An Experimental Study of the Relation Between Eddy-Flux Carbon Uptake Measurements and Tree-Ring Estimates of Growth

N. Pederson, E. Hammond Pyle, A. Barker Plotkin, D. Bryant, G. Jacoby, S. Wofsy

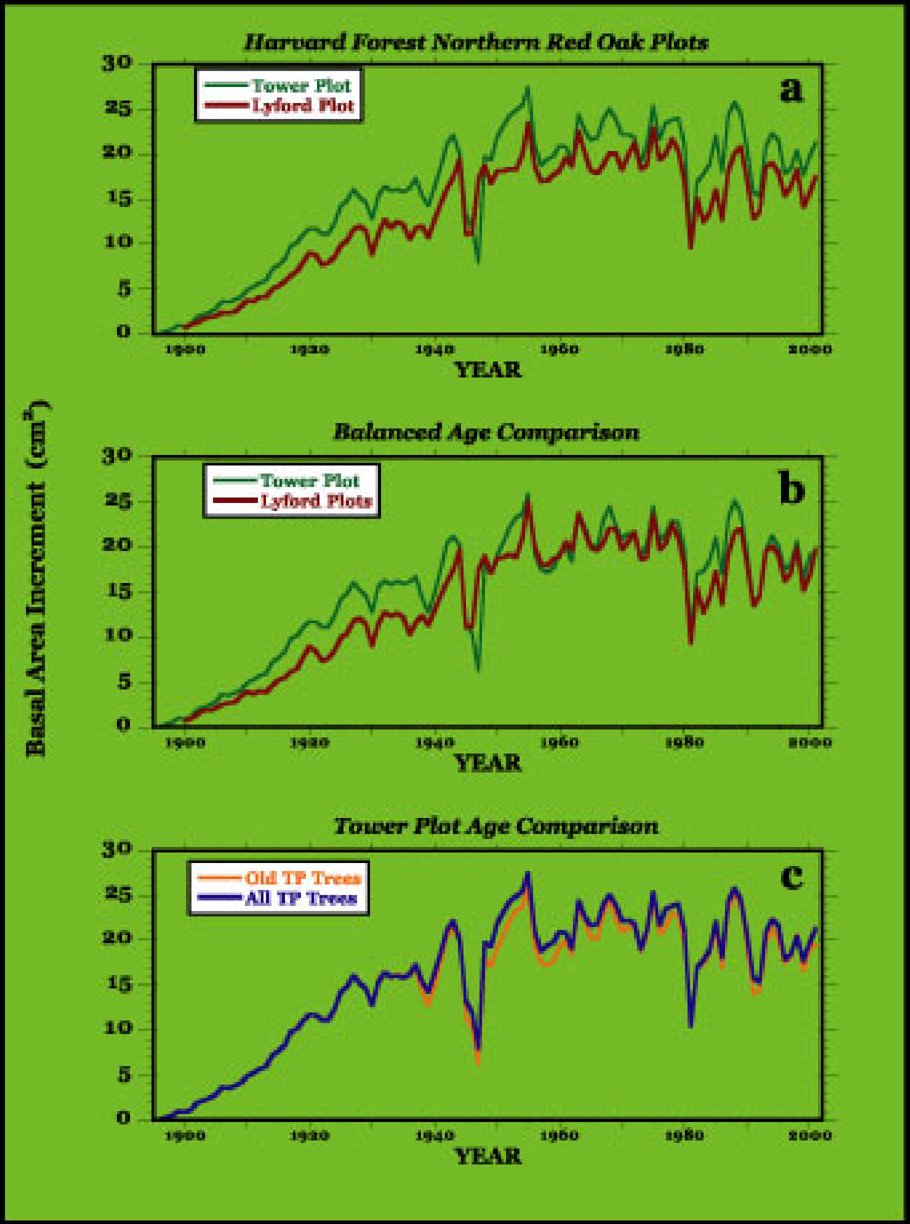
Atmospheric measurements and modeling efforts have indicated that North American forests may play a significant role in the global missing carbon sink. Ecosystem carbon exchange research at the Harvard Forest (HF) has shown consistent annual carbon sequestration. Sixty percent of this sequestration can be accounted for by tree growth, driven primarily by red oak succession and land-use history. An eastern US forest inventory data study predicted that carbon sequestration would level off in the next few decades since results indicated that land-use history, that influences ecosystem carbon accumulation, will lead to less carbon sequestration with time. However, two recent studies suggest that older forests may continue to act as carbon sinks where respiration and assimilation rates do not reach equilibrium over long successional periods. The main goal of this year's research is to place the growth of the HF tower plot red oak population (TP) in a long-term, regional context. Growth in the TP was first compared to the Lyford Plot (LP) in the HF. The HF populations were then compared to populations from NY, northern NJ and MA growing in forests with a range of site qualities and various disturbance/land-use histories. These comparisons will allow the following questions to be answered: Is the TP's red oak growth history representative of the HF? How does HF red oak growth trends compare to other northeast US sites?

Seventy red oaks were randomly selected and cored in the HF; 35 in the eddy-flux tower footprint (TP) and 35 outside the footprint (LP). Three cores/tree were collected. Sites outside the HF were sampled using standard dendrochronological methods; at least 20 trees/site and two cores/tree. Site information can be found in **Table 1**.

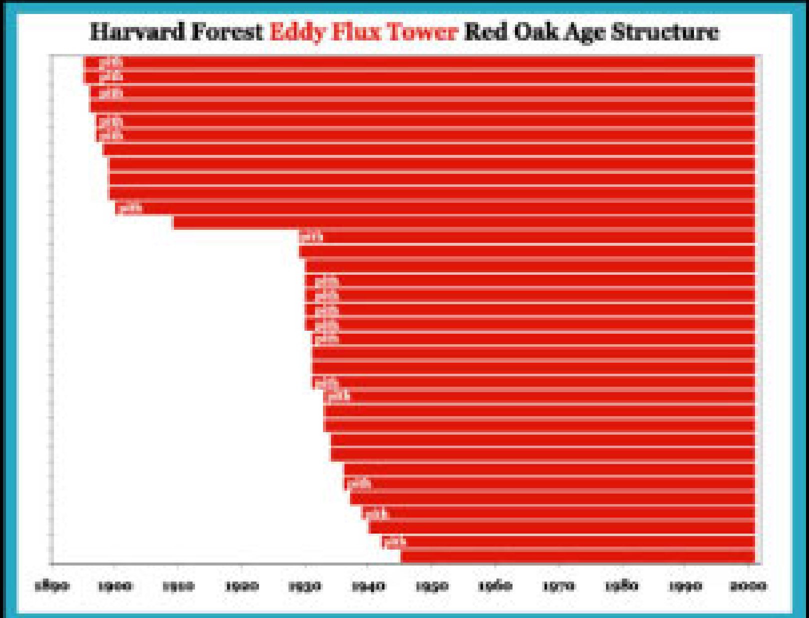
Basal area increment curves (BAI) can be used as proxies of biomass increment. HF BAI curves had similar growth variations, although the TP trees grew slightly faster than LP (**Figure 1**). Both growth curves show a general leveling of biomass increment from 1950-2001. Annual carbon increment of the 20 largest TP trees could account for more than 80% of the randomly selected 35 tree carbon increment. LP's largest 20 trees gave similar results. This suggests that a smaller sampling size might be adequate to study long-term growth trends

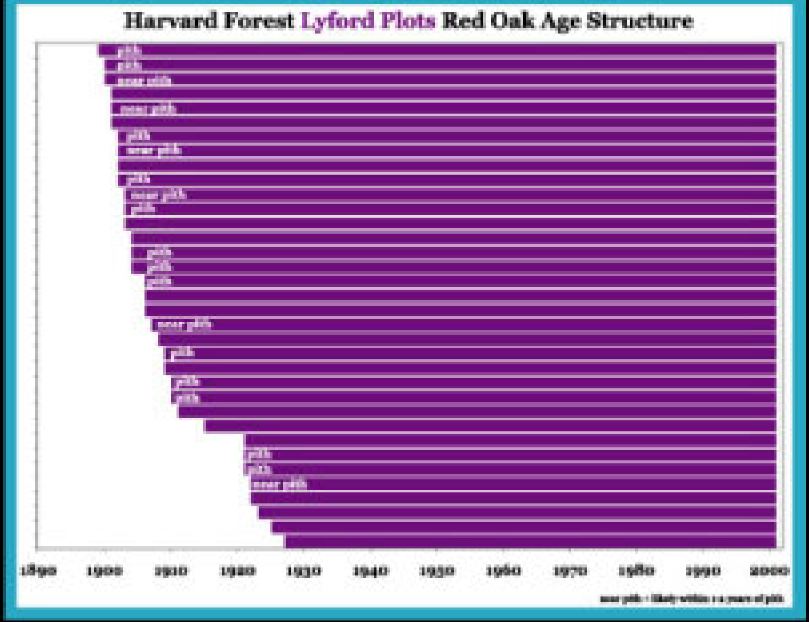
In the comparison of HF to external sites, oak trees in Mohawk Trail State Forest (MTSF) in western Massachusetts, the only population sampled less than 130 years old, had higher average radial increment than the HF red oak (**Figure 2**). Interestingly, unlike the HF populations, the MTSF population showed a sharp increase in growth from 1992 to the present despite no field evidence of recent canopy disturbance in MTSF. **Figure 3** shows the BAI curves of all populations. Only the HF and Prospect Mountain, NY populations show a flat or declining BAI during the latter half of the 20th century. Several factors could play a role or interact with each other to cause differences in growth trends including: disturbance history, stand density, abiotic site characteristics or population climatic sensitivity. However, it is not apparent from these data that tree age limits long-term growth trends.

Future work for this research entails sampling several red oak populations, determining the climatic sensitivity for each population and quantifying the relation between eddy-flux carbon uptake measurements and tree-ring estimates of biomass at HF.



HF age structure

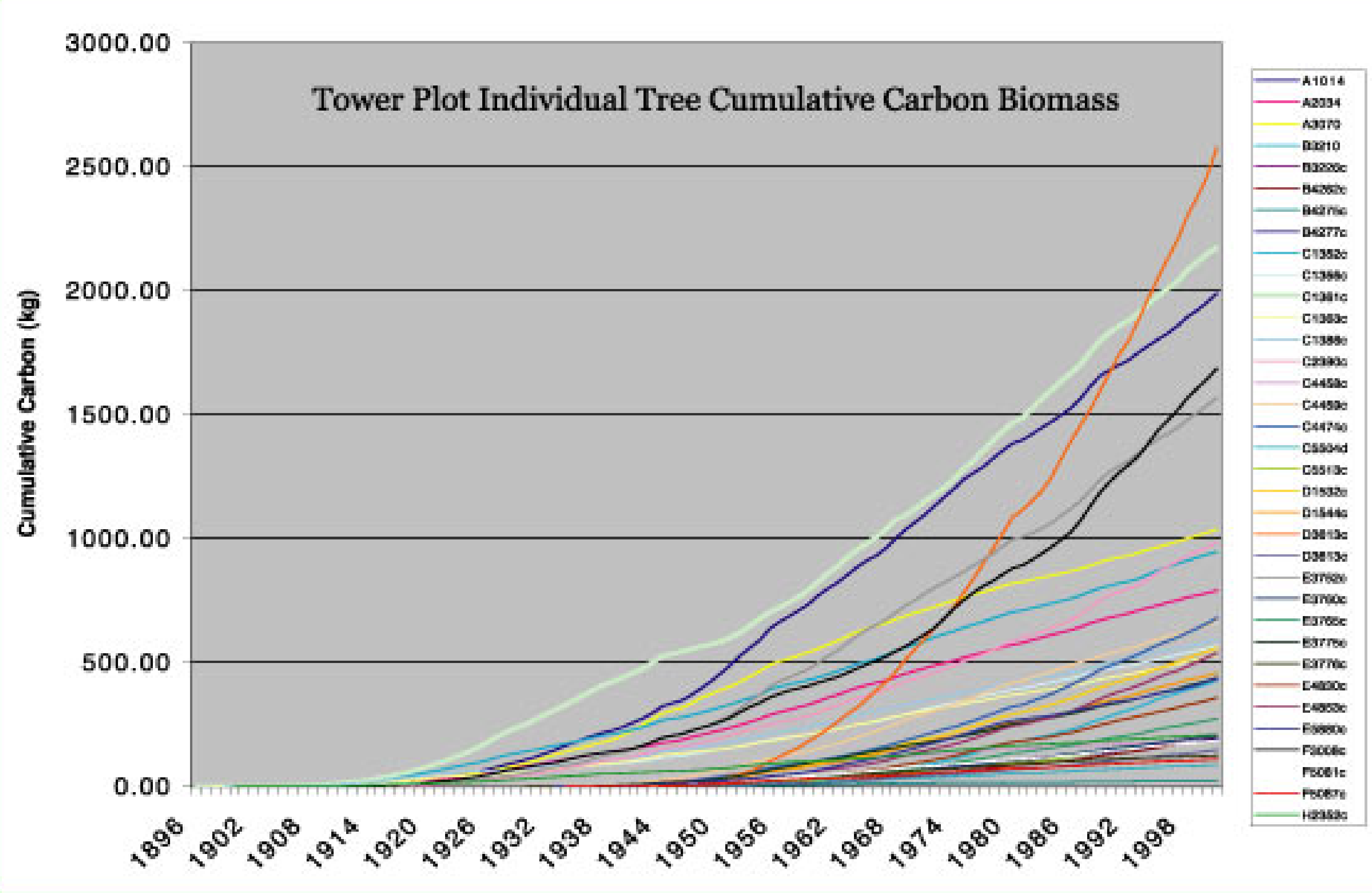


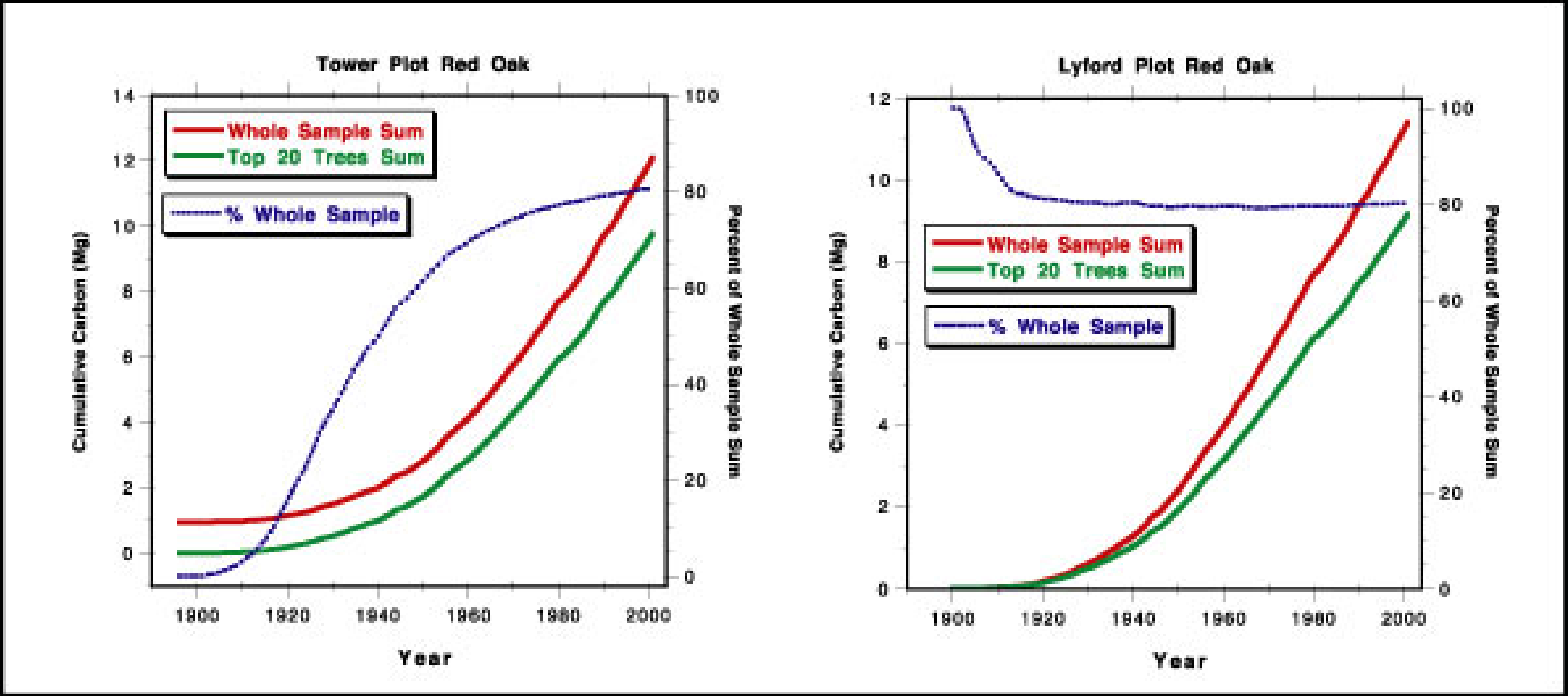


Thirty-five trees were randomly selected in the Tower and Lyford Plots at the Harvard Forest. Ring widths of all samples available for each year were averaged to create a mean ring width or raw ring width chronology. Each chronology was converted to basal area increment [BAI], a biomass proxy, by calculating diameter for each year, multiplying by Pi and subtracting prior yr basal area from current yr to calculate BAI. The Tower Plot [TP] trees grew slightly faster than the Lyford Plot [LP] trees, though probably not significantly so (above left, **a**). TP trees were younger in age (above right). Age structure of both plots was balanced to test if age played a significant role in growth rates. These new BAI chronologies show nearly identical growth rates (above left, **b**). A comparison of the youngest and oldest TP trees shows identical growth rates (above left, **c**). This suggests that the younger TP trees were not the direct cause of higher growth rates. Similar TP and LP stand basal area (Table 1) suggest that the old LP trees likely had reduced growth rates related to a suppressed canopy position.

For this part of the analysis, new chronologies were made of individual tree (right) and whole sample (below) cumulative carbon biomass. These chronologies were created by: 1) averaging ring widths of all cores per tree; 2) entering average radial increment for each tree into a red oak allometric equation; 3) dividing each biomass increment by 0.498 to derive carbon biomass; 4) summing each increment starting with the first year and ending with 2001 for individual tree carbon biomass; and 5) summing across trees for whole sample biomass.

Plots of individual TP biomass shows that top 10 trees accumulated significant amounts of carbon versus the lower 10 trees (**rt.**). Many of the dominant accumulators were the oldest trees.





Based on the results above, whole sample and selected carbon accumulation for the 20 largest TP and LP trees were compared.

The 20 largest trees account for the majority of total sample carbon in both plots over the last 5 decades (left). This suggests that a smaller sampling size might be adequate to efficiently study long-term growth and carbon uptake trends.

Singer Farm, NY

Table 1 - Site Information

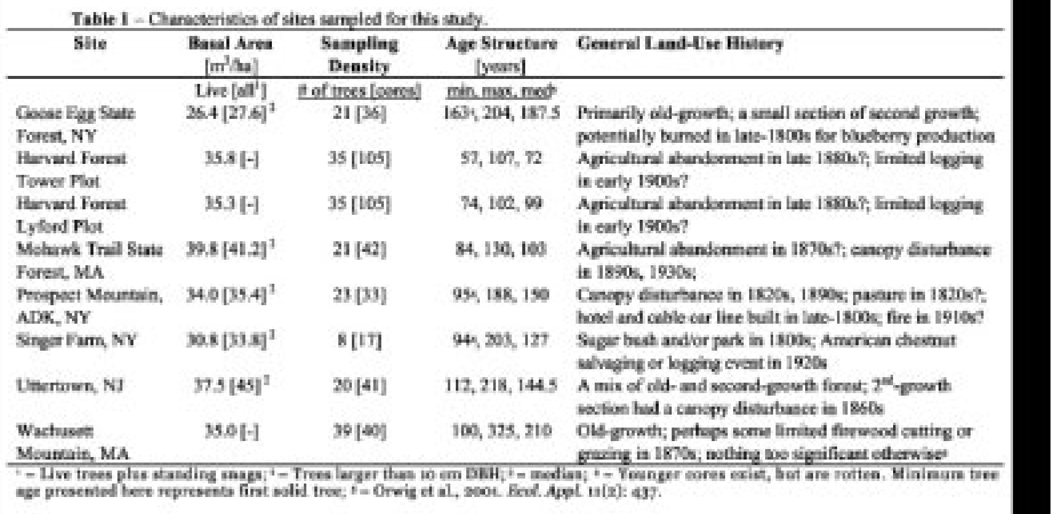


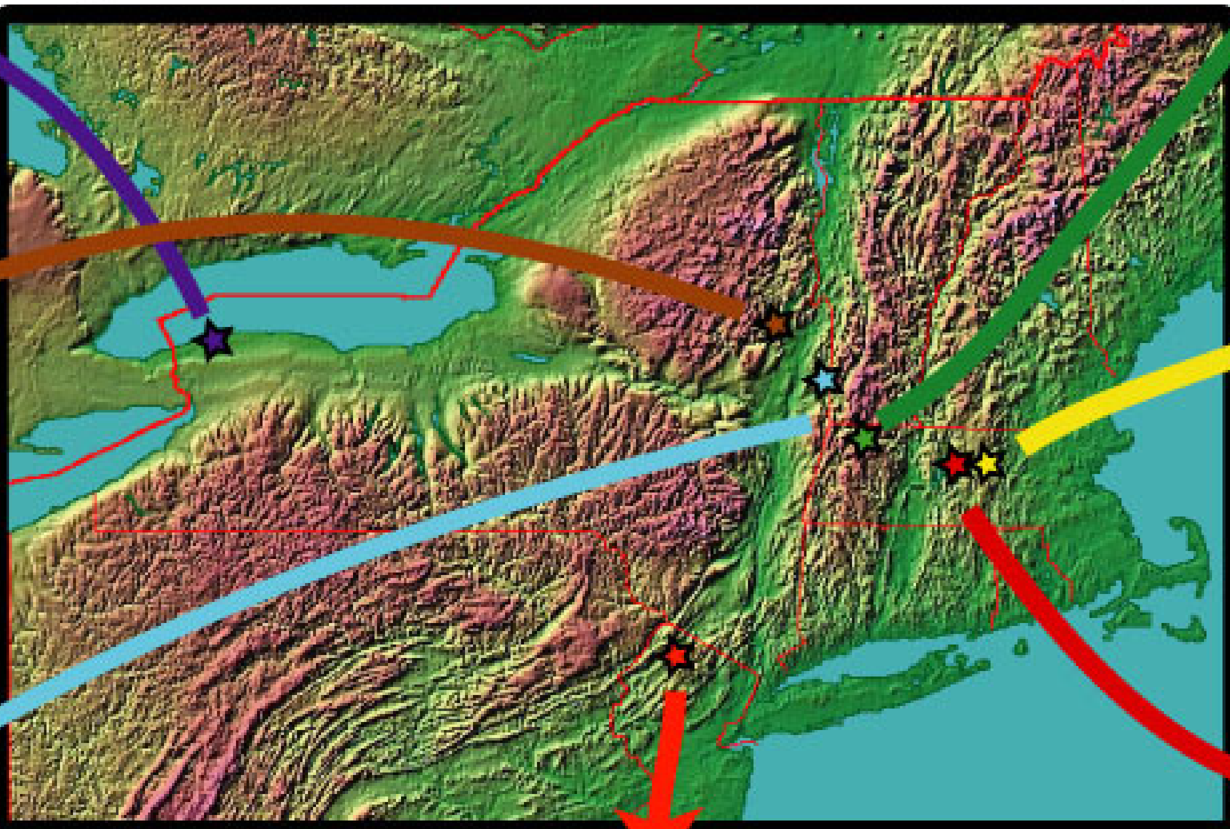
Table 1 – Characteristics of sites sampled for this study.

Site	Basal Area [m^2/ha]	Sampling Density	Age Structure [years]	General Land-Use History
	Live [all^1]	# of trees [cores]	min, max, med^3	
Goose Egg State Forest, NY	26.4 [27.6]^2	21 [36]	163^4, 204, 187.5	Primarily old-growth; a small section of second growth; potentially burned in late-1800s for blueberry production
Harvard Forest Tower Plot	35.8 [-]	35 [105]	57, 107, 72	Agricultural abandonment in late 1880s?; limited logging in early 1900s?
Harvard Forest Lyford Plot	35.3 [-]	35 [105]	74, 102, 99	Agricultural abandonment in late 1880s?; limited logging in early 1900s?
Mohawk Trail State Forest, MA	39.8 [41.2]^2	21 [42]	84, 130, 103	Agricultural abandonment in 1870s?; canopy disturbance in 1890s, 1930s;
Prospect Mountain, ADK, NY	34.0 [35.4]^2	23 [33]	95^4, 188, 150	Canopy disturbance in 1820s, 1890s; pasture in 1820s?; hotel and cable car line built in late-1800s; fire in 1910s?
Singer Farm, NY	30.8 [33.8]^2	8 [17]	94^4, 203, 127	Sugar bush and/or park in 1800s; American chestnut salvaging or logging event in 1920s
Uttertown, NJ	37.5 [45]^2	20 [41]	112, 218, 144.5	A mix of old- and second-growth forest; 2nd-growth section had a canopy disturbance in 1860s
Wachusett Mountain, MA	35.0 [-]	39 [40]	100, 325, 210	Old-growth; perhaps some limited firewood cutting or grazing in 1870s; nothing too significant otherwise^5

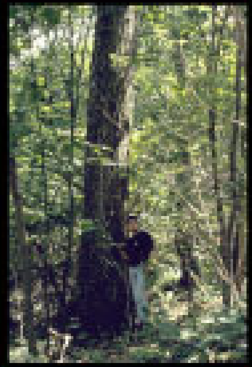
^{1} – Live trees plus standing snags; ^{2} – Trees larger than 10 cm DBH; ^{3} – median; ^{4} – Younger cores exist, but are rotten. Minimum tree age presented here represents first solid tree; ^{5} – Orwig et al., 2001. *Ecol. Appl.* 11(2): 437.

Mohawk Trail State Forest, MA

Prospect Mtn., NY



Wachusett Mtn., MA



Goose Egg, NY

Uttertown, NJ

Harvard For., MA

Regional Growth Trends

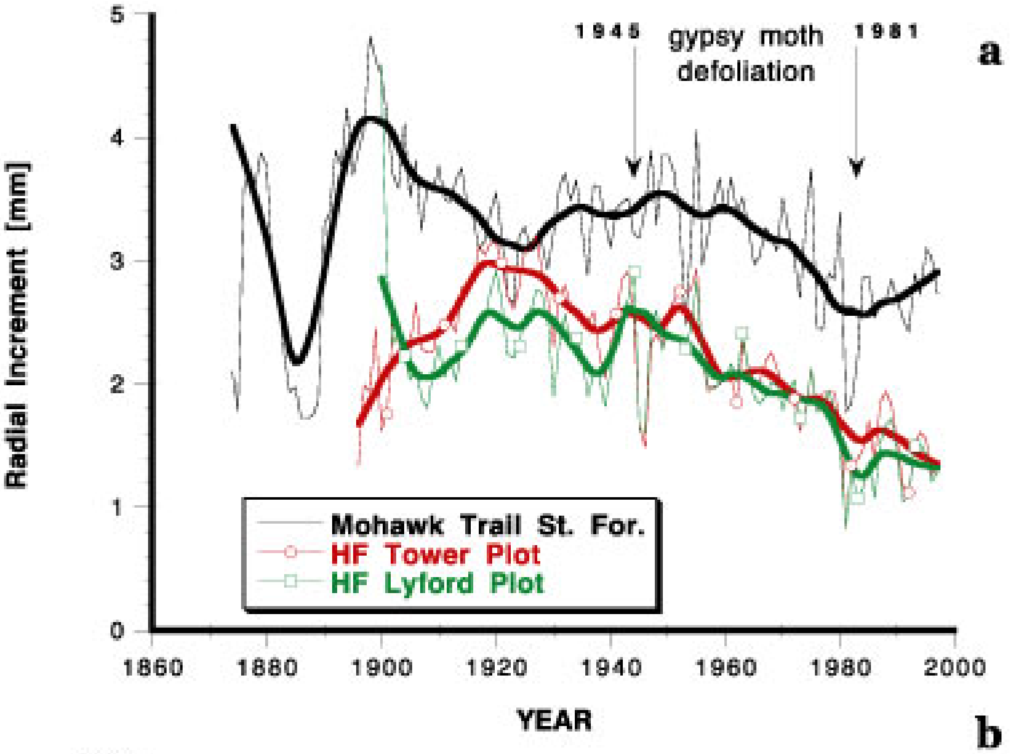
Regional growth comparisons were first made with the Mohawk Trail State Forest red oak [MTSF] population since it is roughly the same age and in the same general climate. Raw ring width chronologies have fewer assumptions compared to basal area increment or allometrically based chronologies and are used here to emphasize the MTSF growth phenomenon.

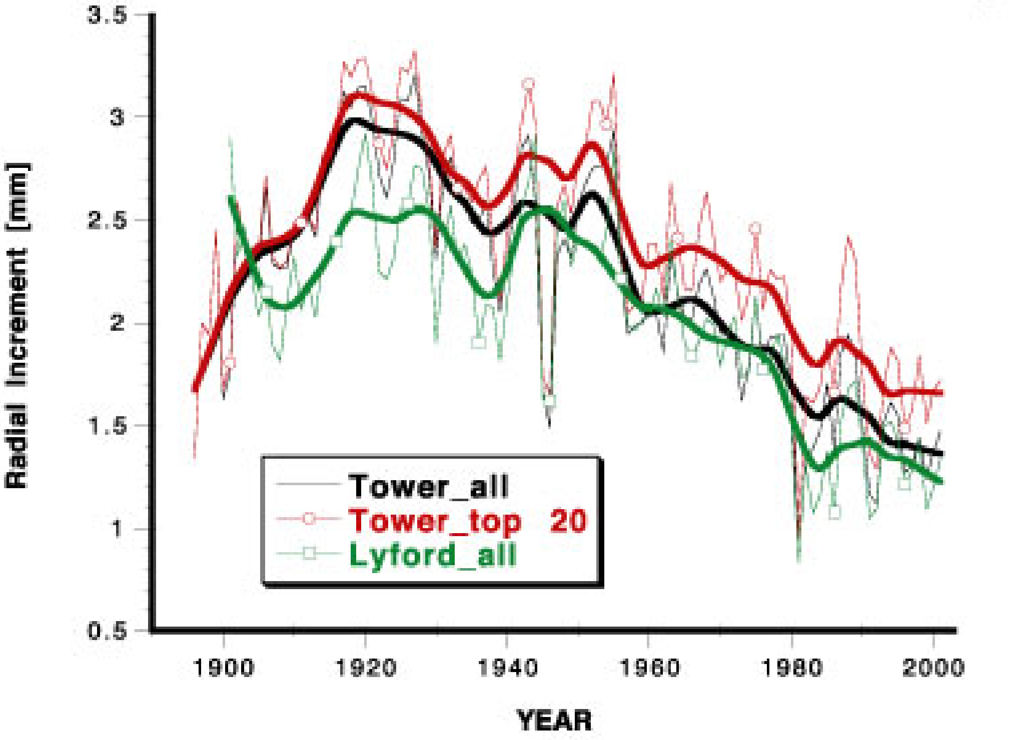
Results of note:

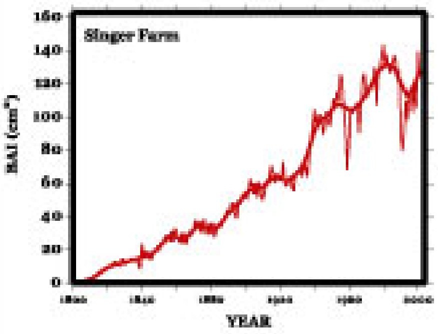
- MTSF is a more productive site with red oak here having consistent higher average radial growth (figure **a**);
- two important growth impacts were the 1945 and 1981 gypsy moth outbreaks; the 1945 looks more severe at the HF with 1981 more severe at MTSF;
- MTSF ring widths were fairly constant from 1930-60, declined from 1960-91 and have since increased. There was no field evidence of recent canopy disturbance that might help explain the increased growth.

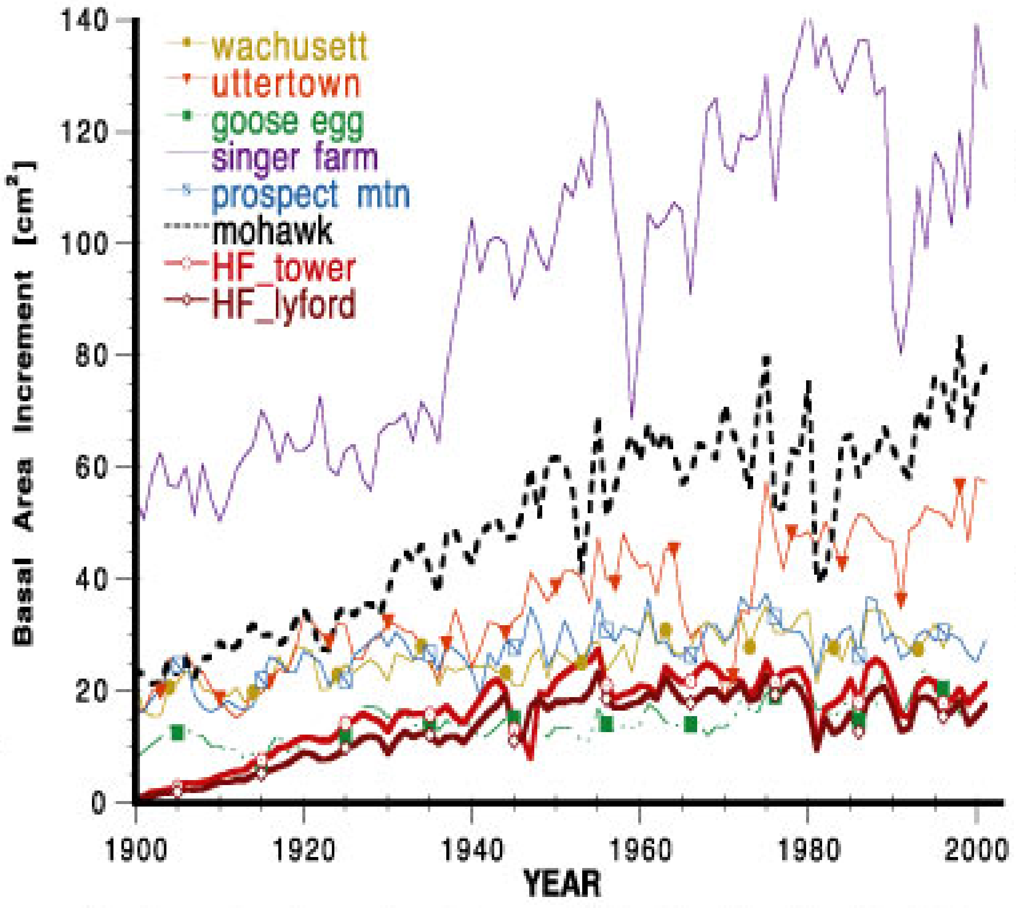
Increased ring widths are unusual because raw ring width chronologies of canopy trees typically decline with age. Wider rings on 100 year-old trees 60-80 cm DBH indicate a substantial increase in biomass production and carbon uptake.

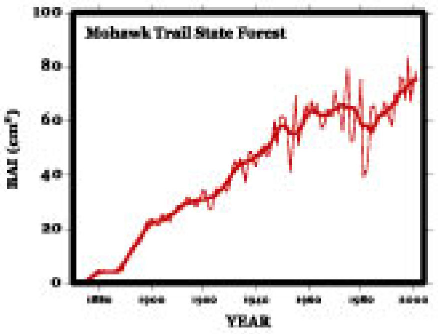
Differences in growth rates appear not to be entirely related to sampling methods (Figure **b**). The 20 largest TP oaks were growing faster than the full HF chronologies, but do not show the recent growth increase observed at MTSF.

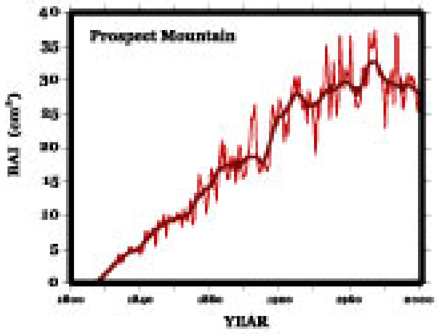


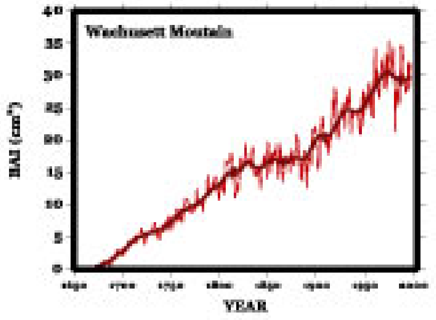


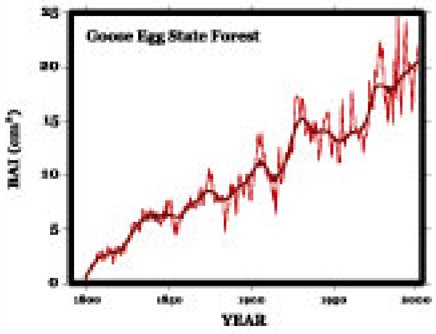


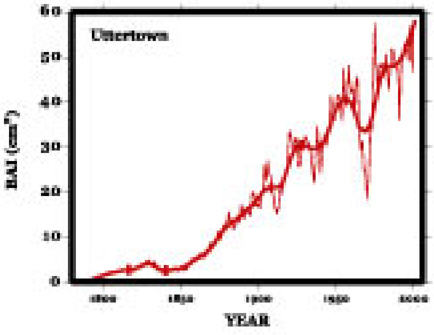


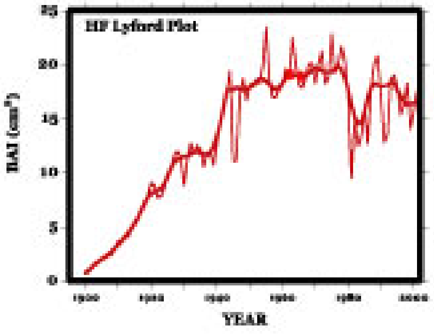


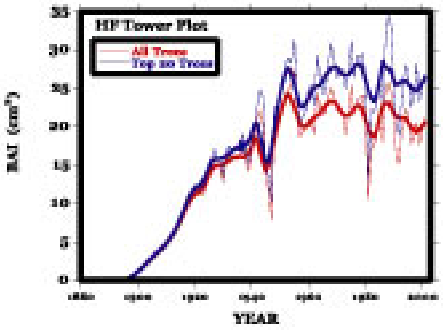












BAI was calculated for seven populations covering western NY, northern NJ and MA. Results of note: a) Uttertown, Goose Egg, and MTSF populations generally had increasing biomass increment throughout the 20th century; b) Wachusett had increasing growth rates until the 1970s and then plateaued; c) only Prospect and HF populations did not persistently increase in biomass increment. Even thought the largest 20 TP trees (blue line) grew faster than the whole sample, it still shows relatively flat biomass increment with time.

Many factors influence long-term growth trends including climate and disturbance/land-use history. MTSF was the most temperature limited population while Prospect was the most drought limited. Sites with the most recent stand-scale disturbance were Singer Farm, Prospect Mountain, HF and MTSF. It is not apparent from these data that tree age limits growth trends. It is also not yet apparent which factor is most important in determining long-term growth trends.

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