | 16%    | CC39 | 19                           | 74                       | 26%    |
| CC19 | 0                         | 41                       | 0%     | CC40 | 5                            | 53                       | 9%     |
| CC20 | 0                         | 98                       | 0%     | CC41 | 1                            | 57                       | 2%     |
| CC21 | 0                         | 31                       | 0%     | CC42 | 4                            | 19                       | 21%    |
| CC22 | 2                         | 58                       | 3%     |      |                              |                          |        |

**Recruitment of new trees to the > 2m height stratum between 2002 and 2012**

The number of new trees recruited to the > 2 m height stratum was highly variable among species and sites (Table 13). Interestingly, *P. serotina* appeared in this layer in large numbers at sites CC34, CC35, CC37, and CC38 – which are all black locust-dominated sites. Numerous *P. rigida* individuals were recorded at CC15 (pine-oak), while more than 10 new *Q. velutina* trees appeared at sites CC03 (pine-oak), CC08 (oak), and CC15 (pine-oak). *Amelanchier* spp. increased by 15 at CC39 (beech) and *A. rubrum* increased by seven and nine trees at CC07 (pine) and CC21 (red maple), respectively. Other species exhibited comparatively minor additions of new trees to the > 2m height class.

**Table 13.** Mean DBH change (cm) by species (all sites) between 2003 and 2012 (SE=standard error of the mean).

| Site | <i>A. rubrum</i> | <i>Amelanchier</i><br><i>spp.</i> | <i>C.</i><br><i>thyoides</i> | <i>F.</i><br><i>grandifolia</i> | <i>N.</i><br><i>sylvatica</i> | <i>P. rigida</i> | <i>P. serotina</i> | <i>Q. alba</i> | <i>Q. velutina</i> | <i>R.</i><br><i>pseudoacacia</i> |
|------|------------------|-----------------------------------|------------------------------|---------------------------------|-------------------------------|------------------|--------------------|----------------|--------------------|----------------------------------|
| CC01 | 5                | 1                                 | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC02 | 0                | 0                                 | 0                            | 0                               | 0                             | 5                | 0                  | 0              | 0                  | 0                                |
| CC03 | 0                | 0                                 | 0                            | 0                               | 0                             | 2                | 0                  | 4              | 15                 | 0                                |
| CC05 | 0                | 0                                 | 0                            | 0                               | 0                             | 1                | 0                  | 0              | 0                  | 0                                |
| CC06 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 6                  | 0                                |
| CC07 | 0                | 0                                 | 0                            | 0                               | 0                             | 5                | 0                  | 0              | 0                  | 0                                |
| CC08 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 2              | 10                 | 0                                |
| CC09 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 1                  | 0                                |
| CC13 | 0                | 0                                 | 0                            | 0                               | 0                             | 1                | 0                  | 0              | 0                  | 0                                |
| CC14 | 0                | 0                                 | 0                            | 0                               | 0                             | 1                | 0                  | 0              | 1                  | 0                                |
| CC15 | 0                | 0                                 | 0                            | 0                               | 0                             | 36               | 0                  | 5              | 12                 | 0                                |
| CC17 | 0                | 0                                 | 0                            | 0                               | 0                             | 5                | 0                  | 0              | 0                  | 0                                |
| CC18 | 1                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC19 | 7                | 0                                 | 0                            | 0                               | 2                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC20 | 1                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC21 | 9                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 1                  | 0                                |
| CC22 | 4                | 0                                 | 0                            | 0                               | 1                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC23 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 3              | 0                  | 0                                |
| CC24 | 0                | 0                                 | 0                            | 0                               | 0                             | 1                | 0                  | 1              | 3                  | 0                                |
| CC25 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 5              | 4                  | 0                                |
| CC26 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 1              | 1                  | 0                                |
| CC28 | 2                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC29 | 2                | 0                                 | 2                            | 0                               | 0                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC31 | 0                | 0                                 | 0                            | 0                               | 0                             | 2                | 0                  | 0              | 0                  | 0                                |
| CC32 | 0                | 0                                 | 0                            | 0                               | 0                             | 1                | 0                  | 0              | 0                  | 0                                |
| CC33 | 0                | 0                                 | 0                            | 0                               | 0                             | 2                | 0                  | 0              | 0                  | 0                                |
| CC34 | 0                | 1                                 | 0                            | 0                               | 0                             | 0                | 34                 | 0              | 0                  | 1                                |
| CC35 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 26                 | 0              | 0                  | 1                                |
| CC36 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 2                  | 0              | 0                  | 1                                |
| CC37 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 71                 | 0              | 0                  | 4                                |
| CC38 | 0                | 0                                 | 0                            | 0                               | 0                             | 0                | 23                 | 0              | 1                  | 2                                |
| CC39 | 2                | 16                                | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC40 | 3                | 0                                 | 0                            | 0                               | 0                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC41 | 1                | 0                                 | 0                            | 4                               | 1                             | 0                | 0                  | 0              | 0                  | 0                                |
| CC42 | 0                | 0                                 | 0                            | 2                               | 1                             | 0                | 0                  | 0              | 0                  | 0                                |

**Changes in the basal area of individual species at individual sites between 2003 and 2012  
– only tagged, live trees, which excludes dead and new trees.**

Note: All basal area values that follow exclude dead and new trees and refer to changes in species at sites only where that species is present.

Changes in basal area sometimes mirrored those of DBH but this was not consistently the case. This is because a change in DBH translates to a much greater change in basal area, since basal area is calculated from the square of DBH/2 (e.g., a doubling of DBH is equivalent to a quadrupling of basal area and a tripling of DBH results in a ninefold increase in basal area).

By species, *R. psuedoacacia* exhibited the largest increase in basal area (58.1 cm<sup>2</sup>), followed by *P. rigida*, *F. grandifolia*, and *Q. velutina* – all of which had mean values of  $\geq 35$  cm<sup>2</sup> (Table 16). In contrast, *N. sylvatica*, *P. serotina*, *C. thyoides*, and *Amelanchier* spp. all had changes of  $< 2$  cm<sup>2</sup>.

**Table 14.** Mean changes in basal area by species (all sites where species present) between 2003 and 2012.

| Species                 | Change in basal area (cm <sup>2</sup> ) |
|-------------------------|-----------------------------------------|
| <i>R. psuedoacacia</i>  | 58.1                                    |
| <i>P. rigida</i>        | 41.4                                    |
| <i>F. grandifolia</i>   | 39.8                                    |
| <i>Q. velutina</i>      | 35.9                                    |
| <i>Q. alba</i>          | 24.8                                    |
| <i>A. rubrum</i>        | 21.3                                    |
| <i>N. sylvatica</i>     | 1.6                                     |
| <i>P. serotina</i>      | 1.3                                     |
| <i>C. thyoides</i>      | 1.3                                     |
| <i>Amelanchier</i> spp. | 0.9                                     |

*P. rigida* increases in basal area ranged between  $< 10$  cm<sup>2</sup> to  $> 100$  cm<sup>2</sup> among sites. Only CC19 (red maple) was a notable exception in that the basal area value was much higher ( $> 500$  cm<sup>2</sup>) (Figure 7).

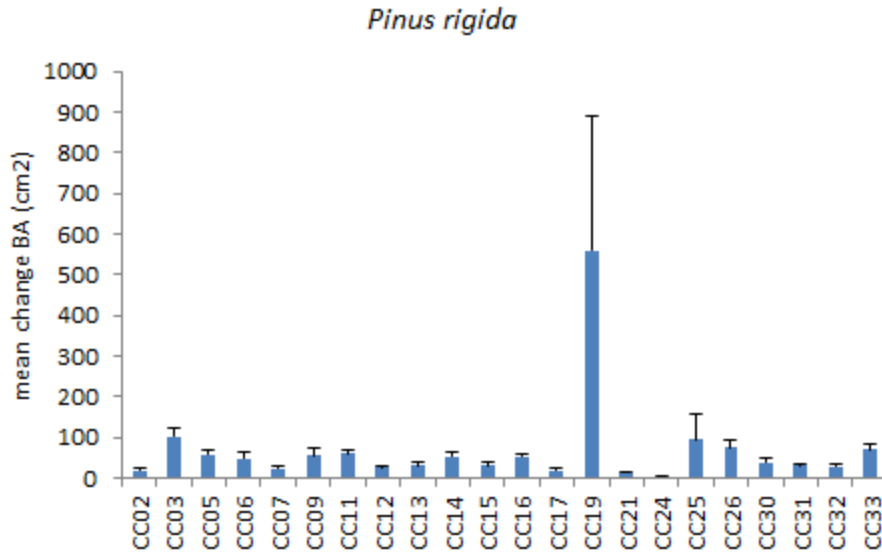


**Figure 7.** *P. rigida* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

Values of change in basal area for *Q. velutina* were relatively high ( $< 150 \text{ cm}^2$ ) at sites CC35 (black locust) and CC40 (beech) (Figure 8). The rest exhibited comparatively minor changes ( $< 100 \text{ cm}^2$ ) but similar to *P. rigida*.

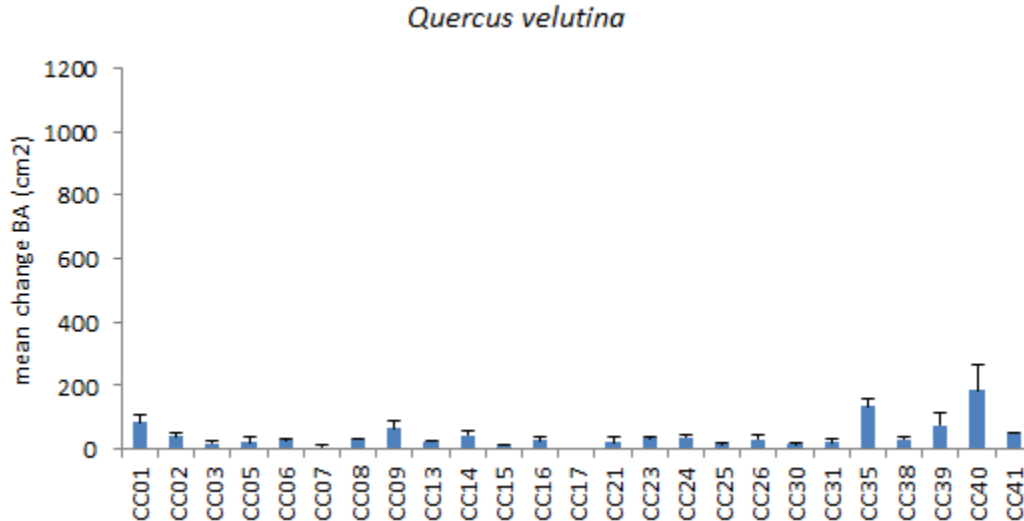


**Figure 8.** *Q. velutina* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

The growth of *Q. alba* was slow compared to *P. rigida* or *Q. velutina* (Figure 9). In this regard, basal area change values were all  $< 100 \text{ cm}^2$  with many that were  $< 50 \text{ cm}^2$ .

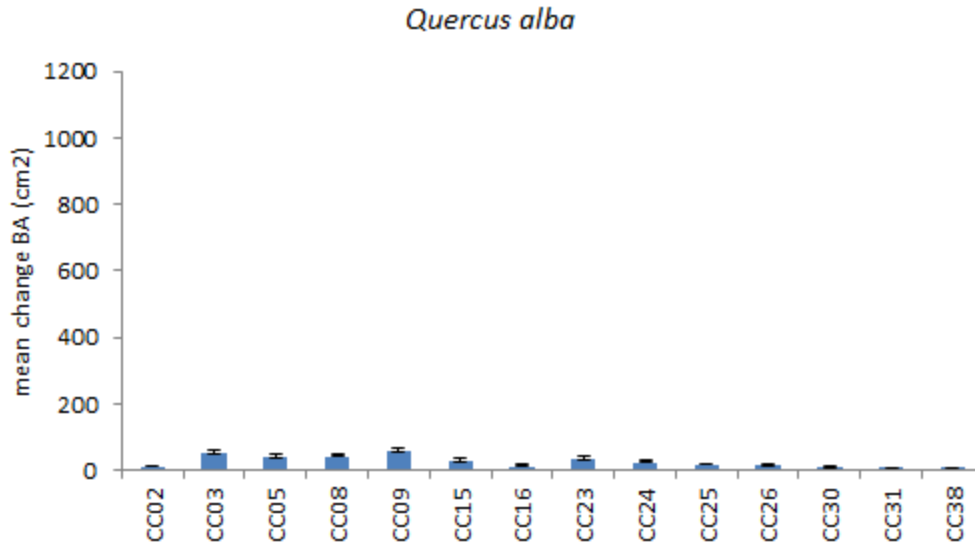


**Figure 9.** *Q. alba* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

*F. grandifolia* only occurred at six sites and there was only one tree at two of those sites (Figure 10). For sites with > 1 tree, changes in basal area were > 50 cm<sup>2</sup>.

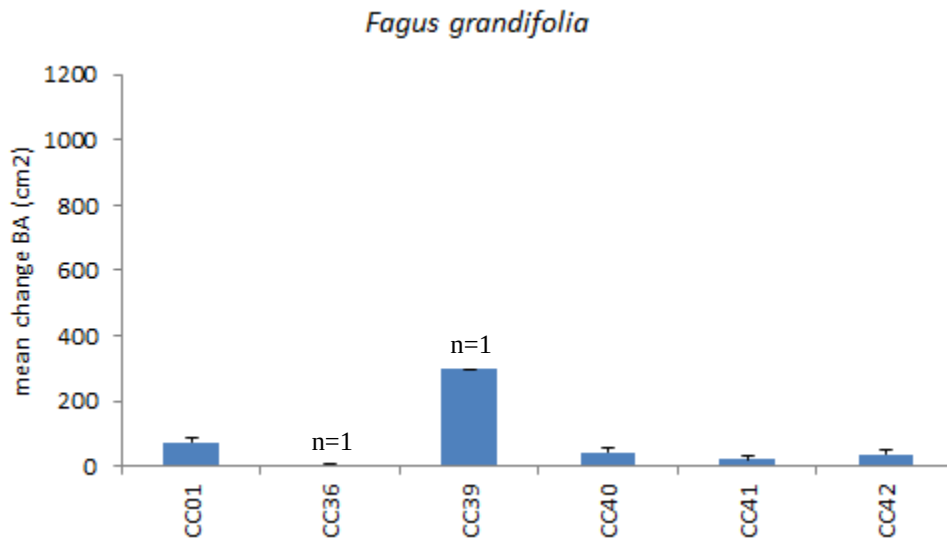


**Figure 10.** *F. grandifolia* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

Changes in the basal area of *A. rubrum* were similar (< 50 cm<sup>2</sup>) to those of *Q. alba*, with slower growth compared to aforementioned taxa (Figure 11).

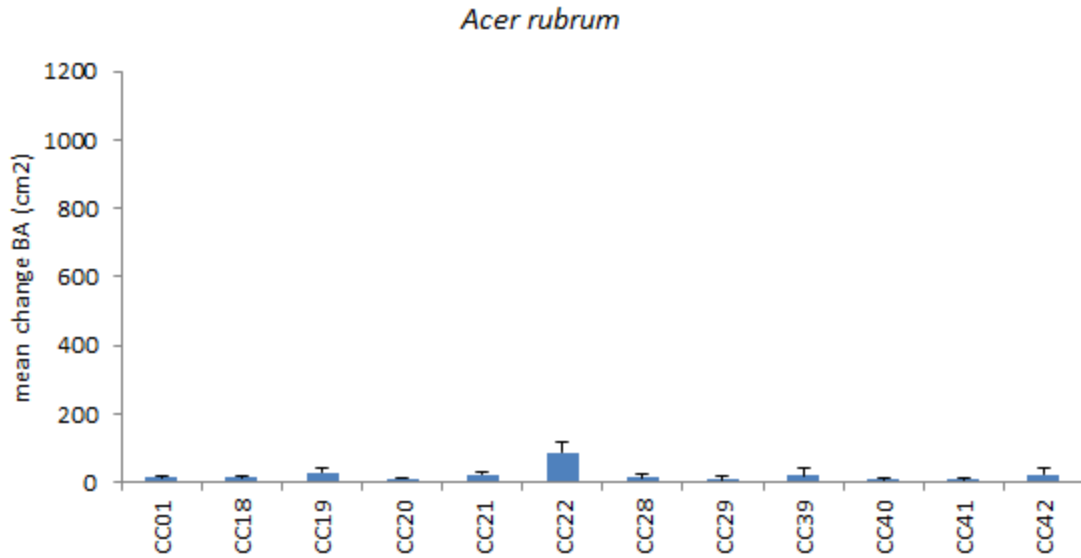


**Figure 11.** *A. rubrum* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

*R. pseudoacacia* occurred at six sites with one site having only one tree present. However, changes among the remaining five sites were more consistent with high average values of ~60 (Figure 12).

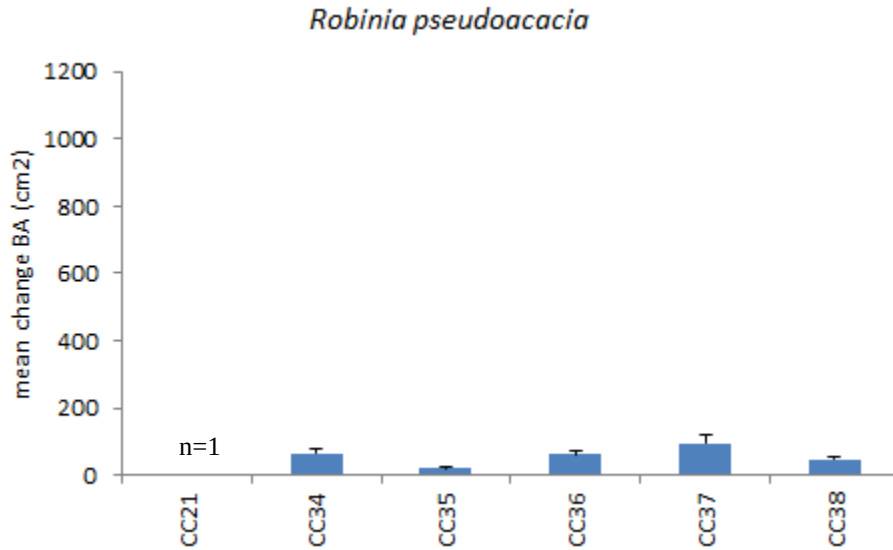


**Figure 12.** *R. pseudoacacia* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

The growth of *Amelanchier* spp., *N. sylvatica*, *P. serotina*, and *C. thyoides* (Figures 13-16) was extremely low compared to all aforementioned species, with values approximately 20-50X lower.

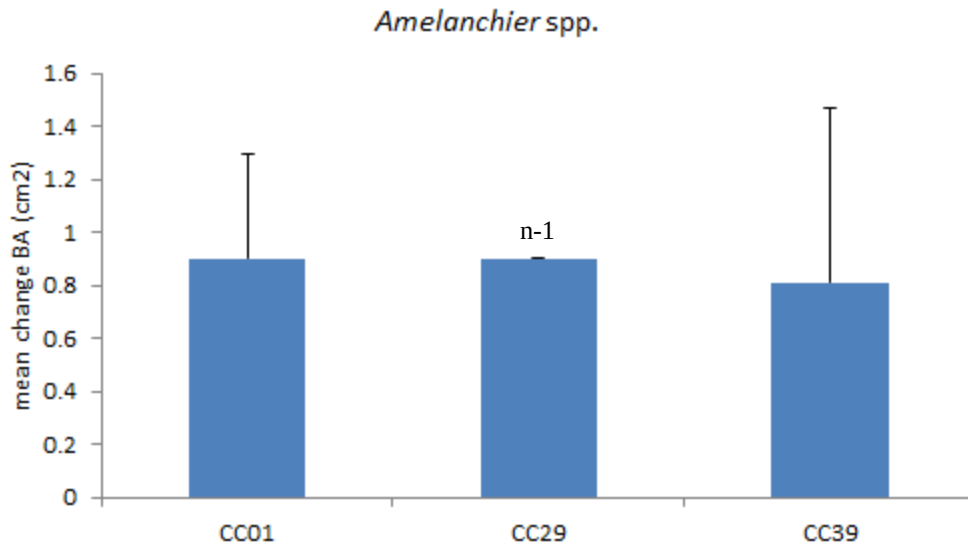


**Figure 13.** *Amelanchier* spp. changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

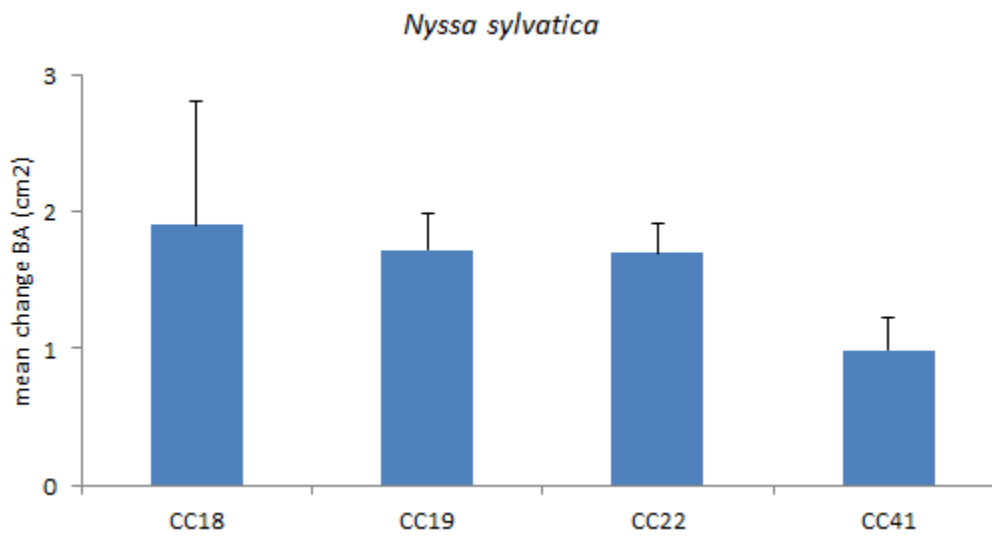


**Figure 14.** *Nyssa sylvatica* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

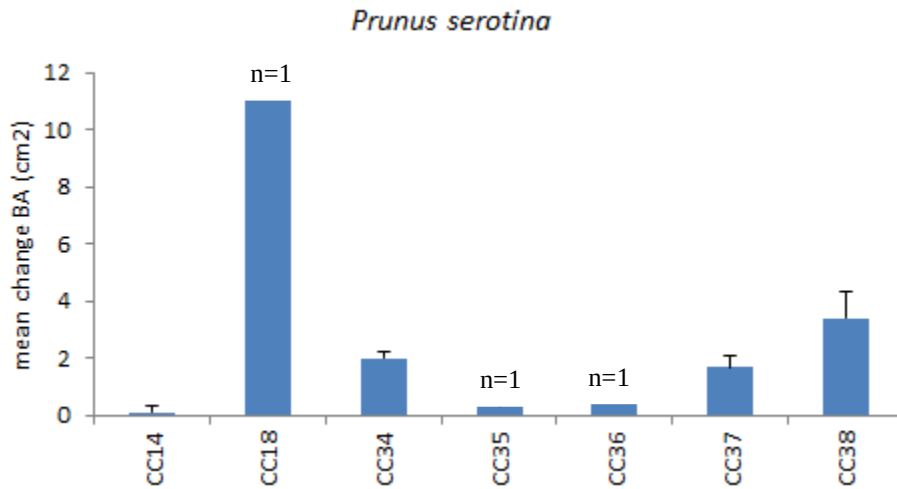


**Figure 15.** *Prunus serotina* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

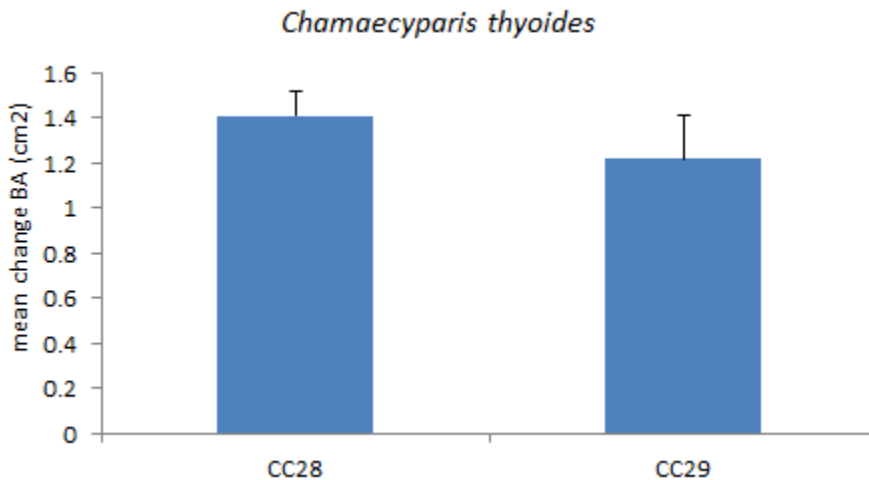


**Figure 16.** *Chamaecyparis thyoides* changes in basal area between 2003 and 2012 (error bars are standard errors of the means).

### **Forest canopy**

Changes in forest canopy cover between 2003 and 2012 were analyzed by comparing black and white pixel counts in fish-eye digital images of canopies converted to these two colors (black = vegetation, white = open sky; for detailed description of these methods see Smith et al. 2011). From this, the percentage of canopy vegetation that obscures open sky, and any changes in this proportion, can be determined. With the exception of one site (CC03, pine-oak), canopy cover has increased substantially (e.g., Figure 17), ranging between 70% (CC11, pine-heathland) and 1% (CC06, pine-oak) (Table 15). The average increase in cover (all sites) was 12% ( $\pm 2.4\%$ ). Grouped by forest type, canopy closure was highest in pine heathlands and lowest in pitch-pine, beech, and black locust dominated sites (Table 15).

**Table 15.** Percent change in canopy cover by site between 2003 and 2012.

|      | Type                 | % canopy (2003) | % canopy (2012) | Change |
|------|----------------------|-----------------|-----------------|--------|
| CC11 | pine-heathland       | 22%             | 37%             | 70%    |
| CC33 | pine-heathland       | 35%             | 53%             | 50%    |
| CC08 | oak                  | 52%             | 71%             | 36%    |
| CC05 | pine-oak             | 47%             | 59%             | 25%    |
| CC18 | red maple            | 82%             | 95%             | 16%    |
| CC28 | Atlantic white cedar | 82%             | 96%             | 16%    |
| CC21 | red maple            | 82%             | 93%             | 14%    |
| CC16 | pine-oak             | 81%             | 92%             | 14%    |
| CC42 | beech                | 82%             | 94%             | 14%    |
| CC19 | red maple            | 82%             | 93%             | 13%    |
| CC38 | black locust         | 82%             | 91%             | 11%    |
| CC37 | black locust         | 83%             | 92%             | 11%    |
| CC24 | oak                  | 84%             | 93%             | 11%    |
| CC23 | oak                  | 86%             | 94%             | 10%    |
| CC13 | pitch pine           | 83%             | 90%             | 9%     |
| CC17 | pitch pine           | 83%             | 90%             | 9%     |
| CC09 | pine-oak             | 85%             | 92%             | 9%     |
| CC31 | pine-heathland       | 86%             | 93%             | 9%     |
| CC26 | oak                  | 84%             | 91%             | 9%     |
| CC29 | Atlantic white cedar | 86%             | 93%             | 8%     |
| CC25 | oak                  | 86%             | 93%             | 8%     |
| CC12 | pine-heathland       | 35%             | 38%             | 8%     |
| CC07 | pitch pine           | 82%             | 89%             | 8%     |
| CC39 | beech                | 86%             | 92%             | 7%     |
| CC22 | red maple            | 88%             | 94%             | 7%     |
| CC40 | beech                | 87%             | 93%             | 7%     |
| CC41 | beech                | 87%             | 92%             | 6%     |
| CC02 | pitch pine           | 87%             | 91%             | 5%     |
| CC34 | black locust         | 89%             | 93%             | 4%     |
| CC32 | pine-heathland       | 49%             | 51%             | 4%     |
| CC30 | pitch pine           | 90%             | 93%             | 3%     |
| CC36 | black locust         | 85%             | 87%             | 3%     |
| CC01 | beech                | 86%             | 88%             | 2%     |
| CC06 | pine-oak             | 93%             | 94%             | 1%     |
| CC03 | pine-oak             | 92%             | 91%             | 0%     |

**Table 16 (continued).** Percent change in canopy cover by site between 2003 and 2012.

|                      | Change | SE  |
|----------------------|--------|-----|
| pine-heathland       | 28%    | 11% |
| oak                  | 15%    | 6%  |
| red maple            | 13%    | 1%  |
| Atlantic white cedar | 12%    | 2%  |
| pine-oak             | 10%    | 8%  |
| pitch pine           | 7%     | 2%  |
| beech                | 7%     | 1%  |
| black locust         | 7%     | 2%  |

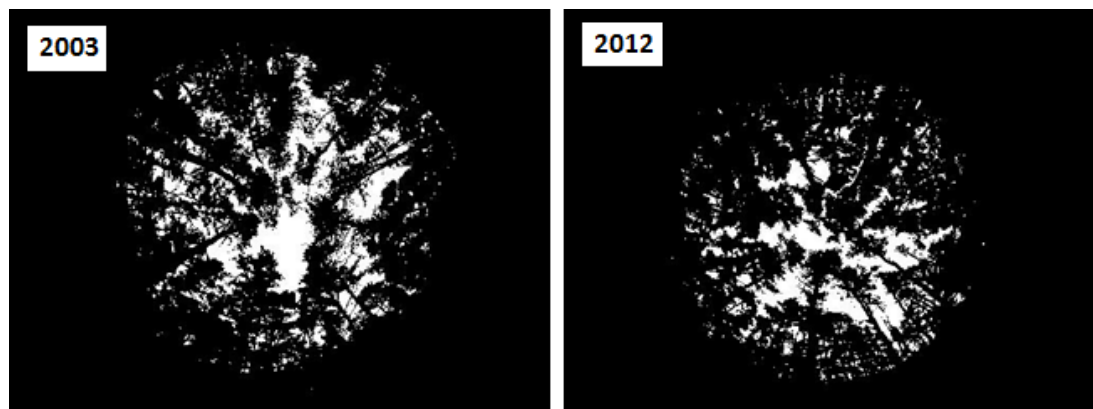


**Figure 17.** Example of photographs showing increase in canopy cover (decrease in open sky) at CC13 between 2003 and 2012.

#### **Changes in tree DBH between 1981 and 2012**

Because of methods changes that were implemented between 1992 and 2003 to transition to fixed-area plot monitoring, only DBH data could be analyzed for all survey years (1981, 1992, 2003, 2012). Moreover, the 1981 and 1992 data only include trees > 2.5 cm in DBH since that was the threshold size for sampling trees with angle gauges. Thus, any values lower than 2.5 cm in more recent data had to be excluded from the analysis. In addition, the number of replicate data points in 1981 and 1992 are significantly greater than in 2003 and 2012 because there were many more sampling locations per site in those earlier years (see Smith et al. 2011 protocol for more background on prior sampling methods). As such, the data are not comparable in a statistically rigorous way.

*P. rigida* has exhibited progressive increases in DBH over time, as might be expected (Table 16). In fact, DBH doubled or more than doubled at certain sites (CC05, CC07, CC12, CC16, and CC17). *Q. alba* also showed increasing trends in DBH with the exception of CC16, where there was an apparent decrease (Table 17). Similarly, *Q. velutina* grew larger in size (with the exception of CC01, where trees were already very large), more than doubling at the majority of sites (Table 18).

**Table 17.** Percent change in canopy cover by site between 2003 and 2012.

| Site | 1981 | 1992 | 2001 | 2002 | 2012 | Change (81-12) |
|------|------|------|------|------|------|----------------|
| CC01 | -    | -    | -    | -    | -    | -              |
| CC02 | 22.8 | 25.5 |      | 22.7 | 31.6 | 39%            |
| CC03 | 19.4 | 21.2 | 26.9 | 26.1 | 31.7 | 63%            |
| CC05 | 12.4 | 12.7 | 20.8 | 17.6 | 28.9 | 134%           |
| CC06 | 20.0 | 22.7 |      | 24.4 | 30.8 | 54%            |
| CC07 | 13.3 | 16.7 | 21.6 | 17.3 | 29.8 | 124%           |
| CC08 | 17.2 | -    | -    | -    | -    |                |
| CC09 | 18.8 | 18.8 | 24.3 | 22.0 | 28.2 | 51%            |
| CC11 |      |      |      | -    | 29.7 | -              |
| CC12 | 15.4 | 10.9 | 9.1  | 12.7 | 30.2 | 97%            |
| CC14 | 16.7 | 22.1 | 22.7 | 22.6 | 28.8 | 72%            |
| CC16 | 15.9 | 18.6 | 23.8 | 20.4 | 30.5 | 91%            |
| CC17 | 12.0 | 18.3 | 20.1 | 17.3 | 27.7 | 130%           |
| mean | 16.7 | 18.8 | 21.2 | 20.3 | 29.8 | 85%            |
| SE   | 1.02 | 1.42 | 1.89 | 1.28 | 0.39 | 11%            |

**Table 18.** Percent change in canopy cover by site between 2003 and 2012.

| Site | 1981 | 1992 | 2001 | 2002 | 2012 | Change (81-12) |
|------|------|------|------|------|------|----------------|
| CC01 | -    | -    | -    | 22.7 | -    | -              |
| CC02 |      |      |      |      |      |                |
| CC03 | 14.3 | 18.2 | -    | 17.1 | 25.6 | 79%            |
| CC05 | -    | -    | -    | 10.5 | 9.4  | -              |
| CC06 | -    | -    | -    | -    | -    | -              |
| CC07 | -    | -    | -    | -    | -    | -              |
| CC08 | 11.4 | 10.5 | 12.6 | 12.0 | 12.5 | 10%            |
| CC09 | 15.9 | 20.4 | 23.4 | 22.1 | 27.8 | 75%            |
| CC11 | -    | -    | -    | -    | -    | -              |
| CC12 | -    | -    | -    | -    | -    | -              |
| CC14 | 18.0 | 22.4 | -    | -    | -    | -              |
| CC16 | 14.6 | 15.2 | 11.9 | 13.9 | 14.4 | -2%            |
| CC17 | -    | -    | -    | -    | -    | -              |
| mean | 14.8 | 17.3 | 15.9 | 16.4 | 26.7 | 41%            |
| SE   | 1.09 | 2.08 | 3.71 | 2.06 | 1.13 | 21%            |

**Table 19.** Percent change in canopy cover by site between 2003 and 2012.

| Site | 1981 | 1992 | 2001 | 2002 | 2012 | Change (81-12) |
|------|------|------|------|------|------|----------------|
| CC01 | 31.5 | 29.0 | 36.2 | 28.7 | 31.3 | -1%            |
| CC02 | -    | -    | -    | -    | -    | -              |
| CC03 | 10.1 | 13.9 | 15.7 | 14.7 | 11.9 | 17%            |
| CC05 | -    | -    | -    | -    | -    | -              |
| CC06 | 13.0 | 14.1 | -    | 16.2 | 31.1 | 140%           |
| CC07 | -    | -    | -    | -    | -    | -              |
| CC08 | 13.2 | 10.6 | 12.2 | 13.0 | 11.2 | -15%           |
| CC09 | 11.4 | 15.8 | 16.2 | 16.9 | 25.5 | 124%           |
| CC11 | -    | -    | -    | -    | -    | -              |
| CC12 | -    | -    | -    | -    | 26.9 | -              |
| CC14 | 7.6  | 13.9 | 16.1 | 13.4 | 12.9 | 69%            |
| CC16 | 9.1  | 13.1 | 15.6 | 14.5 | 25.8 | 185%           |
| CC17 | -    | -    | -    | -    | -    | -              |
| mean | 13.7 | 15.8 | 18.7 | 16.8 | 23.0 | 74%            |
| SE   | 0.90 | 0.70 | 0.74 | 0.62 | 3.25 | 31%            |

Note: Other tree species that can dominate forest habitat such as *F. grandifolia*, *A. rubrum*, and *R. psuedoacacia* were not analyzed since these forest types were not included in the 1981 and 1992 sampling network of sites (they were added in 2003).

## Understory – all sites

### *Species cover changes between 2003 and 2012*

Note: Understory cover data from 1982 and 1992 could not be compared to 2003 and 2012 due to the difference in methodologies and plot size in the former.

Between 2003 and 2013, changes in understory species cover varied widely. The summed cover class values (all sites) reflect this (Table 19). Some species such as *C. pensylvanica*, *R. flagellaris*, *Deschampsia flexuosa*, and *Vaccinium angustifolium* increased by substantial amounts, whereas others such as *Smilax rotundifolia*, *Clethra alnifolia*, *Vaccinium corymbosum*, and *Gaylussacia baccata* exhibited marked decreases. The mechanism(s) driving this change is unknown; however, the majority of species changed very little in comparison.

**Table 20.** Change in summed cover class scores (all sites pooled) between 2003 and 2012 by species (highlighted rows indicate taxa with large negative changes; boxed rows indicate taxa with large positive changes).

| Species                          | Change | Species                        | Change |
|----------------------------------|--------|--------------------------------|--------|
| <i>Acer rubrum</i>               | 41     | <i>Erechtites hieracifolia</i> | 3      |
| <i>Amelanchier spp.</i>          | 30     | <i>Euonymus atropurpurea</i>   | -39    |
| <i>Anthoxanthum odoratum</i>     | 5      | <i>Euonymus europaeus</i>      | 13     |
| <i>Aralia nudicaulis</i>         | -32    | <i>Fagus grandifolia</i>       | 6      |
| <i>Arctostaphylos uva-ursi</i>   | -12    | <i>Festuca sp.</i>             | 1      |
| <i>Berberis vulgaris</i>         | -2     | <i>Fragaria virginiana</i>     | 2      |
| <i>Betula alleghaniensis</i>     | 1      | <i>Gaultheria procumbens</i>   | 57     |
| <i>Betula populifolia</i>        | -1     | <i>Gaylussacia baccata</i>     | -331   |
| <i>Boehmeria cylindrica</i>      | 0      | <i>Gaylussacia frondosa</i>    | 9      |
| <i>Carex lacustris</i>           | -5     | <i>Hamamelis virginiana</i>    | 1      |
| <i>Carex pensylvanica</i>        | 192    | <i>Hedera helix</i>            | 3      |
| <i>Carex scoparia</i>            | 1      | <i>Hieracium</i>               | -2     |
| <i>Carex sp.</i>                 | 26     | <i>Hieracium venosum</i>       | 3      |
| <i>Celastrus sp.</i>             | 7      | <i>Holcus lanatus</i>          | 52     |
| <i>Chamaecyparis thyoides</i>    | -3     | <i>Hudsonia ericoides</i>      | -18    |
| <i>Chelidonium majus</i>         | 13     | <i>Hudsonia tomentosa</i>      | -19    |
| <i>Chimaphila maculata</i>       | 42     | <i>Hypericum perforatum</i>    | 2      |
| <i>Chrysopsis falcata</i>        | -1     | <i>Hypochoeris radicata</i>    | 2      |
| <i>Clethra alnifolia</i>         | -142   | <i>Ilex glabra</i>             | -13    |
| <i>Comptonia peregrina</i>       | -9     | <i>Ilex laevigata</i>          | 8      |
| <i>Convallaria majalis</i>       | 24     | <i>Ilex opaca</i>              | 7      |
| <i>Corema conradii</i>           | 81     | <i>Ilex verticillata</i>       | 80     |
| <i>Crataegus sp.</i>             | 2      | <i>Ionactis linariifolia</i>   | 2      |
| <i>Cypripedium acaule</i>        | 3      | <i>Juncus</i>                  | -9     |
| <i>Daucus carota</i>             | -1     | <i>Juncus acuminatus</i>       | 24     |
| <i>Decodon verticillatus</i>     | 9      | <i>Juncus canadensis</i>       | 5      |
| <i>Dennstaedtia punctilobula</i> | -6     | <i>Juncus sp.</i>              | 2      |
| <i>Deschampsia flexuosa</i>      | 135    | <i>Juniperus communis</i>      | -1     |
| <i>Dichanthelium acumentatum</i> | 2      | <i>Kalmia angustifolia</i>     | -23    |
| <i>Dichanthium annulatum</i>     | 2      | <i>Kalmia angustifolia</i>     | 12     |
| <i>Epifagus virginiana</i>       | -2     | <i>Lechea maritima</i>         | 1      |
| <i>Epigaea repens</i>            | 48     | <i>Leonurus cardiaca</i>       | 2      |

| Species                            | Change |
|------------------------------------|--------|
| <i>Lepidium campestre</i>          | -2     |
| <i>Ligustrum vulgare</i>           | 18     |
| <i>Lonicera japonica</i>           | 2      |
| <i>Lonicera morrowii</i>           | -43    |
| <i>Lyonia ligustrina</i>           | 62     |
| <i>Lysimachia terrestris</i>       | 5      |
| <i>Maianthemum canadense</i>       | 74     |
| <i>Malus</i> sp.                   | 2      |
| <i>Melampyrum lineare</i>          | 2      |
| <i>Mentha arvensis</i>             | 1      |
| <i>Mentha arvensis</i>             | 9      |
| <i>Monotropa uniflora</i>          | 1      |
| <i>Myrica pensylvanica</i>         | 13     |
| <i>Nyssa sylvatica</i>             | 28     |
| <i>Onoclea sensibilis</i>          | 5      |
| <i>Osmunda cinnamomea</i>          | -86    |
| <i>Oxalis stricta</i>              | 5      |
| <i>Panicum</i>                     | -4     |
| <i>Panicum clandestinum</i>        | 12     |
| <i>Panicum lanuginosum</i>         | -2     |
| <i>Parthenocissus quinquefolia</i> | 78     |
| <i>Photinia</i>                    | 17     |
| <i>Photinia melenocarpa</i>        | 4      |
| <i>Photinia</i> sp.                | 4      |
| <i>Phytolacca americana</i>        | 26     |
| <i>Pinus rigida</i>                | 44     |
| <i>Polygonella articulata</i>      | 5      |
| <i>Polygonum scandens</i>          | 0      |
| <i>Populus tremuloides</i>         | -2     |
| <i>Prunus maritima</i>             | 17     |
| <i>Prunus serotina</i>             | -186   |
| <i>Pteridium aquilinum</i>         | -53    |
| <i>Quercus</i>                     | -4     |
| <i>Quercus alba</i>                | 71     |

| Species                         | Change |
|---------------------------------|--------|
| <i>Quercus ilicifolia</i>       | 17     |
| <i>Quercus rubra</i>            | -1     |
| <i>Quercus velutina</i>         | -28    |
| <i>Rhamnus cathartica</i>       | -37    |
| <i>Rhododendron nudiflorum</i>  | 5      |
| <i>Rhododendron viscosum</i>    | -127   |
| <i>Rhynchospora</i> sp.         | 10     |
| <i>Robinia pseudoacacia</i>     | -5     |
| <i>Rosa carolina</i>            | 0      |
| <i>Rosa multiflora</i>          | 53     |
| <i>Rosa palustris</i>           | -53    |
| <i>Rosa rugosa</i>              | 1      |
| <i>Rosa virginiana</i>          | -7     |
| <i>Rubus allegheniensis</i>     | 7      |
| <i>Rubus flagellaris</i>        | 190    |
| <i>Rubus hispidus</i>           | 53     |
| <i>Rubus occidentalis</i>       | 9      |
| <i>Rumex crispus</i>            | -4     |
| <i>Saponaria officinalis</i>    | 2      |
| <i>Sassafras albidum</i>        | 24     |
| <i>Schizachyrium scoparium</i>  | 9      |
| <i>Scirpus cyperinus</i>        | 2      |
| <i>Sisymbrium officinale</i>    | -11    |
| <i>Smilax rotundifolia</i>      | -145   |
| <i>Solanum dulcamara</i>        | -15    |
| <i>Solidago rugosa</i>          | 24     |
| <i>Solidago</i> sp.             | 12     |
| <i>Sparganium americanum</i>    | 9      |
| <i>Spiraea alba</i>             | -53    |
| <i>Spiraea tomentosa</i>        | 22     |
| <i>Spiranthes gracilis</i>      | 2      |
| <i>Streptopus amplexifolius</i> | 1      |
| <i>Toxicodendron radicans</i>   | 122    |
| <i>Toxicodendron vernix</i>     | -46    |

| Species                        | Change |
|--------------------------------|--------|
| <i>Trientalis borealis</i>     | 125    |
| <i>Typha latifolia</i>         | -7     |
| <i>Vaccinium angustifolium</i> | 162    |
| <i>Vaccinium corymbosum</i>    | -200   |
| <i>Vaccinium macrocarpon</i>   | -4     |
| <i>Viburnum cassinoides</i>    | -57    |

| Species                    | Change |
|----------------------------|--------|
| <i>Viburnum dentatum</i>   | -30    |
| <i>Viburnum nudum</i>      | 33     |
| <i>Vitis labrusca</i>      | -5     |
| <i>Woodwardia areolata</i> | -1     |

A NMDS plot (Figure 18) shows the distribution of forest sites based on cover class values by species. The different survey years are not spatially distinct from each other and the ANOSIM test indicated no significant change in species composition. SIMPER results show the five species contributing most to dissimilarities among years. They are: *Gaylussacia baccata* (black huckleberry), *Vaccinium angustifolium* (lowbush blueberry), *Quercus ilicifolia* (scrub oak), *Gaultheria procumbens* (wintergreen), and *Deschampsia flexuosa* (hairgrass).

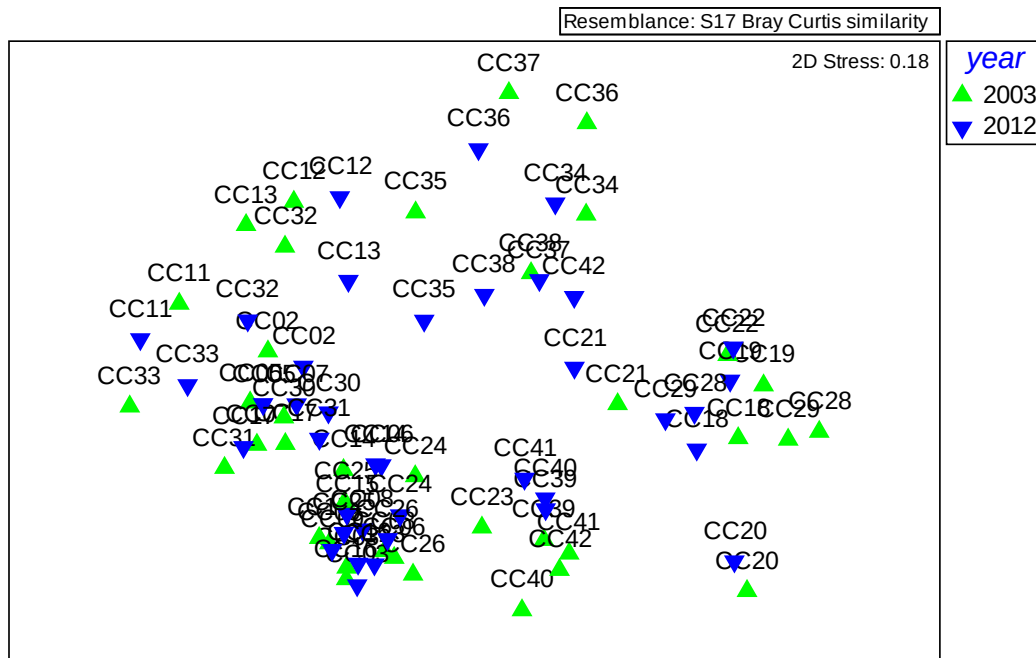


**Figure 18.** NMDS of cover by species in 2003 vs. 2012.

**Table 21.** ANOSIM and SIMPER analysis of changes in basal area between 2003 and 2012 (Contrib% indicates contribution of variable to dissimilarity between years)<sup>1</sup>.

| species                        | mean-03 | mean-12 | Contrib% |
|--------------------------------|---------|---------|----------|
| <i>Gaylussacia baccata</i>     | 26.87   | 18.16   | 9.35     |
| <i>Vaccinium angustifolium</i> | 11.39   | 15.66   | 5.73     |
| <i>Quercus ilicifolia</i>      | 10.97   | 11.42   | 4.98     |
| <i>Gaultheria procumbens</i>   | 9.39    | 10.89   | 4.71     |
| <i>Deschampsia flexuosa</i>    | 6.37    | 9.92    | 4.44     |

<sup>1</sup>**ANOSIM** R=0.006, p=0.27 (not significant)  
**SIMPER**

### Species richness changes between 2003 and 2012

Note: Understory species cover in 2003 was quantified over different spatial scales, depending on plant heights. In this survey, understory species < 0.5 m in height were assessed within 1m<sup>2</sup> subplots, whereas species between 0.5 and 2 m in height were assessed in 10 m<sup>2</sup> subplots (Hubbard 2001). Thus, to format the 2003 data for comparison with the 2012 survey, the 10 m<sup>2</sup> subplot values were used in place of 1 m<sup>2</sup> values if the same species was recorded in both height strata. If the species was only recorded in the < 0.5 m height stratum, then this value was used. In 2012 all taxa below 2 m in height were assessed in 10 m<sup>2</sup> plots.

Species richness increased at the vast majority of sites between 2003 and 2012, with the largest changes occurring at CC34 (black locust; +17) and CC37 (black locust; +14) (Table 21). Apparent decreases occurred at CC09 (pine-oak; -1), CC11 (pine-heathland; -6), CC15 (pine-oak; -2), CC17 (pine; -2), and CC23 (oak; -16).

**Table 22.** Species richness in 2003 and 2012 by site and the difference between the two survey

| Site                    | 2003 | 2012 | Change |
|-------------------------|------|------|--------|
| CC02 (pine)             | 5    | 17   | +12    |
| CC03 (pine-oak)         | 15   | 7    | -8     |
| CC05 (pine-oak)         | 17   | 14   | -3     |
| CC06 (pine-oak)         | 6    | 13   | +7     |
| CC07 (pine)             | 10   | 10   | 0      |
| CC08 (oak)              | 13   | 15   | 2      |
| CC09 (pine-oak)         | 12   | 11   | -1     |
| CC11 (pine-heathland)   | 19   | 13   | -6     |
| CC12 (pine-heathland)   | 13   | 15   | +2     |
| CC13 (pine)             | 10   | 10   | 0      |
| CC14 (pine-oak)         | 15   | 18   | +3     |
| CC15 (pine-oak)         | 18   | 16   | -2     |
| CC16 (pine-oak)         | 15   | 17   | +2     |
| CC17 (pine)             | 17   | 15   | -2     |
| CC18 (red maple)        | 10   | 22   | +12    |
| CC19 (red maple)        | 7    | 14   | +7     |
| CC20 (red maple)        | 12   | 17   | +5     |
| CC21 (red maple)        | 19   | 30   | +11    |
| CC22 (red maple)        | 11   | 16   | +5     |
| CC23 (oak)              | 26   | 10   | -16    |
| CC24 (oak)              | 15   | 21   | +6     |
| CC25 (oak)              | 14   | 20   | +6     |
| CC26 (oak)              | 8    | 13   | +5     |
| CC28 (Atl. White cedar) | 6    | 13   | +7     |
| CC29 (Atl. White cedar) | 11   | 17   | +6     |
| CC30 (pine)             | 20   | 23   | +3     |
| CC31 (pine-heathland)   | 9    | 16   | +7     |
| CC32 (pine-heathland)   | 7    | 15   | +8     |
| CC33 (pine-heathland)   | 6    | 13   | +7     |
| CC34 (black locust)     | 18   | 35   | +17    |
| CC35 (black locust)     | 15   | 21   | +6     |
| CC36 (black locust)     | 25   | 30   | +5     |
| CC37 (black locust)     | 13   | 27   | +14    |
| CC38 (black locust)     | 13   | 16   | +3     |
| CC39 (beech)            | 7    | 15   | +8     |
| CC40 (beech)            | 11   | 22   | +11    |
| CC41 (beech)            | 18   | 21   | +3     |
| CC42 (beech)            | 14   | 25   | +11    |

***Growth form changes between 2003 and 2012***

In general, there was substantial variability among sites in how the different proportions of trees, shrubs and herbaceous vegetation changed between 2003 and 2012 (Table 22). However, the net change (all sites pooled) showed an increase in trees and herbaceous species and a decrease in shrubs. Despite this change, the vegetation overall (i.e., all sites collectively) did not exhibit a statistically significant change between survey years (Figure 19, Table 23).

**Table 23.** Changes in summed cover class values by site between 2003 and 2012 based on growth form.

| Site                    | Change by site |       |      |
|-------------------------|----------------|-------|------|
|                         | Herb           | Shrub | Tree |
| CC02 (pine)             | 40             | 32    | 21   |
| CC03 (pine-oak)         | -33            | -57   | -2   |
| CC05 (pine-oak)         | -16            | -28   | 31   |
| CC06 (pine-oak)         | 7              | 4     | -3   |
| CC07 (pine)             | 12             | -28   | -55  |
| CC08 (oak)              | -25            | -35   | -11  |
| CC09 (pine-oak)         | 4              | -40   | -16  |
| CC11 (pine-heathland)   | -13            | -78   | 16   |
| CC12 (pine-heathland)   | 5              | 5     | 8    |
| CC13 (pine)             | -5             | -3    | 11   |
| CC14 (pine-oak)         | -12            | -43   | 7    |
| CC15 (pine-oak)         | -2             | -43   | -67  |
| CC16 (pine-oak)         | -8             | -65   | -25  |
| CC17 (pine)             | 0              | 39    | -21  |
| CC18 (red maple)        | 6              | -99   | 18   |
| CC19 (red maple)        | 32             | -50   | -1   |
| CC20 (red maple)        | -88            | -38   | 7    |
| CC21 (red maple)        | 18             | 59    | 9    |
| CC22 (red maple)        | -16            | -42   | 4    |
| CC23 (oak)              | -60            | -38   | -14  |
| CC24 (oak)              | 43             | 26    | 44   |
| CC25 (oak)              | 8              | 49    | -15  |
| CC26 (oak)              | 11             | 22    | 1    |
| CC28 (Atl. White cedar) | 16             | -65   | 24   |
| CC29 (Atl. White cedar) | 12             | -69   | 21   |
| CC30 (pine)             | 82             | 30    | -10  |
| CC31 (pine-heathland)   | 71             | 57    | 47   |
| CC32 (pine-heathland)   | 29             | 42    | 6    |
| CC33 (pine-heathland)   | 9              | 102   | 15   |
| CC34 (black locust)     | 97             | 38    | 3    |
| CC35 (black locust)     | 132            | 21    | 46   |

**Table 24 (continued).** Changes in summed cover class values by site between 2003 and 2012 based on growth form.

| Site                | Change by site |       |      |
|---------------------|----------------|-------|------|
|                     | Herb           | Shrub | Tree |
| CC36 (black locust) | 33             | -4    | 4    |
| CC37 (black locust) | 68             | 63    | 31   |
| CC38 (black locust) | 23             | 23    | 13   |
| CC39 (beech)        | 13             | -82   | 20   |
| CC40 (beech)        | 73             | -20   | 44   |
| CC41 (beech)        | 43             | -16   | 7    |
| CC42 (beech)        | -14            | -5    | -9   |

| Net Change |       |      |
|------------|-------|------|
| Herb       | Shrub | Tree |
| 595        | 336   | 209  |

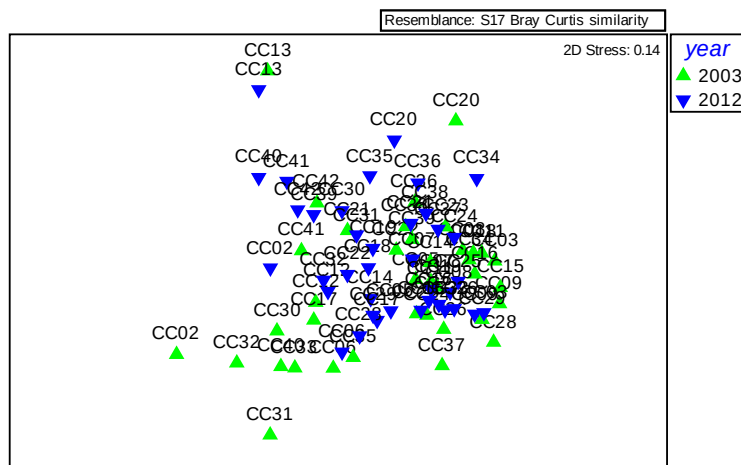


**Figure 19.** NMDS of all sites in 2003 and 2012 based on growth form categories.

**Table 25.** ANOSIM and SIMPER analysis of understory changes between 2003 and 2012 based on growth form (Contrib% indicates contribution of variable to dissimilarity between years).

| Growth Form | Mean-03 | Mean-12 | Contrib% |
|-------------|---------|---------|----------|
| Shrub       | 126.42  | 117.58  | 48.32    |
| Herb        | 40.74   | 56.39   | 33.24    |
| Tree        | 34.66   | 40.16   | 18.47    |

<sup>1</sup>ANOSIM R= 0.014, p=0.16 (not significant)  
SIMPER

### Frequency changes between 2003 and 2012

Frequency was calculated as the number of occurrences divided by the total number of plots. The most frequent understory species in 2012 were *Q. velutina* (76%), *Carex pensylvanica* (66%), *Vaccinium angustifolium* (61%), *Q. alba* (61%), and *Amelanchier* spp. (61%) (Table 24). The least frequent species were present at 3% of the sites and are too numerous (n=52) to list here. Certain species in the understory exhibited large changes in frequency while others showed minimal to no shifts. However, far more species exhibited positive changes (78 species) than negative (38 species). The highest positive changes in frequency occurred with *Carex pensylvanica* (+37%), *Trientalis borealis* (+26%), and *Mianthemum canadense* (+24%). The largest negative changes were observed in *Cypripedium acaule* (-11%), *Prunus serotina* (-8%), *Pteridium aquilinum* (-8%), and *Rosa palustris* (-8%). Thirty seven species not recorded in 2003 were present in the 2012 survey. Conversely, 22 species disappeared between surveys.

**Table 26.** Understory species frequencies in 2003 and 2012 and the difference between years.

| Species                        | 2003 | 2013 | Change |
|--------------------------------|------|------|--------|
| <i>Carex pensylvanica</i>      | 29%  | 66%  | 37%    |
| <i>Trientalis borealis</i>     | 16%  | 42%  | 26%    |
| <i>Mianthemum canadense</i>    | 8%   | 32%  | 24%    |
| <i>Epigaea repens</i>          | 8%   | 26%  | 18%    |
| <i>Chimaphila maculata</i>     | 11%  | 29%  | 18%    |
| <i>Toxicodendron radicans</i>  | 13%  | 32%  | 18%    |
| <i>Gaultheria procumbens</i>   | 16%  | 34%  | 18%    |
| <i>Deschampsia flexuosa</i>    | 34%  | 53%  | 18%    |
| <i>Arctostaphylos uva-ursi</i> | 24%  | 39%  | 16%    |
| <i>Vaccinium angustifolium</i> | 45%  | 61%  | 16%    |
| <i>Lyonia ligustrina</i>       | 0%   | 13%  | 13%    |
| <i>Rubus flagellaris</i>       | 11%  | 24%  | 13%    |
| <i>Holcus lanatus</i>          | 3%   | 13%  | 11%    |
| <i>Nyssa sylvatica</i>         | 13%  | 24%  | 11%    |
| <i>Quercus velutina</i>        | 66%  | 76%  | 11%    |
| <i>Celastrus</i> sp.           | 0%   | 8%   | 8%     |
| <i>Convallaria majalis</i>     | 0%   | 8%   | 8%     |
| <i>Juncus acuminatus</i>       | 0%   | 8%   | 8%     |
| <i>Rosa multiflora</i>         | 0%   | 8%   | 8%     |
| <i>Carex wet</i> spp.          | 3%   | 11%  | 8%     |
| <i>Sassafras albidum</i>       | 5%   | 13%  | 8%     |
| <i>Chelidonium majus</i>       | 0%   | 5%   | 5%     |
| <i>Gaylussacia frondosa</i>    | 0%   | 5%   | 5%     |
| <i>Hypochaeris radicata</i>    | 0%   | 5%   | 5%     |
| <i>Photinia</i> sp.            | 0%   | 5%   | 5%     |
| <i>Phytolacca americana</i>    | 0%   | 5%   | 5%     |
| <i>Prunus maritima</i>         | 0%   | 5%   | 5%     |

**Table 24 (continued).** Understory species frequencies in 2003 and 2012 and the difference between years.

| <b>Species</b>                     | <b>2003</b> | <b>2013</b> | <b>Change</b> |
|------------------------------------|-------------|-------------|---------------|
| <i>Saponaria officinalis</i>       | 0%          | 5%          | 5%            |
| <i>Mitchella repens</i>            | 3%          | 8%          | 5%            |
| <i>Oxalis stricta</i>              | 3%          | 8%          | 5%            |
| <i>Solanum dulcamara</i>           | 3%          | 8%          | 5%            |
| <i>Ilex glabra</i>                 | 5%          | 11%         | 5%            |
| <i>Ilex opaca</i>                  | 5%          | 11%         | 5%            |
| <i>Parthenocissus quinquefolia</i> | 21%         | 26%         | 5%            |
| <i>Gaylussacia baccata</i>         | 50%         | 55%         | 5%            |
| <i>Pinus rigida</i>                | 53%         | 58%         | 5%            |
| <i>Quercus alba</i>                | 55%         | 61%         | 5%            |
| <i>Anthoxanthum odoratum</i>       | 0%          | 3%          | 3%            |
| <i>Crataegus sp.</i>               | 0%          | 3%          | 3%            |
| <i>Decodon verticillatus</i>       | 0%          | 3%          | 3%            |
| <i>Dichanthelium acumentatum</i>   | 0%          | 3%          | 3%            |
| <i>Dichanthium annulatum</i>       | 0%          | 3%          | 3%            |
| <i>Erechtites hieracifolia</i>     | 0%          | 3%          | 3%            |
| <i>Festuca sp.</i>                 | 0%          | 3%          | 3%            |
| <i>Hamamelis virginiana</i>        | 0%          | 3%          | 3%            |
| <i>Hypericum perforatum</i>        | 0%          | 3%          | 3%            |
| <i>Ilex laevigata</i>              | 0%          | 3%          | 3%            |
| <i>Ilex verticillata</i>           | 0%          | 3%          | 3%            |
| <i>Ionactis linariifolia</i>       | 0%          | 3%          | 3%            |
| <i>Juncus canadense</i>            | 0%          | 3%          | 3%            |
| <i>Ligustrum vulgare</i>           | 0%          | 3%          | 3%            |
| <i>Malus sp.</i>                   | 0%          | 3%          | 3%            |
| <i>Photinia melenocarpa</i>        | 0%          | 3%          | 3%            |
| <i>Rhynchospora sp.</i>            | 0%          | 3%          | 3%            |
| <i>Rosa rugosa</i>                 | 0%          | 3%          | 3%            |
| <i>Rubus hispidus</i>              | 0%          | 3%          | 3%            |
| <i>Rubus occidentalis</i>          | 0%          | 3%          | 3%            |
| <i>Rumex crispus</i>               | 0%          | 3%          | 3%            |
| <i>Solidago sp.</i>                | 0%          | 3%          | 3%            |
| <i>Sparganium americanum</i>       | 0%          | 3%          | 3%            |
| <i>Spiraea tomentosa</i>           | 0%          | 3%          | 3%            |
| <i>Streptopus amplexifolius</i>    | 0%          | 3%          | 3%            |
| <i>Hudsonia tomentosa</i>          | 3%          | 5%          | 3%            |
| <i>Lysimachia terrestris</i>       | 3%          | 5%          | 3%            |
| <i>Onoclea sensibilis</i>          | 3%          | 5%          | 3%            |
| <i>Polygonella articulata</i>      | 3%          | 5%          | 3%            |

**Table 24 (continued).** Understory species frequencies in 2003 and 2012 and the difference between years.

| <b>Species</b>                   | <b>2003</b> | <b>2013</b> | <b>Change</b> |
|----------------------------------|-------------|-------------|---------------|
| <i>Rosa carolina</i>             | 3%          | 5%          | 3%            |
| <i>Scirpus cyperinus</i>         | 3%          | 5%          | 3%            |
| <i>Rubus allegheniensis</i>      | 5%          | 8%          | 3%            |
| <i>Schizachyrium scoparium</i>   | 5%          | 8%          | 3%            |
| <i>Kalmia angustifolia</i>       | 8%          | 11%         | 3%            |
| <i>Fagus grandifolia</i>         | 13%         | 16%         | 3%            |
| <i>Rhododendron viscosum</i>     | 18%         | 21%         | 3%            |
| <i>Aralia nudicaulis</i>         | 24%         | 26%         | 3%            |
| <i>Morella pensylvanica</i>      | 26%         | 29%         | 3%            |
| <i>Viburnum dentatum</i>         | 34%         | 37%         | 3%            |
| <i>Smilax rotundifolia</i>       | 50%         | 53%         | 3%            |
| <i>Amelanchier spp.</i>          | 58%         | 61%         | 3%            |
| <i>Betula sp</i>                 | 3%          | 3%          | 0%            |
| <i>Daucus carota</i>             | 3%          | 3%          | 0%            |
| <i>Juniperus communis</i>        | 3%          | 3%          | 0%            |
| <i>Leonurus cardiaca</i>         | 3%          | 3%          | 0%            |
| <i>Sisymbrium officinale</i>     | 3%          | 3%          | 0%            |
| <i>Spiranthes sp.</i>            | 3%          | 3%          | 0%            |
| <i>Toxicodendron vernix</i>      | 3%          | 3%          | 0%            |
| <i>Typha latifolia</i>           | 3%          | 3%          | 0%            |
| <i>Vaccinium macrocarpon</i>     | 3%          | 3%          | 0%            |
| <i>Woodwardia areolata</i>       | 3%          | 3%          | 0%            |
| <i>Boehmeria cylindrica</i>      | 5%          | 5%          | 0%            |
| <i>Polygonum scandens</i>        | 5%          | 5%          | 0%            |
| <i>Corema conradii</i>           | 8%          | 8%          | 0%            |
| <i>Lonicera morrowii</i>         | 8%          | 8%          | 0%            |
| <i>Osmunda cinnamomea</i>        | 11%         | 11%         | 0%            |
| <i>Clethra alnifolia</i>         | 13%         | 13%         | 0%            |
| <i>Dennstaedtia punctilobula</i> | 13%         | 13%         | 0%            |
| <i>Viburnum nudum</i>            | 13%         | 13%         | 0%            |
| <i>Acer rubrum</i>               | 37%         | 37%         | 0%            |
| <i>Vaccinium corymbosum</i>      | 45%         | 45%         | 0%            |
| <i>Quercus ilicifolia</i>        | 50%         | 50%         | 0%            |
| <i>Aster linariifolius</i>       | 3%          | 0%          | -3%           |
| <i>Berberis vulgaris</i>         | 3%          | 0%          | -3%           |
| <i>Calamagrostis canadensis</i>  | 3%          | 0%          | -3%           |
| <i>Chrysopsis falcata</i>        | 3%          | 0%          | -3%           |
| <i>Epifagus virginiana</i>       | 3%          | 0%          | -3%           |
| <i>Iris versicolor</i>           | 3%          | 0%          | -3%           |

**Table 24 (continued).** Understory species frequencies in 2003 and 2012 and the difference between years.

| Species                       | 2003 | 2013 | Change |
|-------------------------------|------|------|--------|
| <i>Lechea maritima</i>        | 3%   | 0%   | -3%    |
| <i>Lepidium campestre</i>     | 3%   | 0%   | -3%    |
| <i>Mentha arvensis</i>        | 3%   | 0%   | -3%    |
| <i>Panicum lanuginosum</i>    | 3%   | 0%   | -3%    |
| <i>Populus tremuloides</i>    | 3%   | 0%   | -3%    |
| <i>Quercus rubra</i>          | 3%   | 0%   | -3%    |
| <i>Rhamnus cathartica</i>     | 3%   | 0%   | -3%    |
| <i>Ribes hirtellum</i>        | 3%   | 0%   | -3%    |
| <i>Rosa virginiana</i>        | 3%   | 0%   | -3%    |
| <i>Salicornia maritima</i>    | 3%   | 0%   | -3%    |
| <i>Vitis labrusca</i>         | 3%   | 0%   | -3%    |
| <i>Euonymus atropurpurea</i>  | 5%   | 3%   | -3%    |
| <i>Fragaria virginiana</i>    | 5%   | 3%   | -3%    |
| <i>Hudsonia ericoides</i>     | 5%   | 3%   | -3%    |
| <i>Juncus</i>                 | 5%   | 3%   | -3%    |
| <i>Robinia pseudoacacia</i>   | 5%   | 3%   | -3%    |
| <i>Spiraea alba</i>           | 5%   | 3%   | -3%    |
| <i>Comptonia peregrina</i>    | 8%   | 5%   | -3%    |
| <i>Lonicera japonica</i>      | 8%   | 5%   | -3%    |
| <i>Melampyrum lineare</i>     | 8%   | 5%   | -3%    |
| <i>Panicum sp.</i>            | 8%   | 5%   | -3%    |
| <i>Solidago rugosa</i>        | 11%  | 8%   | -3%    |
| <i>Monotropa uniflora</i>     | 16%  | 13%  | -3%    |
| <i>Chamaecyparis thyoides</i> | 5%   | 0%   | -5%    |
| <i>Hieracium spp.</i>         | 5%   | 0%   | -5%    |
| <i>Prenanthes trifoliata</i>  | 5%   | 0%   | -5%    |
| <i>Rumex crispus</i>          | 5%   | 0%   | -5%    |
| <i>Solidago canadensis</i>    | 5%   | 0%   | -5%    |
| <i>Cypripedium acaule</i>     | 13%  | 5%   | -8%    |
| <i>Pteridium aquilinum</i>    | 21%  | 13%  | -8%    |
| <i>Prunus serotina</i>        | 53%  | 45%  | -8%    |
| <i>Rosa palustris</i>         | 13%  | 3%   | -11%   |

**Understory tree seedling/saplings density changes between 2003 and 2012**

Tree seedling/sapling densities (potential overstory tree species that were < 2m) exhibited very large differences in 2003 vs. 2012 (Table 25). *A. rubrum* exhibited the largest total reduction of -3,635. In many species there were very large decreases, with the exception of *Q. ilicifolia/velutina*, which showed a large increase of 3,378.

**Table 27.** Total tree seedling counts by species in 2003 and 2012 and the difference (Diff) between the two years.

| Species                               | 2003 | 2013 | Diff  |
|---------------------------------------|------|------|-------|
| <i>Acer rubrum</i>                    | 4103 | 468  | -3635 |
| <i>Quercus velutina</i>               | 2070 | 190  | -1880 |
| <i>Prunus serotina</i> (black cherry) | 1278 | 84   | -1194 |
| <i>Quercus ilicifolia</i>             | 1324 | 370  | -954  |
| <i>Quercus alba</i>                   | 822  | 0    | -822  |
| <i>Pinus rigida</i>                   | 755  | 1    | -754  |
| <i>Amelanchier</i> spp.               | 654  | 1    | -653  |
| <i>Chamaecyparis thyoides</i>         | 568  | 0    | -568  |
| <i>Fagus grandifolia</i>              | 201  | 7    | -194  |
| <i>Nyssa sylvatica</i> (black gum)    | 124  | 27   | -97   |
| <i>Robinia pseudoacacia</i>           | 2    | 0    | -2    |
| <i>Sassafras albidum</i>              | 19   | 195  | 176   |
| <i>Quercus ilicifolia/velutina</i>    | 391  | 3769 | 3378  |

By site, CC22 (red maple) and CC29 (Atlantic White Cedar) lost the most seedlings between survey years while CC21 (red maple) and CC05 (pine-oak) gained the most (Table 26). The average change in the number of seedlings per site was 195.

**Table 28.** Total tree seedling counts by species in 2003 and 2012 and the difference (Diff) between the two years.

| Site                  | Change<br>(2003 and 2012) | Site                    | Change<br>(2003 and 2012) |
|-----------------------|---------------------------|-------------------------|---------------------------|
| CC02 (pine)           | -92                       | CC24 (oak)              | -315                      |
| CC03 (pine-oak)       | -26                       | CC25 (oak)              | 112                       |
| CC05 (pine-oak)       | 262                       | CC26 (oak)              | -50                       |
| CC06 (pine-oak)       | -476                      | CC28 (Atl. white cedar) | -204                      |
| CC07 (pine)           | -229                      | CC29 (Atl. white cedar) | -804                      |
| CC08 (oak)            | -214                      | CC30 (pine)             | -84                       |
| CC09 (pine-oak)       | -13                       | CC31 (pine-heathland)   | 26                        |
| CC11 (pine-heathland) | -119                      | CC32 (pine-heathland)   | -40                       |
| CC12 (pine-heathland) | -14                       | CC33 (pine-heathland)   | -145                      |
| CC13 (pine)           | -64                       | CC34 (black locust)     | -245                      |
| CC14 (pine-oak)       | -45                       | CC35 (black locust)     | -61                       |
| CC15 (pine-oak)       | -289                      | CC36 (black locust)     | 11                        |
| CC16 (pine-oak)       | -245                      | CC37 (black locust)     | 18                        |
| CC17 (pine)           | 4                         | CC38 (black locust)     | -42                       |
| CC19 (red maple)      | -21                       | CC39 (beech)            | -95                       |
| CC20 (red maple)      | -19                       | CC40 (beech)            | -139                      |
| CC21 (red maple)      | 413                       | CC41 (beech)            | -120                      |
| CC22 (red maple)      | -3404                     | CC42 (beech)            | -148                      |
| CC23                  | -283                      |                         |                           |

**Species richness changes between 2003 and 2012**

In general, species richness of understory species tended to increase (68% of the sites) over this time period (Table 27). Many of the increases were quite large (> 10 species), whereas decreasing trends typically had low values of change (< 3 species). Collectively, average species richness increased significantly by 4.4 species ( $T = 1.99$ ,  $p < 0.001$ ).

**Table 29.** Number of understory species (species richness) by site in 2003 and 2012.

| Site                    | 2003 | 2012 | Diff |
|-------------------------|------|------|------|
| CC02 (pine)             | 5    | 17   | 12   |
| CC03 (pine-oak)         | 15   | 7    | -8   |
| CC05 (pine-oak)         | 17   | 14   | -3   |
| CC06 (pine-oak)         | 6    | 13   | 7    |
| CC07 (pine)             | 10   | 10   | 0    |
| CC08 (oak)              | 13   | 15   | 2    |
| CC09 (pine-oak)         | 12   | 11   | -1   |
| CC11 (pine-heathland)   | 19   | 13   | -6   |
| CC12 (pine-heathland)   | 13   | 15   | 2    |
| CC13 (pine)             | 10   | 10   | 0    |
| CC14 (pine-oak)         | 15   | 18   | 3    |
| CC15 (pine-oak)         | 18   | 16   | -2   |
| CC16 (pine-oak)         | 15   | 17   | 2    |
| CC17 (pine)             | 17   | 15   | -2   |
| CC18 (red maple)        | 10   | 22   | 12   |
| CC19 (red maple)        | 7    | 14   | 7    |
| CC20 (red maple)        | 12   | 17   | 5    |
| CC21 (red maple)        | 19   | 30   | 11   |
| CC22 (red maple)        | 11   | 16   | 5    |
| CC23 (oak)              | 26   | 10   | -16  |
| CC24 (oak)              | 15   | 21   | 6    |
| CC25 (oak)              | 14   | 20   | 6    |
| CC26 (oak)              | 8    | 13   | 5    |
| CC28 (Atl. white cedar) | 6    | 13   | 7    |
| CC29 (Atl. white cedar) | 11   | 17   | 6    |
| CC30 (pine)             | 20   | 23   | 3    |
| CC31 (pine-heathland)   | 9    | 16   | 7    |
| CC32 (pine-heathland)   | 7    | 15   | 8    |
| CC33 (pine-heathland)   | 6    | 13   | 7    |
| CC34 (black locust)     | 18   | 35   | 17   |
| CC35 (black locust)     | 15   | 21   | 6    |
| CC36 (black locust)     | 25   | 30   | 5    |
| CC37 (black locust)     | 13   | 27   | 14   |
| CC38 (black locust)     | 13   | 16   | 3    |
| CC39 (beech)            | 7    | 15   | 8    |

**Table 27 (continued).** Number of understory species (species richness) by site in 2003 and 2012.

| Site         | 2003 | 2012 | Diff |
|--------------|------|------|------|
| CC40 (beech) | 11   | 22   | 11   |
| CC41 (beech) | 18   | 21   | 3    |
| CC42 (beech) | 14   | 25   | 11   |

## Understory – individual sites

### ***Species composition and growth form changes between 2003 and 2012***

As indicated by p values from Spearman correlation analysis (p values  $\leq 0.05$  indicate that plant communities in 2003 and 2012 are significantly correlated or not different), significant changes in overall species composition were not detected at any site except CC42 (beech) (Table 28).

Thus, despite sometimes large changes in certain species at certain sites there was enough similarities among other taxa between years to negate any statistical significance related to community-level changes. When grouped by growth form (herbaceous, shrubs, trees), many more significant differences were evident. In fact, 14 sites were statistically different (not significantly correlated) between survey years and this group encompassed many forest types. The largest changes were observed in understory tree and shrub species, both of which decreased in cover.

**Table 30.** Correlation analysis of species composition and growth form changes between 2003 and 2012 by site (significant results in this case indicate no significant changes in species composition between years and vice versa) and forest type. p=statistical probability values. Highlighted cells indicate sites with statistically significant changes.

| Species | type                 | p        | Growth form | type                 | p        |
|---------|----------------------|----------|-------------|----------------------|----------|
| CC02    | beech                | < 0.0001 | CC02        | beech                | < 0.0001 |
| CC03    | pitch pine           | < 0.0001 | CC03        | pitch pine           | 1.00     |
| CC05    | pine-oak             | < 0.0001 | CC05        | pine-oak             | 1.00     |
| CC06    | pine-oak             | < 0.0001 | CC06        | pine-oak             | < 0.0001 |
| CC07    | pine-oak             | < 0.0001 | CC07        | pine-oak             | 1.00     |
| CC08    | pitch pine           | < 0.0001 | CC08        | pitch pine           | < 0.0001 |
| CC09    | oak                  | < 0.0001 | CC09        | oak                  | < 0.0001 |
| CC11    | pine-oak             | < 0.0001 | CC11        | pine-oak             | < 0.0001 |
| CC12    | pine-heathland       | < 0.0001 | CC12        | pine-heathland       | < 0.0001 |
| CC13    | pine-heathland       | < 0.0001 | CC13        | pine-heathland       | < 0.0001 |
| CC14    | pitch pine           | < 0.0001 | CC14        | pitch pine           | < 0.0001 |
| CC15    | pine-oak             | < 0.0001 | CC15        | pine-oak             | < 0.0001 |
| CC16    | pine-oak             | < 0.0001 | CC16        | pine-oak             | < 0.0001 |
| CC17    | pine-oak             | < 0.0001 | CC17        | pine-oak             | 1.00     |
| CC18    | pitch pine           | < 0.0001 | CC18        | pitch pine           | < 0.0001 |
| CC19    | red maple            | < 0.0001 | CC19        | red maple            | < 0.0001 |
| CC20    | red maple            | < 0.0001 | CC20        | red maple            | < 0.0001 |
| CC21    | red maple            | < 0.0001 | CC21        | red maple            | < 0.0001 |
| CC22    | red maple            | < 0.0001 | CC22        | red maple            | < 0.0001 |
| CC23    | red maple            | < 0.0001 | CC23        | red maple            | 1.00     |
| CC24    | oak                  | < 0.0001 | CC24        | oak                  | < 0.0001 |
| CC25    | oak                  | < 0.0001 | CC25        | oak                  | < 0.0001 |
| CC26    | oak                  | < 0.0001 | CC26        | oak                  | < 0.0001 |
| CC28    | oak                  | < 0.0001 | CC28        | oak                  | 0.33     |
| CC29    | Atlantic white cedar | < 0.0001 | CC29        | Atlantic white cedar | 1.00     |
| CC30    | Atlantic white cedar | < 0.0001 | CC30        | Atlantic white cedar | 0.33     |
| CC31    | pitch pine           | < 0.0001 | CC31        | pitch pine           | 1.00     |
| CC32    | pine-heathland       | < 0.0001 | CC32        | pine-heathland       | 1.00     |
| CC33    | pine-heathland       | < 0.0001 | CC33        | pine-heathland       | < 0.0001 |
| CC34    | pine-heathland       | < 0.0001 | CC34        | pine-heathland       | < 0.0001 |
| CC35    | black locust         | < 0.0001 | CC35        | black locust         | 1.00     |
| CC36    | black locust         | < 0.0001 | CC36        | black locust         | < 0.0001 |
| CC37    | black locust         | < 0.0001 | CC37        | black locust         | < 0.0001 |
| CC38    | black locust         | < 0.0001 | CC38        | black locust         | < 0.0001 |
| CC39    | black locust         | < 0.0001 | CC39        | black locust         | 1.00     |
| CC40    | beech                | < 0.0001 | CC40        | beech                | 0.33     |
| CC41    | beech                | < 0.0001 | CC41        | beech                | 1.00     |
| CC42    | beech                | 0.37     | CC42        | beech                | < 0.0001 |

## Environmental variables

### **Soil properties (2012)**

Collectively, the 0.25-0.5 mm and 0.5-1mm particle size fractions comprised the bulk of the forest soil samples (Table 29). These particle sizes are characteristic of fine-coarse sand. Fine particles (<0.05-0.1 mm), which are associated with mud-very fine sand, were comparatively much lower. This pattern of fractionation did not vary greatly among sites – i.e., the various proportions remained relatively similar (Table 30). A couple of notable exceptions are CC12 (pine-heathland), CC18 (red maple), and CC40 (beech) where the 0.5-1.0 mm size fraction (coarse sand) accounted for > 60% of the samples by weight. At CC20 (red maple), CC22 (red maple), CC28 (Atlantic white cedar), and CC29 (Atlantic white cedar) the coarsest particles (1-2 mm; very coarse sand) constituted > 30% of the samples.

**Table 31.** Mean particle size fractions by percent of total sample weight (all sites).

| 1-2mm   | 0.5-1mm | 0.25-0.5mm | 0.1-0.25mm | 0.05-0.1mm | <0.05mm |
|---------|---------|------------|------------|------------|---------|
| 14%     | 36%     | 30%        | 11%        | 5%         | 3%      |
| (±1.3%) | (±1.8%) | (±1.7%)    | (±1.0%)    | (±0.7%)    | (±0.4%) |

**Table 32.** Mean particle size fractions by percent of total sample weight (all sites) (AWC=Atlantic White Cedar, black loc-black locust).

|      | Type       | > 2mm | 1-2mm | 0.5-1mm | 0.25-0.5mm | 0.1-0.25mm | 0.05-0.1mm | <0.05mm |
|------|------------|-------|-------|---------|------------|------------|------------|---------|
| CC01 | beech      | 2%    | 16%   | 46%     | 15%        | 7%         | 6%         | 8%      |
| CC02 | pitch pine | 0%    | 12%   | 35%     | 37%        | 12%        | 2%         | 2%      |
| CC03 | pine-oak   | 0%    | 16%   | 39%     | 32%        | 8%         | 2%         | 3%      |
| CC05 | pine-oak   | 0%    | 17%   | 39%     | 30%        | 7%         | 2%         | 4%      |
| CC06 | pine-oak   | 0%    | 8%    | 33%     | 40%        | 12%        | 3%         | 3%      |
| CC07 | pitch pine | 0%    | 15%   | 40%     | 28%        | 7%         | 3%         | 6%      |
| CC08 | oak        | 0%    | 13%   | 39%     | 34%        | 7%         | 3%         | 4%      |
| CC09 | pine-oak   | 0%    | 18%   | 41%     | 29%        | 6%         | 2%         | 3%      |
| CC11 | pine-heat  | 0%    | 7%    | 31%     | 46%        | 10%        | 2%         | 3%      |
| CC12 | pine-heat  | 0%    | 8%    | 79%     | 11%        | 1%         | 1%         | 1%      |
| CC13 | pitch pine | 0%    | 11%   | 30%     | 43%        | 12%        | 2%         | 3%      |
| CC14 | pine-oak   | 0%    | 10%   | 34%     | 41%        | 10%        | 2%         | 2%      |
| CC15 | pine-oak   | 0%    | 16%   | 38%     | 31%        | 7%         | 3%         | 5%      |
| CC16 | pine-oak   | 0%    | 14%   | 38%     | 33%        | 8%         | 3%         | 4%      |
| CC17 | pitch pine | 0%    | 17%   | 41%     | 24%        | 8%         | 4%         | 7%      |
| CC18 | red maple  | 0%    | 11%   | 61%     | 10%        | 8%         | 5%         | 4%      |
| CC19 | red maple  | 0%    | 17%   | 35%     | 34%        | 11%        | 2%         | 1%      |

**Table 30 (continued).** Mean particle size fractions by percent of total sample weight (all sites) (AWC=Atlantic White Cedar, black loc-black locust).

|      | Type       | > 2mm | 1-2mm | 0.5-1mm | 0.25-0.5mm | 0.1-0.25mm | 0.05-0.1mm | <0.05mm |
|------|------------|-------|-------|---------|------------|------------|------------|---------|
| CC20 | red maple  | 2%    | 34%   | 26%     | 20%        | 12%        | 5%         | 2%      |
| CC21 | red maple  | 0%    | 6%    | 30%     | 44%        | 15%        | 2%         | 2%      |
| CC22 | red maple  | 0%    | 7%    | 14%     | 40%        | 34%        | 4%         | 1%      |
| CC23 | oak        | 0%    | 22%   | 39%     | 27%        | 5%         | 4%         | 3%      |
| CC24 | oak        | 0%    | 18%   | 35%     | 27%        | 8%         | 7%         | 5%      |
| CC25 | oak        | 0%    | 14%   | 41%     | 30%        | 9%         | 4%         | 2%      |
| CC26 | oak        | 0%    | 12%   | 37%     | 37%        | 9%         | 4%         | 2%      |
| CC28 | AWC        | 3%    | 41%   | 30%     | 16%        | 6%         | 3%         | 1%      |
| CC29 | AWC        | 1%    | 38%   | 32%     | 17%        | 7%         | 3%         | 1%      |
| CC30 | pitch pine | 0%    | 8%    | 21%     | 38%        | 22%        | 8%         | 3%      |
| CC31 | pine-heat  | 0%    | 13%   | 37%     | 32%        | 9%         | 6%         | 3%      |
| CC32 | pine-heat  | 0%    | 9%    | 27%     | 44%        | 17%        | 3%         | 0%      |
| CC33 | pine-heat  | 0%    | 4%    | 25%     | 50%        | 17%        | 3%         | 1%      |
| CC34 | black loc  | 0%    | 9%    | 25%     | 33%        | 19%        | 10%        | 3%      |
| CC35 | black loc  | 1%    | 19%   | 37%     | 30%        | 8%         | 3%         | 2%      |
| CC36 | black loc  | 0%    | 7%    | 31%     | 35%        | 17%        | 7%         | 2%      |
| CC37 | black loc  | 0%    | 18%   | 39%     | 29%        | 9%         | 3%         | 2%      |
| CC38 | black loc  | 0%    | 5%    | 23%     | 39%        | 26%        | 6%         | 1%      |
| CC39 | beech      | 0%    | 9%    | 45%     | 17%        | 9%         | 13%        | 7%      |
| CC40 | beech      | 0%    | 8%    | 58%     | 13%        | 6%         | 9%         | 5%      |
| CC41 | beech      | 0%    | 6%    | 42%     | 15%        | 10%        | 17%        | 8%      |
| CC42 | beech      | 0%    | 7%    | 34%     | 15%        | 11%        | 21%        | 11%     |

When fraction percentages are plotted by site using PCA (Figure 20), it becomes evident that virtually all classes contribute equally to the divergence of sites in ordinal space. In other words, large disparities in the percentages of particular size fraction among sites do not cause the array of sites to be stretched in any direction.

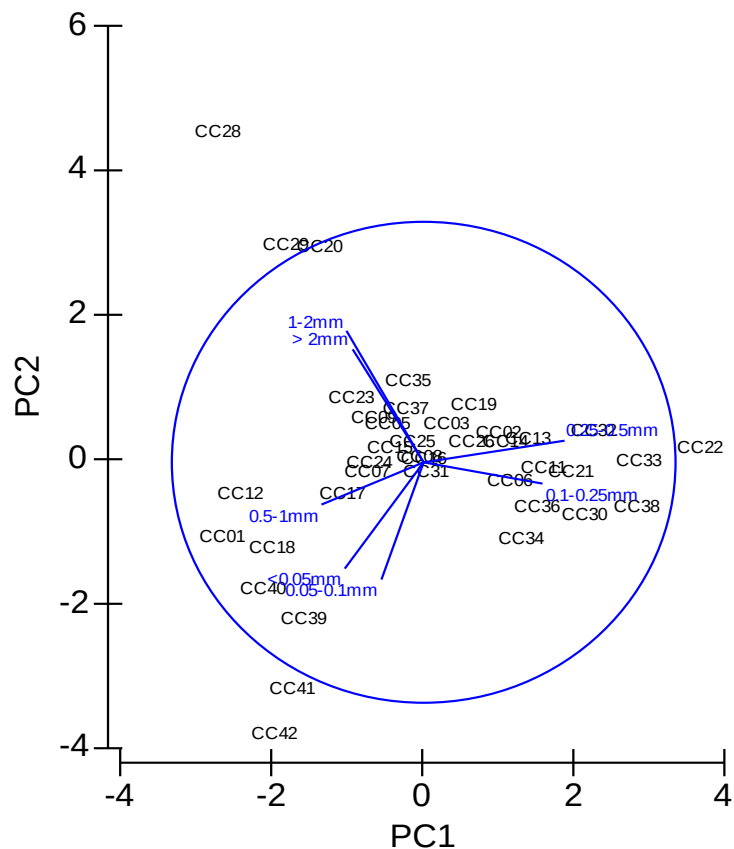


**Figure 20.** PCA of forest sites based on soil particle size fractions.

When grouped by forest type, a slightly different PCA pattern emerges – one in which the Atlantic white cedar and beech forest sites are distinctly different from the other types based on their higher proportions of very fine and very coarse particle sizes, respectively (Figure 21).

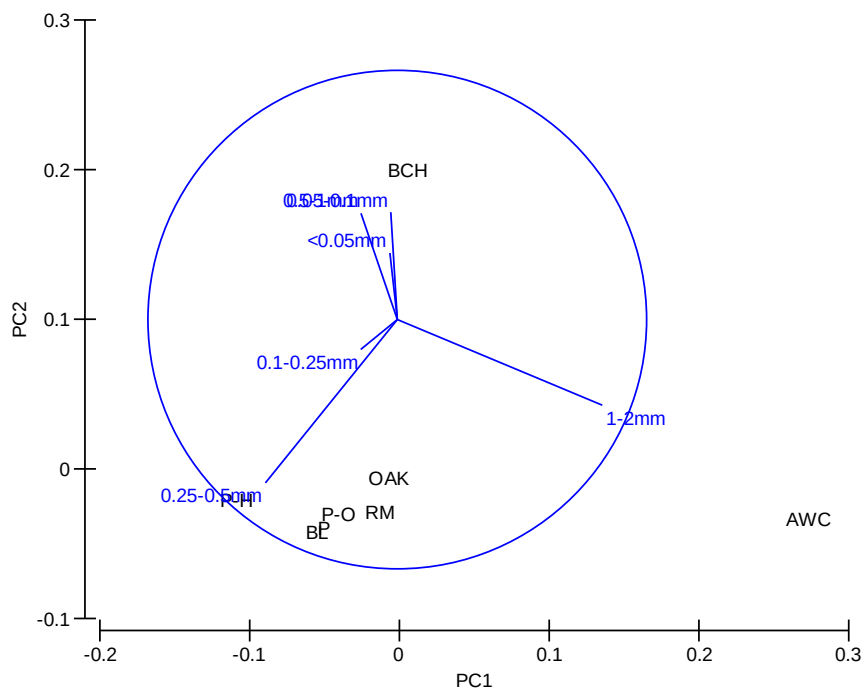


**Figure 21.** PCA of soil particle size fractions based on forest type (AWC=Atlantic White Cedar, BCH=beech, BL=black locust, OAK= oak, P-H=pine-heath, P-O=pine-oak, P=pine, RM=red maple).

Soil organic matter was relatively uniform and generally < 10% among the majority of sites (Figure 22). CC19 (red maple) and CC26 (oak) had higher proportions (25-30%) and CC20 (red maple), CC28 (Atlantic white cedar) and CC29 (Atlantic white cedar) had very high proportions of >70%. This is reflected in Figure 23 in which sites are grouped by forest type.

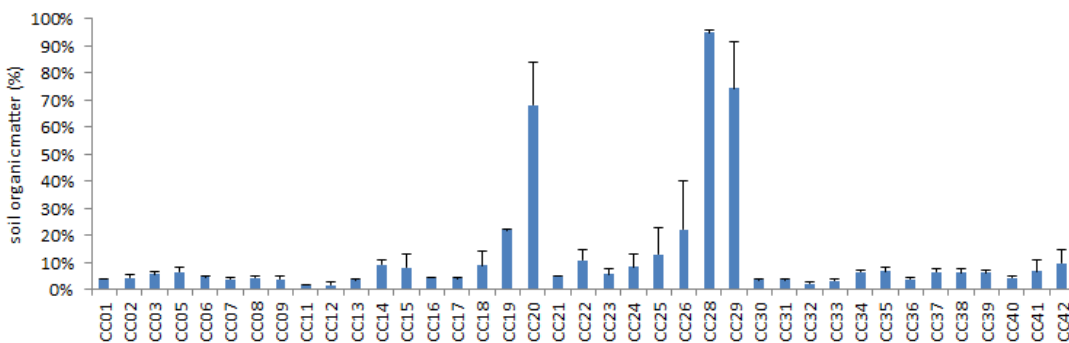


**Figure 22.** Soil organic matter (%) by site in 2012.

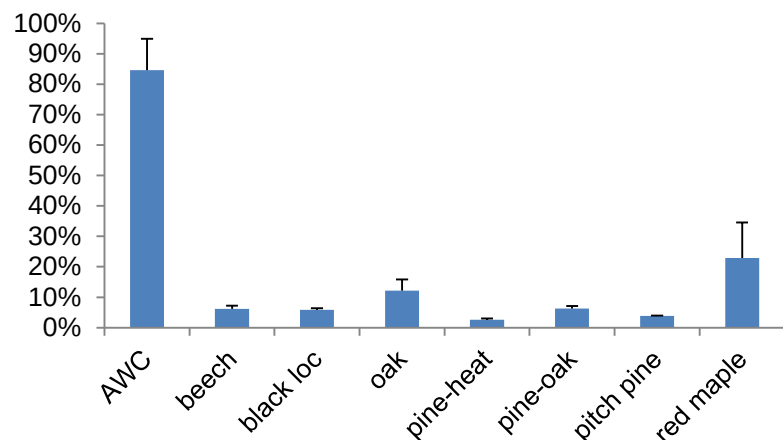


**Figure 23.** Soil organic matter (%) by forest type in 2012.

Mean litter depth was highly disparate among sites, ranging between 0 cm (CC20; red maple) and 6.3 cm (CC23; oak) with an average value of 3.0 cm ( $\pm 0.30$ ) (Figure 24).

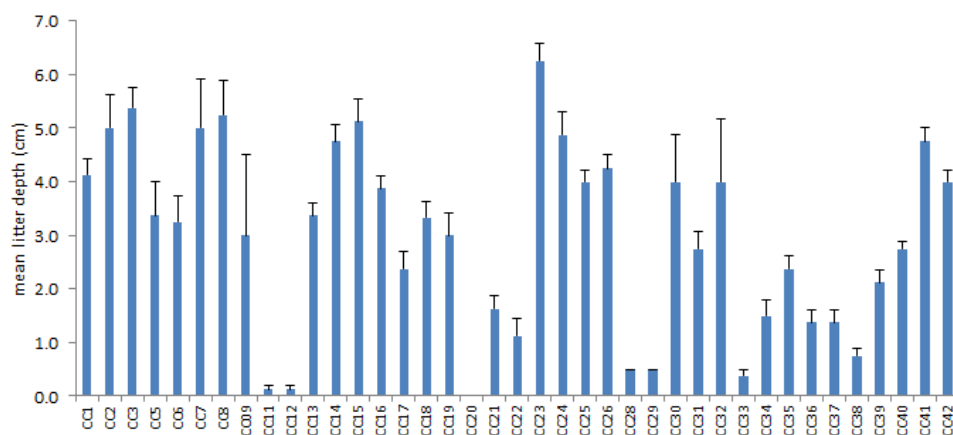


**Figure 24.** Mean litter depth (cm) by site.

By forest type, mean litter depth was highest in oak-dominated areas (~5 cm) (Table 31). Pine, pine-oak, and beech forest had less litter, but the numbers were fairly similar to beech (~3.5-4.0). However, red maple, pine-heathland, black locust, and Atlantic white cedar had much less litter than the aforementioned types, with values < 2 cm.

**Table 33.** Mean particle size fractions by percent of total sample weight (all sites).

| Type                 | mean litter depth (cm) | SE  |
|----------------------|------------------------|-----|
| oak                  | 4.9                    | 0.4 |
| pitch pine           | 4.1                    | 0.5 |
| pine-oak             | 4.1                    | 0.5 |
| beech                | 3.6                    | 0.5 |
| red maple            | 1.8                    | 0.7 |
| pine-heathland       | 1.5                    | 0.9 |
| black locust         | 1.5                    | 0.3 |
| Atlantic white cedar | 0.5                    | 0   |

### ***Elevation of forest monitoring sites***

As explained previously, site elevations were estimated using a geo-referenced image of elevations from a 2010 Army Corps of Engineers LIDAR dataset. The average elevation values are somewhat predictable in that wetland types (red maple, Atlantic white cedar) are very low compared to the others (Figure 25). Oak and pine-oak types occurred at the highest elevations. All other types lay in between wetland and oak/pine-oak types and were relatively similar to each other.

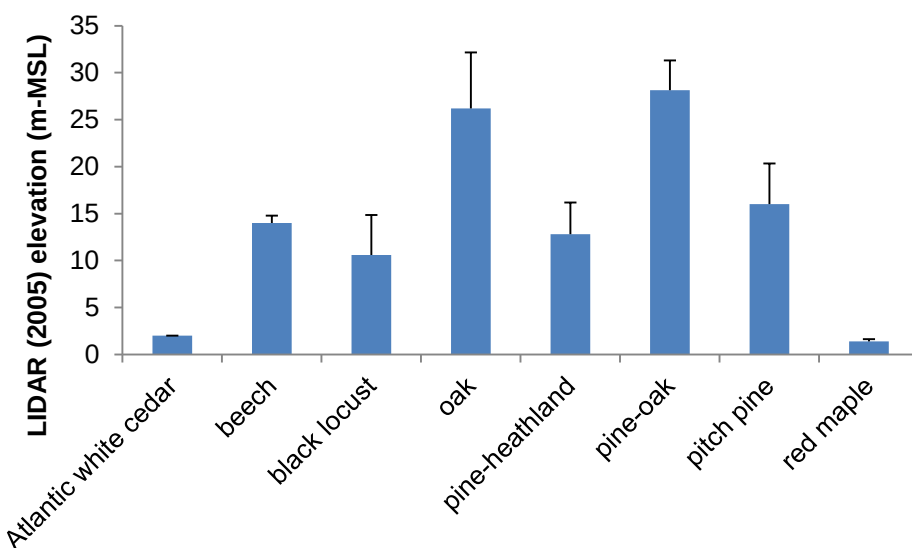


**Figure 25.** LIDAR-based elevations of monitoring sites by forest type.

### ***Qualitative assessment of forest canopy changes between 2003 and 2012 using aerial photography***

Examination of aerial photography from 1995 and 2012 photography (provided in Google Earth™) shows some fairly obvious trends in forest cover (Figure 26, 27). While succession from pine to oak (i.e., decreasing pine cover, increasing oak cover) was not conspicuous in the forest canopy, the expansion of pitch pine cover was. In fact, increases in pine canopy were obvious in many areas, but this reflected the growth and maturation of existing trees rather than an increase in new trees. Thus, the expected succession process of oak replacing pine has not

occurred within the overstory to any significant extent. Instead, changes in forest overstory structure have mostly been limited to the growth of small, immature trees into large, mature trees.

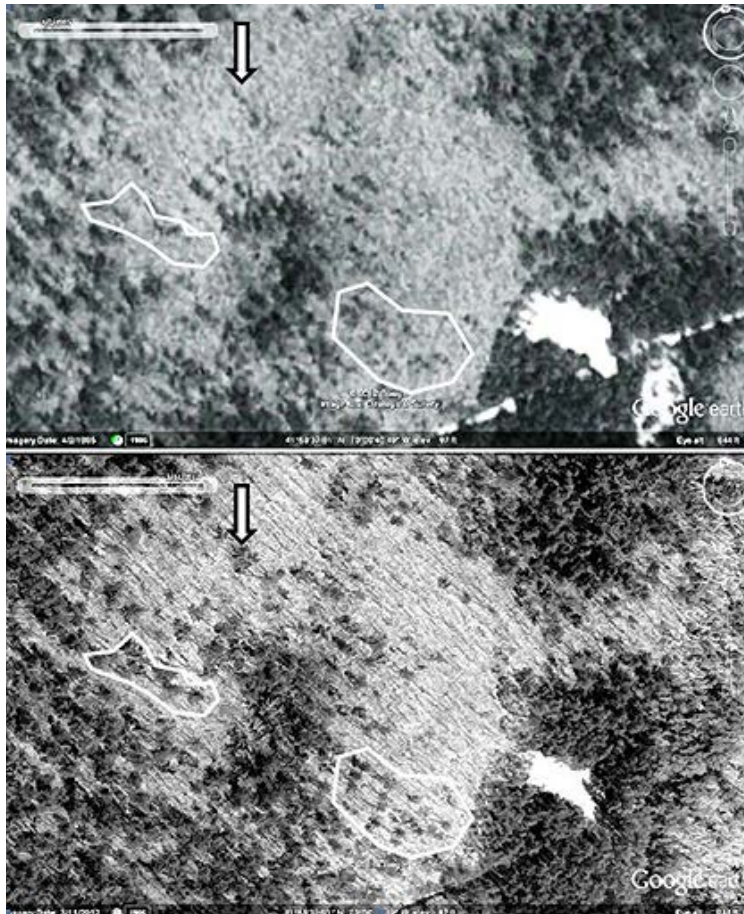


**Figure 26.** Photographs showing the change in landscape between 1995 (top) and 2012 (bottom) (Google Earth). Note the thickening of pine (dark signature) inside polygons.

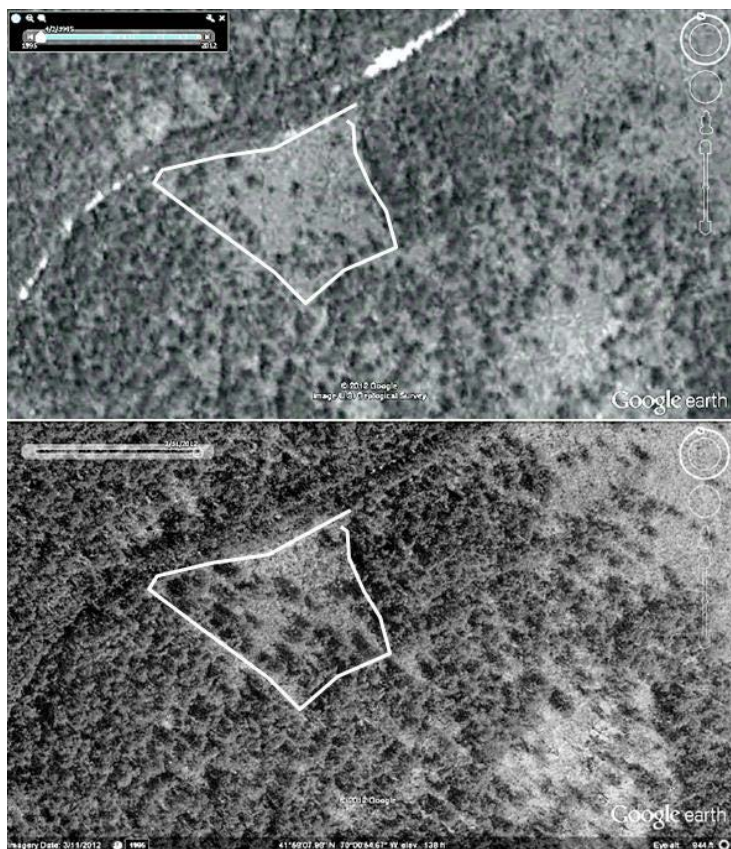


**Figure 27.** Photographs showing the change in landscape at S4 between 1995 (top) and 2012 (bottom) (Google Earth). Note the thickening of pine (dark signature) inside polygons.

## Discussion

At this point in time, CACO forests reflect past land-use history in that they are still recovering from denudation (Eberhardt 2001, Eberhardt et al. 2003, Motzkin et al. 2002) and the kinds of structural and taxonomic shifts associated with older-growth forests have not yet begun to manifest themselves.

Comparisons of tree data from 2003 and 2013 shows that secondary succession within the forest overstory, as would be evidenced by changes in tree species composition, has not occurred to any significant extent. In many areas, species such *P. rigida* that became established on the open landscape following deforestation are still growing and filling in open space rather than being outcompeted by other species. In fact, the total number of live trees actually decreased for most species, suggesting the importance of intraspecific competition and the continued growth of fewer, but older trees.

In the long term, however, it is expected that the relative abundance of *P. rigida* will decline, eventually giving way to the shade-tolerant and longer-lived *Q. velutina* and *Q. alba*. Although areas of *Quercus* spp. have sporadically been defoliated by gypsy and/or winter moths over the latter half of the 1900s and early 2000s, the predictable successional sequence of *P. rigida* to *Q. velutina*/*Q. alba* in the overstory should occur across large portions of upland habitat - a process that is likely accelerated by fire suppression (Patterson 1983, Chokkalingam 1995, Barron 2005). Succession in some areas may also depend upon forest site elevations relative to the groundwater table. For example, high, dry sites will most likely succeed to *Quercus* spp. more quickly since these species have a very high drought tolerance compared with others. In places where short periods of flooding occur, *P. rigida* may have a competitive advantage over oaks since the former is more tolerant of wet conditions. At sites with extreme levels of flooding, the dominant wetland trees (*A. rubrum* *C. thyoides*) should continue to exclude flood-intolerant taxa as long as hydrology does not change dramatically. *R. pseudoacacia*, by virtue of its nitrogen-fixing ability, alters soil chemistry in a way that facilitates the establishment and persistence of exotic understory vegetation (VonHolle et al 2012). However, the density of vegetation in the understory at these sites greatly limits the recruitment of new trees. Moreover, black locust is highly susceptible to blow-down from high wind events due to its shallow root system.

Of all tree species within the CACO forest monitoring sites, *P. rigida* and *Q. velutina* are growing the most rapidly. These taxa were the only ones to exhibit increases in basal area of 150 cm<sup>2</sup> or more (with the exception of a single *F. grandifolia* tree at CC39). *P. rigida* growth was particularly high at CC19, which is a red maple site adjacent to a permanent pond. This may be because trees at this site have more or less constant access to moisture compared to those at higher elevation, drier sites. The growth of *Q. velutina* was anomalously high at CC35 and CC40. CC35 is a black locust site so the soils may be slightly enriched in nitrogen. However, *Q. velutina* occurs at CC38 (black locust) as well and its growth there is unremarkable. Furthermore, CC40 is a beech forest site and while these areas are thought to be substantially older and more developed with respect to successional processes, soil organic matter there was not high relative to other sites where this species was present.

In the understory, plant succession does seem to be occurring. This seems plausible given the 12% average increase in canopy cover between 2003 and 2012. Canopy closure has resulted in a

fairly substantial reduction (although highly variable among sites) in light penetration to the forest floor, which results in a shift to more shade-tolerant species. Along these lines, the three herbaceous species that increased most in frequency were *Carex pensylvanica* (Pennsylvania sedge; sedge), *Trientalis borealis* (starflower; forb), and *Mianthemum canadense* (Canada Mayflower; forb), all of which are typically found in shady environments. Furthermore, the shade-tolerant *Q. velutina* and *Q. alba* both increased in frequency in the understory by 11% and 5%, respectively. This trend was not observed for tree seedling densities, which actually decreased quite dramatically between 2003 and 2012. However, it is important to realize that only a few of many tree seedlings will make it from the seedling to the sapling stage and therefore a reduction in the number of tree seedlings does not necessarily equate with a reduction in species cover or frequency in the understory since it takes only a few individuals to grow large and begin to dominate. Moreover, the survival of trees seedlings may be limited by succession itself in that the growth of understory vegetation reduces the amount of available space over which seedling recruitment can occur.

Understory species richness generally exhibited an increasing trend at the sites – another indicator of early successional processes. However, while a number of new species appeared between 2003 and 2012, overall plant community composition did not change significantly. In contrast, the proportion of the various growth forms did, with shrub species exhibiting large decreases compared to forb vegetation (the latter increasing at most sites). This makes sense given that there are many more herbaceous species that are shade-tolerant than there are shrub species.

### **General conclusion**

With the exception of black locust, which has a maximum lifespan of about 100 years, the tree species that dominate the various forest types monitored at CACO can live to between 400-600 years old. Almost complete deforestation of Cape Cod occurred between first European contact (~400 years before present) and the early 1990s (~100 years before present). Thus, the forests in CACO are quite young and have yet to become fully developed. There is evidence for succession in the understory but it may be a while before this manifests itself in the overstory. The next survey scheduled for 2022 will shed more light on the rate at which this processes is occurring.

### **Comments on methodology and future monitoring**

Tagging and tracking individual trees has proven a worthwhile endeavor since temporal trends can be elucidated without the confounding factors of 1) sapling recruitment to the > 2m layer and 2) tree mortality. Moreover, the latter two variables themselves can now be followed very specifically as each tree will have its own dataset associated with it.

Analysis of soil particle size and organic matter provided interesting but perhaps marginally useful data. The information essentially confirms what is already known about these systems. For example, it was no surprise that the substrate is 1) composed mainly of sand, 2) that organic matter is much higher in wet (Atlantic white cedar, red maple) vs. dry sites, and 3) that organic matter is also higher at sights in more advanced successional stages (oak). What could be useful is information related to temporal changes in soils, particularly in organic matter content. Thus, in order to adequately assess this importance of monitoring these variables a second data set (to be collected in 2022) is necessary.

The automation of aerial photograph analysis would provide very useful data for interpreting site-level forest dynamics in the context of the broader landscape. The qualitative assessment described in this report was helpful in this regard, but for long-term monitoring a more rigorous, objective technique should be used.

Finally, a comprehensive age analysis through tree coring would provide valuable information for assessing spatial variability in growth and in interpreting forest vegetation structure. This can be accomplished fairly easily by extracting thin cores from the boles of trees of different sizes and then using ring counts to estimate an age. Unfortunately, the field crew in 2013 did not have time to accomplish this task, but it should be made a priority for the next survey or, alternatively, as a separate project.



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