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Recent Growth Increases in an Eastern Forest -- A Response to Climate Change?

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RECENT GROWTH INCREASES IN AN EASTERN FOREST -- A RESPONSE TO CLIMATE CHANGE?

By Geoffrey G. Parker

SUMMARY

In the course of a long-term study of forests in the vicinity of the nation's capital we found evidence that these forests have recently been growing faster than expected. We were able to do this because we had an unusual combination of observations: one sort illustrated the general pattern of long-term forest growth over centuries and another type provided repeated observations on numerous individual forests over 23 years. When compared to the pattern expected from long-term trends, the growth rates of recently studied forests were much higher. Ours was an observational rather than an experimental study, so we have no direct evidence for the cause. However, several local environmental factors have changed markedly over the past century that might cause this accelerated growth either individually or in concert: higher temperatures, longer growing seasons, and greater concentrations of atmospheric CO_2. These are all components of a changing climate.

INTRODUCTION

A forest can be understood as an entity. Especially in parts of the world with long histories of agriculture and timber harvesting, most forests have a starting date (when agriculture or timbering stopped, allowing trees to grow undisturbed), a variety of stages of development (where trees grow and die, but the forest as a whole matures), and an end, where the forest is mostly or entirely cleared due to usually man-made or natural events such as logging, fires, storms, or pest outbreaks. In many cases such an incident marks the 'start' of the next forest community. For much of highly populated areas of the world the event that 're-sets' the forest is simply the abandonment of land that was formerly cropland or pasture. This developmental process can span a couple of hundred years or even a thousand years in some regions. It is impossible to study even the shortest-lived forests directly. We chose to employ an alternative approach, called the "chronosequence" (or "space-for-time substitution") in order to understand long term forest development by looking at different stages side-by-side.

In ecology, a chronosequence is a set of observations made at one time of a group of subjects differing in age. Applied to forests this means simultaneously studying a group of individual stands of differing ages but similar in all other respects as much as possible. Such a set of observations is used as a proxy for general patterns in time, much as a motion picture is a series of still photographs

viewed sequentially. This method is not without limitations, because it confuses age and time. It assumes that a forest that is now old resembled in its youth a forest that is currently young. And conversely, it supposes that a young forest observed today will behave when old as an old forest we observe today. However, it is unlikely that all conditions affecting the establishment, growth, and survival of trees have remained static for hundreds of years. For example, forest fires are actively suppressed currently in order to protect property, whereas fires (natural as well as human-set) were not suppressed historically. Fires have a variety of effects on forests, and changing the incidence of fires will affect those features. Also, because of the accelerated pace of global traffic, there has been a great mixing of species between ecosystems, allowing the introduction of new species: plants, animals, pathogens, and pests. Changing the species composition of an ecosystem can have numerous effects. Despite these drawbacks, the chronosequence approach is often the only available option for understanding long-term patterns in general characteristics. Our hybrid study combined information on the long-term trend of forest growth (a cross-sectional approach) with data on the biomass changes in individual stands over recent decades (a longitudinal approach).

METHODS

We conducted our studies in and around the Smithsonian Environmental Research Center (SERC) in Edgewater MD, about an hour east of Washington DC. We found 55 forest plots in the locally dominant forest type, called the "tulip poplar" association, that we felt were similar in most respects save their ages. This forest type has a diverse mixture of deciduous hardwood species. All of the studied forests were on gentle slopes with similar soil types. The forests ranged in age from 5 to 250 years. Stand ages were determined by finding the ages of the ten oldest trees in each plot. This was done by extracting dowel-shaped "increment cores" that penetrated to the center of the tree trunk. The number of annual rings in these cores indicates the age of the tree. For younger stands we referred to a series of aerial photographs taken of SERC and surroundings since 1938. These photos helped in corroborating the ages and land-use histories of the plot. The initiating event for most of the forests in our chronosequence was the cessation of agriculture. Thus, this series of forests provides a picture of the process of recovery from land abandonment.

In each forest we established and marked out a rectangular plot and noted the species and condition and measured the size of every tree in the plot of at least 2.0 cm in diameter. The plot sizes varied according to the composition of the stand: we sampled smaller areas in young forests than in older forests. We marked the corners of each plot so we could return for additional measurements. The conventional measure of tree size is the Diameter at Breast Height (DBH)

measured at 1.3 m on the trunk above ground. With this measure it is possible to estimate various characteristics of the tree, such as its total aboveground biomass, the total dry weight of the tree. We also studied the production of leaves by collecting the leaves fallen. Finally, we studied the vertical structure of the forest canopy, the combination of all the crowns in the forest. This we accomplished using a laser rangefinder to measure the heights of canopy elements. We returned to the plots for re-measurements at intervals that varied from 1 to 10 years.

CHANGES IN SPECIES COMPOSITION The tulip poplar forest type is prevalent on rich, well-drained, and wind-protected sites on the mid-Atlantic Coastal Plain and Piedmont of the eastern US. It is a very diverse mixture of predominantly broadleaved trees species; the species composition changes during forest development (Figure 1). Open sites are quickly colonized by a group of rapidly growing pioneer species, principally sweetgum (scientific name Liquidambar styraciflua) and tulip poplar (Liriodendron tulipifera). Pioneer species typically grow best in high light; neither they nor their progeny can persist under dark conditions (because of this property they are often called "shade-intolerant"). Sweetgum is a short-lived pioneer and disappears from older closed forests, whereas tulip poplar is long-lived and can persist for several centuries. After about 50 years following abandonment shade-tolerant species appear. These are of two types: species that will persist in the understory (shrubs and small trees such as flowering dogwood, Cornus florida, and ironwood, Carpinus carolinianus), as well as the trees that will eventually dominate the forest overstory, including various oaks (the genus Quercus), hickories (Carya) and American beech (Fagus grandifolia). This broad pattern can vary somewhat among stands due to differences in soil, moisture and disturbance history. Recently, many of the flowering dogwoods in these forests have been killed by the dogwood anthracnose blight (Discula destructiva), an introduced fungal disease.

CHANGES IN FOREST STRUCTURE Following land abandonment, open ground is rapidly colonized with young trees, eventually covering nearly all the area ("crown closure"). Next is a phase of coordinated vertical growth of crowns, rapidly at first and then more slowly. At this stage the forest is composed of numerous small stems of similar size and only a few species. The forest may resemble a thicket and be very dark. This stage ends as the crowns approach their maximum height, which is often controlled by site factors such as nutrients, water availability, and disturbances. At this stage, the assemblage of crowns may appear as a single elevated, nearly uniform layer, with few crowns near the forest floor. The vertical distribution of canopy material may be termed "top-heavy" and the canopy surface is smooth. Small differences in initial position and competition for light then begin to cause differentiation of crowns, such that some
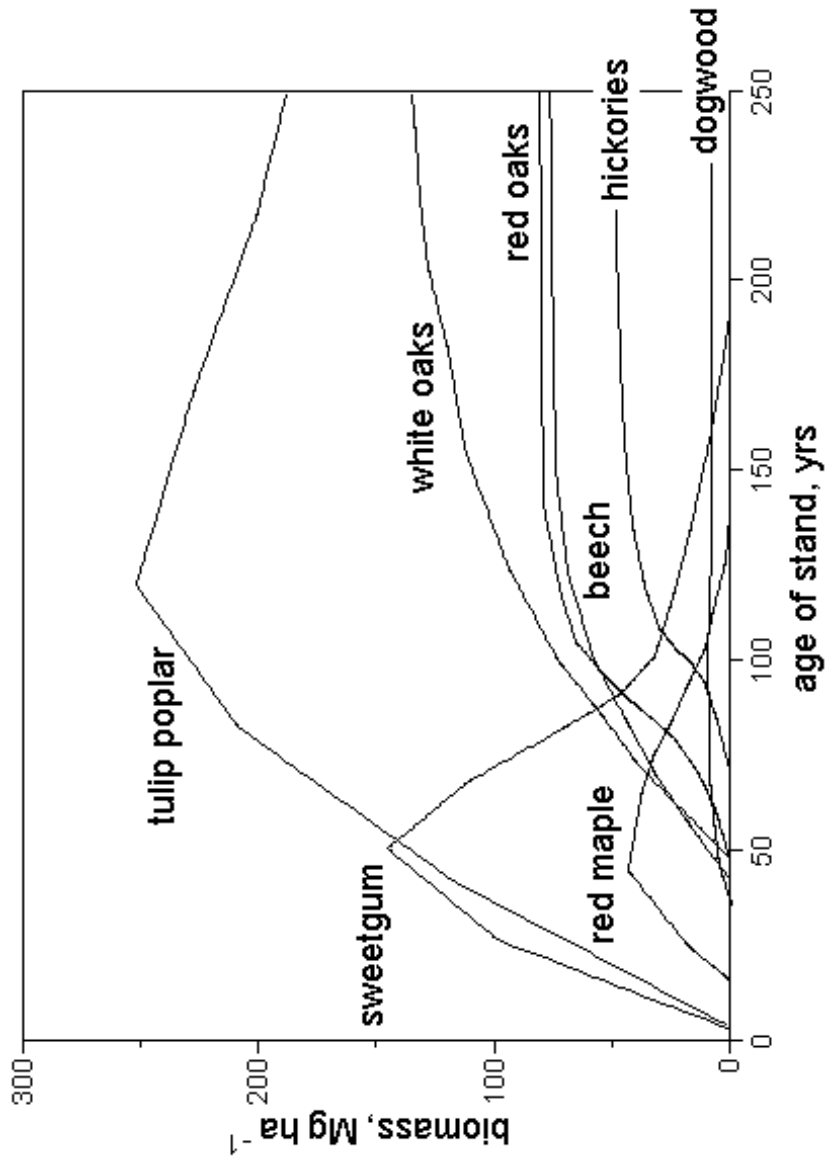
Figure 1. Trends in the composition of major species in the "tulip poplar" association during stand development.

increase in height relative to neighbors. The canopy surface becomes more rumpled. The loss of some trees through competition creates numerous small openings, which enhances light at the forest floor and stimulates the growth of additional shade-tolerant species. Together, the crowns of these species constitute a second but slower-growing vertical wave of canopy material. At the beginning of this stage, the vertical canopy profile may have distinct peaks in both the under- and over-story. Later, as canopy material accumulates all at heights, the peaks become less distinct. In the last stage, over-story trees die, leaving large lighted openings, stimulating regeneration. Unlike the wave of vertical growth stimulated by the competitive death of young crowns, here the regeneration is local. Because of the large gaps and continued crown differentiation, the canopy surface at this point is increasingly complex. Continued mortality of over-story trees results in a distribution of localities in different stages of regeneration with a spectrum of local vertical patterns. The structure of the canopy is then dominated by features with a large spatial scale – that is, big crowns and big gaps. The vertical canopy profile can be more or less uniform, or more commonly, concentrated near the forest floor ("bottom-heavy"). In this stage, often called "old-growth," there are many tree species in a variety of tree sizes, and the complexity of the outer canopy is highest. These changes in canopy heights over time are illustrated in Figure 2.

CHANGES IN BIOMASS   From a measurement of tree's DBH one can estimate its living aboveground weight ("biomass"). This is done using published equations relating DBH to biomass that were derived by harvesting, drying and weighing whole trees. Numerous such equations exist - we used those that were appropriate for our species, tree sizes, and location. When we add together such estimates for all trees in a given plot, we have the amount of biomass present per unit area. When we compare the total amount of biomass in our chronosequence by forest age we see a curving relation - the line describes the overall trend in the process of recovery following abandonment (Figure 3). There is an initial rapid rise in biomass followed by a leveling off as the canopy fills in and biomass shifts from many small stems to fewer larger ones. At the extremes, young forests have little biomass but are growing rapidly, whereas old forests have lots of material but are adding to it very slowly. From the slope of such a curve one can estimate the growth rate for a forest of any age: the rate is highest for the young stands and steadily declines as forest age. Similar growth patterns have been observed in other types of forests, although the initial rate and maximum biomass often differ.

When we overlay the curve describing the long-term trends with the short term changes in individual stands we found a surprising pattern (Figure 4). The lines connecting the individual plots sampled over time (each stand has a different color) generally show growth trends that are greater than those expected for their
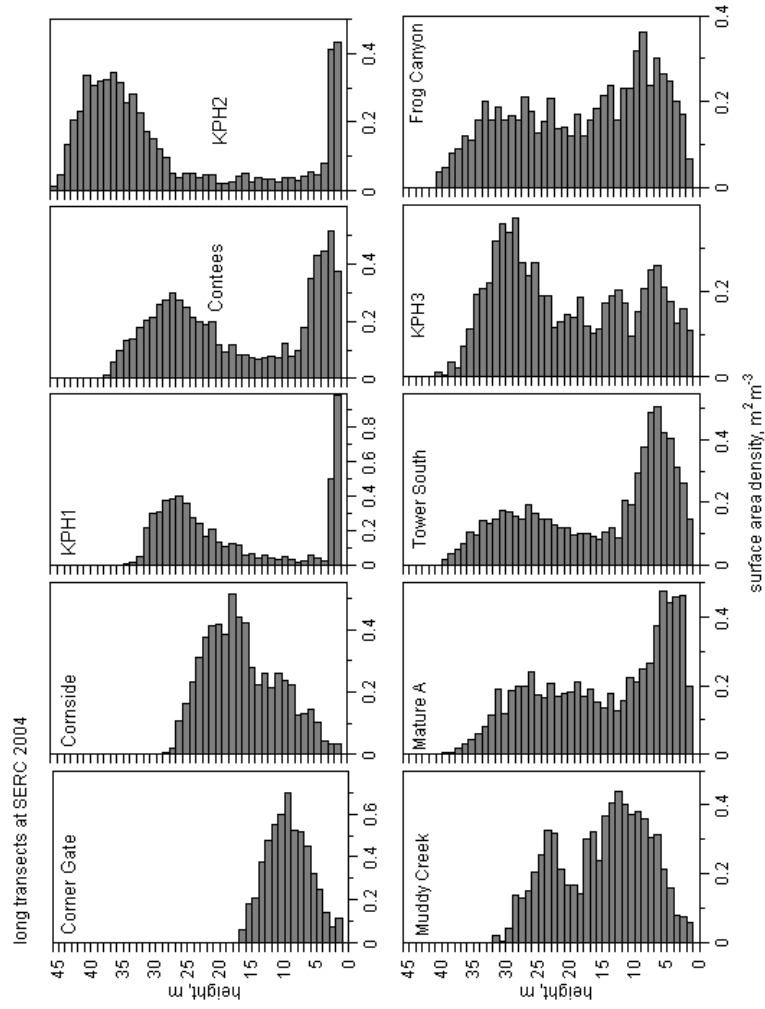
Figure 2. Changes in canopy vertical structure during stand development of the "tulip poplar" association. The plots show the average amount of surface area for each meter of height in 10 stands of increasing age. The panels are organized by forest age, with the youngest on the top left and the oldest to the bottom right. The labels give the stand names.
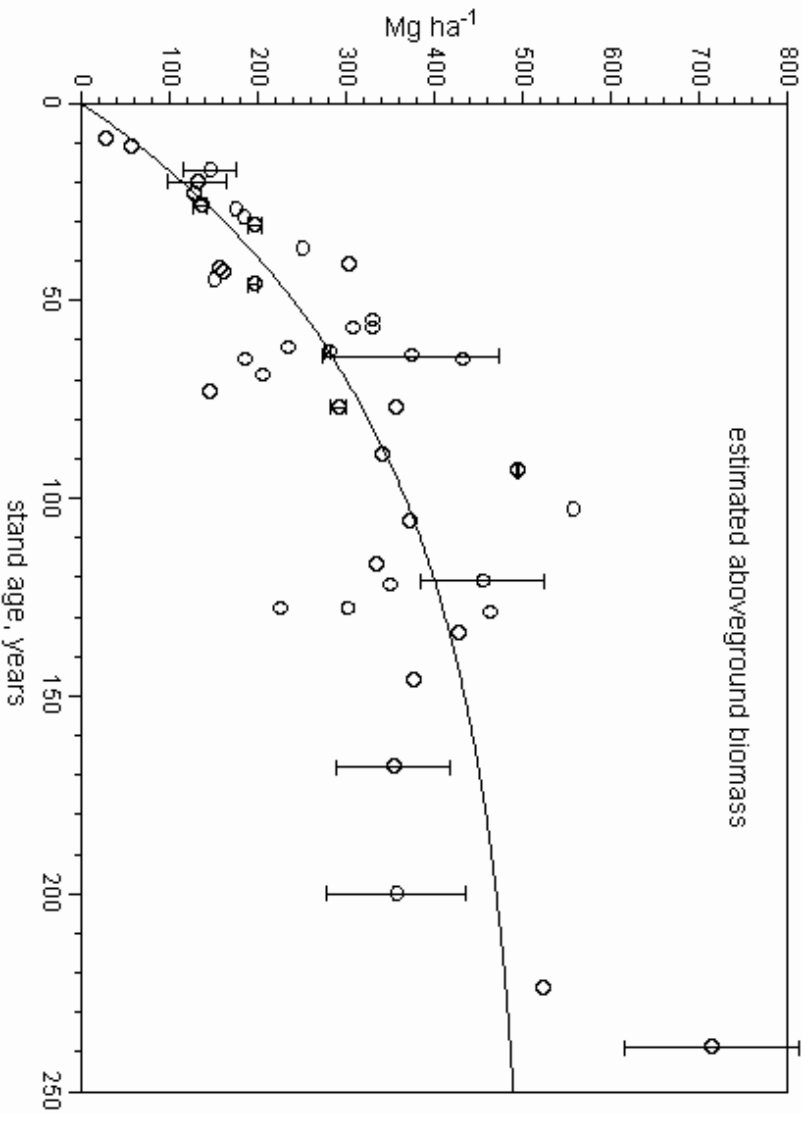
Figure 3. General pattern of biomass accumulation during stand development in the "tulip poplar" association. Each symbol represents one forest – the error bars are for cases when the forest was represented by several replicates.
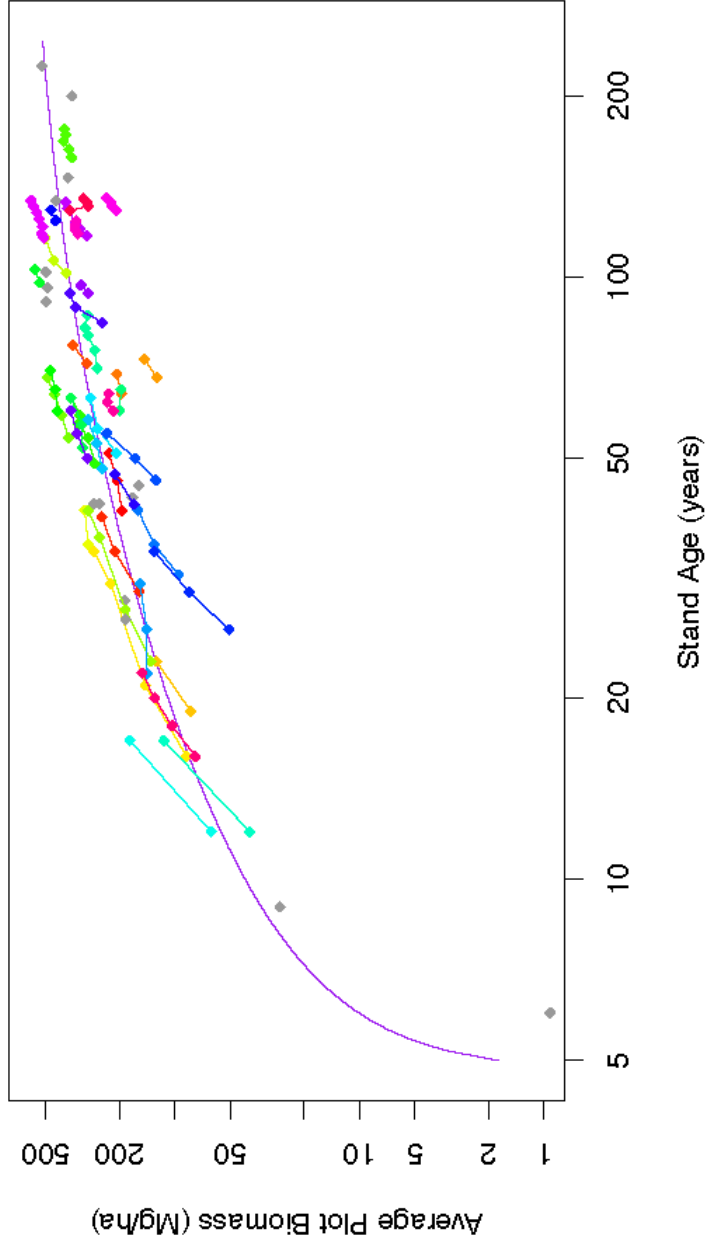
Figure 4. A comparison of the growth trajectories of individual stands sampled over the last 23 years (colored line segments) with the overall trend derived from the chronosequence (purple line).

age. That is, the slopes of the individual stand lines are far greater than the slope for the overall ensemble for the same age range. In a sense we have a comparison for each stand between the predicted growth, given by the slope of the overall chronosequence curve, and the actual growth, given by the slopes of the recently observed segments. Figure 5 shows that in the majority of our sampled intervals, the actual growth was far greater than expected.
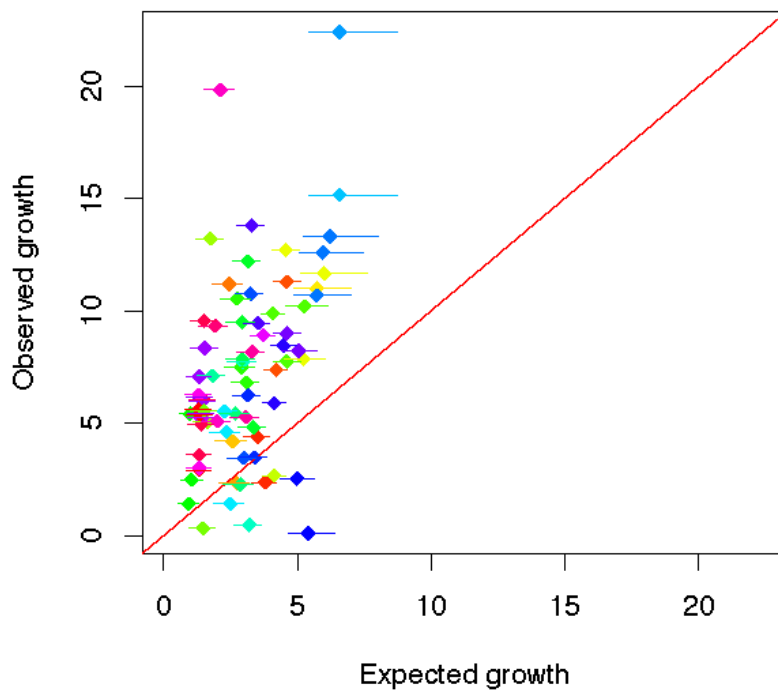

Figure 5. Comparison of the predicted and expected growth per sampling interval. The symbol colors refer to the same stands shown in Figure 4. Cases that behaved as expected would fall on the orange 1:1 line.

Cause of the Growth Enhancement

Although we have uncovered evidence of a surprising enhancement of growth, we don't fully understand the cause. Our data cannot point definitively to a cause because this study was not an experiment. However, there are a number of plausible possibilities that are worth exploring.

GROWTH ENHANCEMENTS BY FERTILIZATION We know from their land-use histories that these forest plots were not amended with chemical fertilizers. Nor has there been much change over the study period in the amount of nutrients (principally nitrogen and phosphorus) delivered in atmospheric deposition. In fact, some aspects of air pollution, such as the acidity of precipitation, have improved somewhat over the study period. It doesn't appear that the observed growth was stimulated by fertilization.

LOCAL GROWTH STIMULATION When an over-story tree dies the growth of the neighboring trees formerly in the shade is often stimulated (this is called "release"). This effect resembles at a local scale the burst of growth seen at the stand level after stand initiation. Could we, by chance, have measured our forests mostly when they were experiencing such local stimulations? While deaths of large trees were apparent in some of the intervals we sampled the growth rates were not higher in those cases, so this effect is unlikely to have contributed.

SPECIES-SPECIFIC RESPONSES Some species, such as the pioneers sweet gum and tulip poplar, can grow much more rapidly than others. Might the increased growth be due to a shift in species composition to these rapid responders? We found that all species responded similarly with extra growth and there was no special enhancement in the growth of pioneers.

WARMER AIR TEMPERATURES Long-term air temperature measurements at a weather station near SERC show an increase in average annual temperature of about 0.13 ° C per decade, or about 0.30 ° C over the 23 years of our study (Figure 6). This increase is mostly due to increasing annual maximum temperatures – annual minimum temperatures show no trend. Warmer temperatures are known to stimulate plant growth and could be a causative factor.

LONGER GROWING SEASONS One measure of the length of the growing season is the duration in days between the last frost in the winter and the first frost the following autumn. While there is much variation in this period from year to year, spring generally arrives earlier and autumn comes later every year in this vicinity. By this measure the growing season length has increased by 7.8 days over the study period (Figure 7). Longer growing seasons allow extended growth and could be a contributing factor in the extra growth we observed.
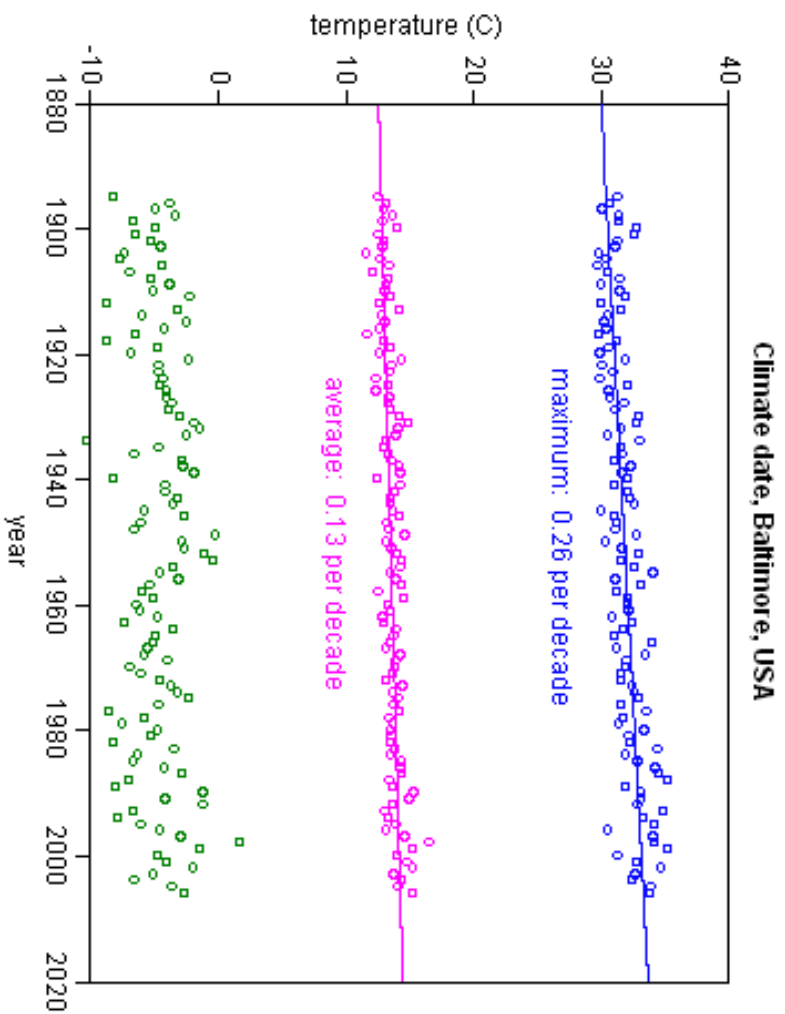
Figure 6. Long term trends in the minimum (green symbols and line), mean (pink), and maximum (blue) annual temperatures at the BWI weather station, near SERC.
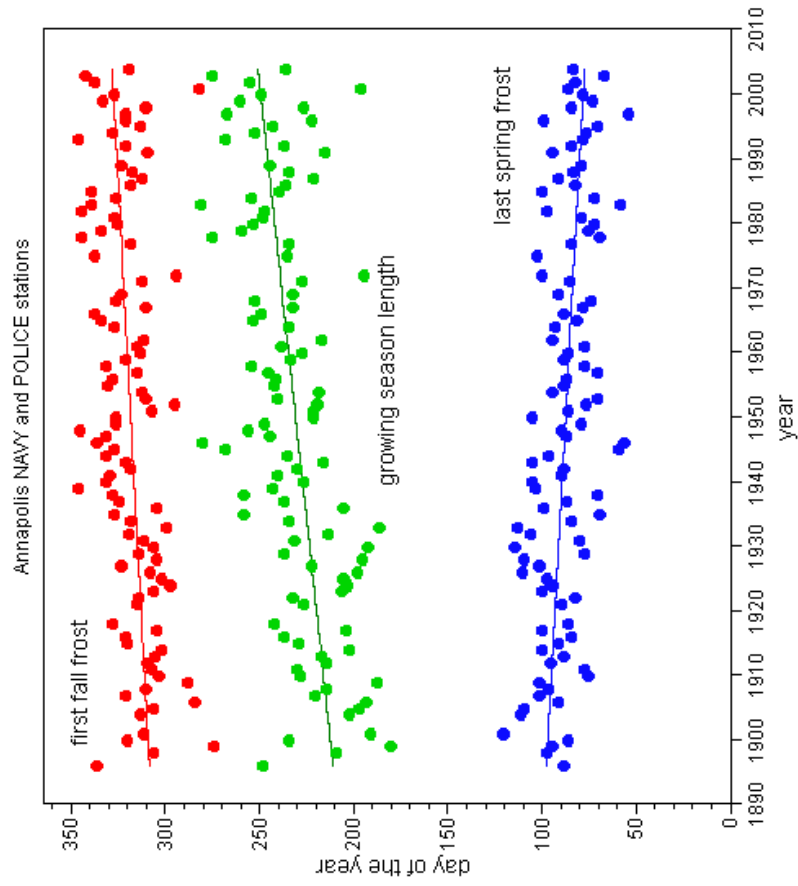
Figure 7. Long-term trends of the dates of last spring frost (blue symbols and line) and first fall frost (red symbols and line) and the difference between these dates, the growing season length (green symbols and line) from weather stations near SERC.

HIGHER ATMOSPHERIC CO2 CONCENTRATIONS Plants take up atmospheric carbon dioxide and use it for a variety of purposes, including the production of new biomass. Many field and lab experiments where extra CO2 was added to the air around trees have shown a marked stimulation of growth. Most of those studies compared the effects of current and highly enriched CO2 levels (often a doubling of current levels) and may not strictly apply to the relatively small 12 % increase seen over the study period . Nonetheless, higher CO2 levels are likely to have resulted in more growth (Figure 8).

Environmental conditions that have changed over the course of this study, warmer air temperature, longer growing seasons and higher CO2 concentrations, are all known to stimulate tree growth. All are components of recent climate changes, led by the increase of atmospheric carbon dioxide.

Our findings are similar to other reports that forests in many regions (tropical, temperate and boreal) seem to be showing enhanced growth. But it's difficult to evaluate changes in growth rates without the context of disturbance history – the age of a forest is a major determinant of its growth. That is, is a particular change unusual or not? What is the expected behavior of the stand at a particular stage of development? Our study is unusual in that we have repeated observations of individual stand biomass as well as a long-term developmental framework within which to evaluate these recent changes.

WHERE TO GO FROM HERE?

The results of this study raise some questions. First, is the trend that we have seen from this sort of evidence limited to the vicinity of SERC or is it widespread? If widespread, how do other growth rates compare with those we've found? To do this we are encouraging other researchers who may have similar datasets from other regions to inspect their own records in the same way we have. Next, when did the changes we observed begin and how long might they persist? We believe that the increased forest growth we have observed of is both recent and unlikely to persist for very long. We think it's a recent phenomenon because if it were old and persistent then either all the stand ages are seriously underestimated or the stands have had very unusual growth trajectories. We hope to learn if there was a period in the past where growth began to accelerate by examining the growth patterns captured in the annual growth rings of trees. We also don't expect this extra growth to continue forever – usually the growth of plants becomes limited by some other factor, such as nutrients or the supply of water. To see if there is a deceleration in growth, we will continue to monitor these plots. Finally, we wonder if this acceleration of the forest carbon cycle has had consequences to other ecosystem functions. Has it affected forest nutrient cycles, the chemical composition of leaves, or the quality of the wood? New studies of these other
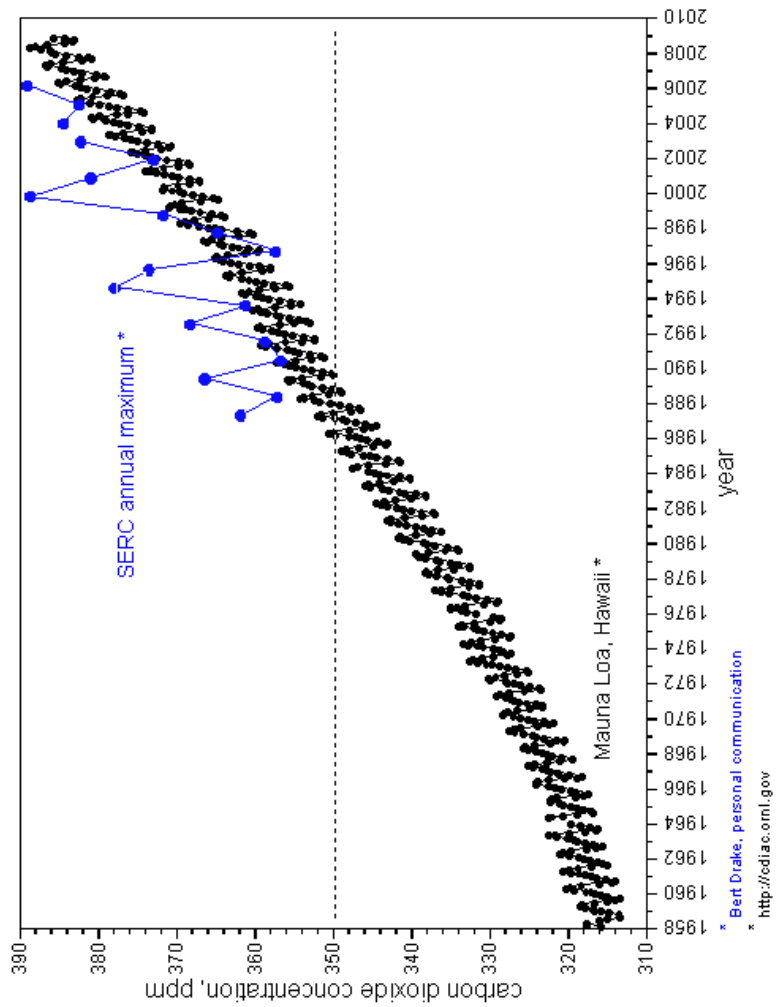
Figure 8. Monthly concentration of atmospheric CO2 from the Mauna Loa observatory in Hawaii (black symbols and line) and recent maximum annual values at SERC. The dashed line corresponds to about 350 parts per million, the CO2 concentration at the start of this project in 1987.

components of our forest ecosystems have been initiated to answer these questions.