Flux and Biometric Measurements of CO2 Exchange at Harvard Forest

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Abstract

Forest inventories and atmospheric studies both indicate that forests in northern mid-latitudes have sequestered significant atmospheric CO2 since 1980, although the magnitude and distribution of the sink is the subject of lively debate. Factors controlling net carbon uptake must be understood in order to predict future growth rates of atmospheric CO2, and to enable management of regional carbon budgets. Recent analyses have attributed net C uptake to land use, fire history, longer growing seasons, and fertilization by anthropogenic CO2 and N. Our carbon exchange studies at Harvard Forest use eddy covariance and biometry, two independent methods, in order to: (1) monitor net ecosystem exchange (NEE) of CO2 over time scales from hours to several years, (2) place CO2 exchange measurements in the context of past land use, disturbance and current tree species demography, (3) facilitate comparisons with other forested ecosystems.

Over a seven-year period (1993-2000), annual NEE averaged -1.9 Mg C ha-1 yr-1, with 50% inter-annual variations (Summary, Figure 1, Figure 2). Biometric measurements in the eddy covariance footprint compare well with long-term NEE, with 60-70% of mean NEE attributed to above-ground wood increment (AGWI), and the balance to soils and coarse woody debris (Table 1). However, the ratio AGWI/(-NEE) for individual years with detailed dendrometry was 1 (1998), 0.6 (1999) and 0.7 (2000) (Figure 3). This variation arises from asynchrony between carbon cycle processes, such as lagging respiration of leaf litter in dry years, and use of stored carbohydrate for tree growth. Tree mortality also contributed to inter-annual variation in the carbon budget (0.4, 1.0, and 0.3 Mg C ha-1 yr-1 in 1998-2000, respectively).

Current C sequestration at Harvard Forest may be attributed to ecosystem characteristics, which have been strongly influenced by land-use and disturbance history. The 1938 hurricane and subsequent salvage allowed establishment of fast-growing, shade-intolerant northern red oak (Quercus rubra]. These oaks are now approximately half mature size and constitute half of above-ground woody biomass and AGWI (Figure 4). Their growth rate is relatively slow for the species, which argues against significant fertilization by CO2 or N deposition. Harvard Forest soils are extremely N poor, which strongly curbs the likelihood of CO2 fertilization at ambient levels. Anthropogenic N deposition rates at Harvard Forest are modest, contributing on the order of 10% of the annual N mineralization rate, but chronic deposition over decades has likely contributed to C storage at the site.

We find that decadal mean C uptake rates were controlled by stand age and composition, representing legacies of prior disturbance. Inter-annual fluctuations reflected ecosystem response to climate variations, through changes in litter decay rates and tree mortality. Given the broad spatial cohesion of global climate anomalies and high variability in the atmospheric CO2 increase rate, it seems likely that year-to-year variations in C sequestration by the terrestrial biosphere are also influenced by climatic factors quite different from the ecological factors regulating long-term sequestration.

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- F. Frizzell, S. Heath *(Summer 2000 HF-REU's).*

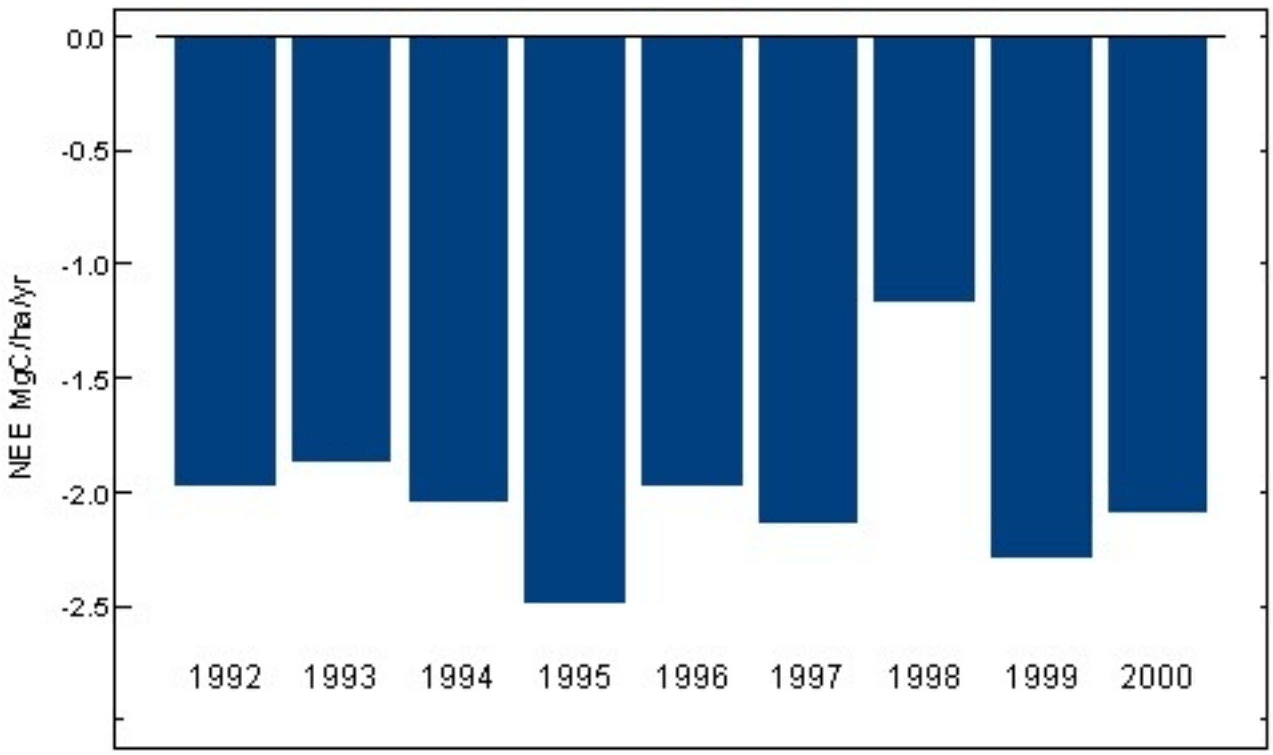
Why Use Flux + Biometry?

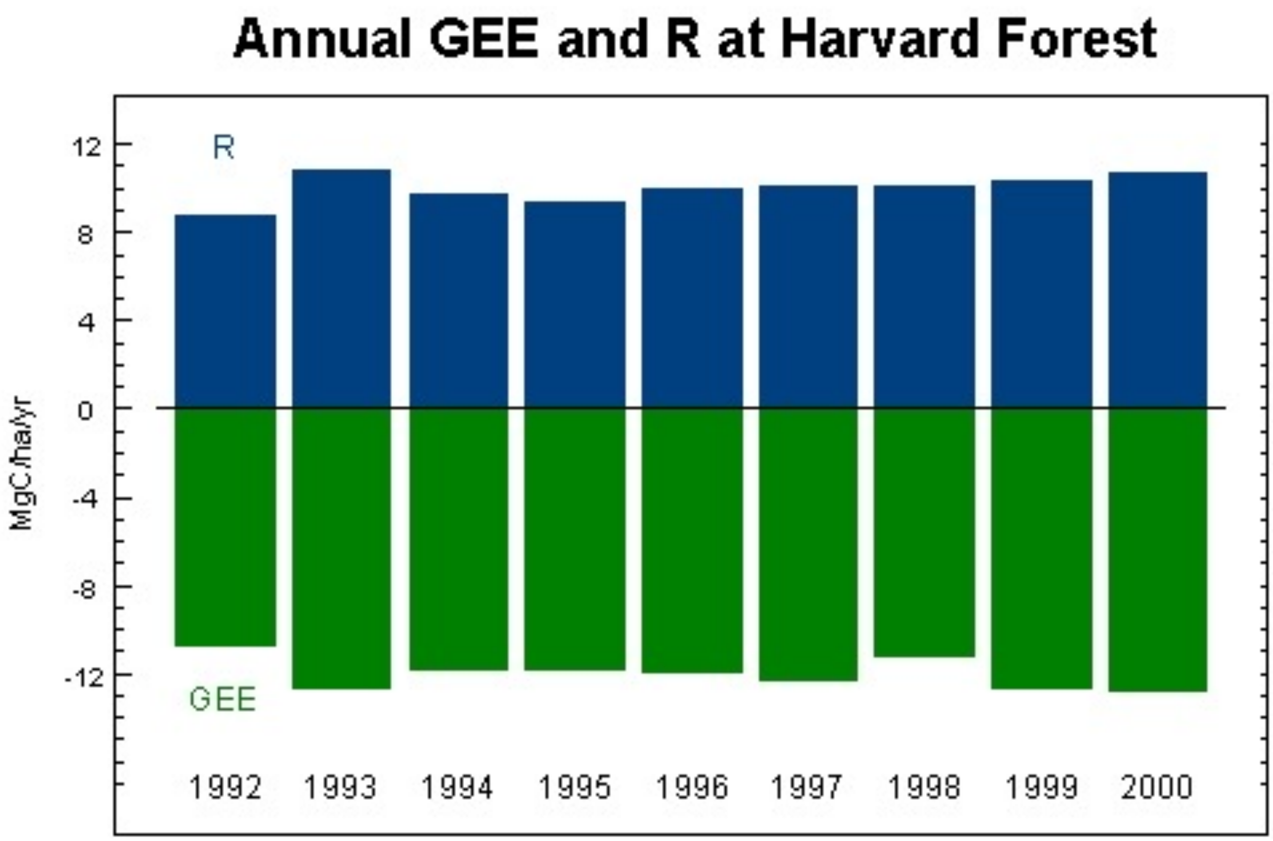
- Long flux record reveals biophysical controls over NEE
  - Short time scales (hours):
    - weather,
    - diel cycle
  - Longer time scales (years):
    - seasonal cycle
    - inter-annual climate variations
- Biometry shows links between NEE and forest ecology
  - Succession
  - Stand development (growth & mortality)

A Decade of Flux Data: Quick Review

- Mean annual NEE = -1.9 Mg C ha^{-1} yr^{-1}.
- Range = -1.1 (1998) to -2.4 (1995) Mg C ha^{-1} yr^{-1}.
- Key weather features determine NEE:
  - Timing of budbreak and leaf senescence
  - Summer drought or cloudiness
  - Snow cover in winter
- HF follows mesic regime (drought = more net uptake).

Annual NEE at Harvard Forest: 1992-2000




Annual GEE and R at Harvard Forest
R
GEE
12
8
4
0
-4
-8
-12
MgC/ha/yr
1992
1993
1994
1995
1996
1997
1998
1999
2000

Biometric Measurements

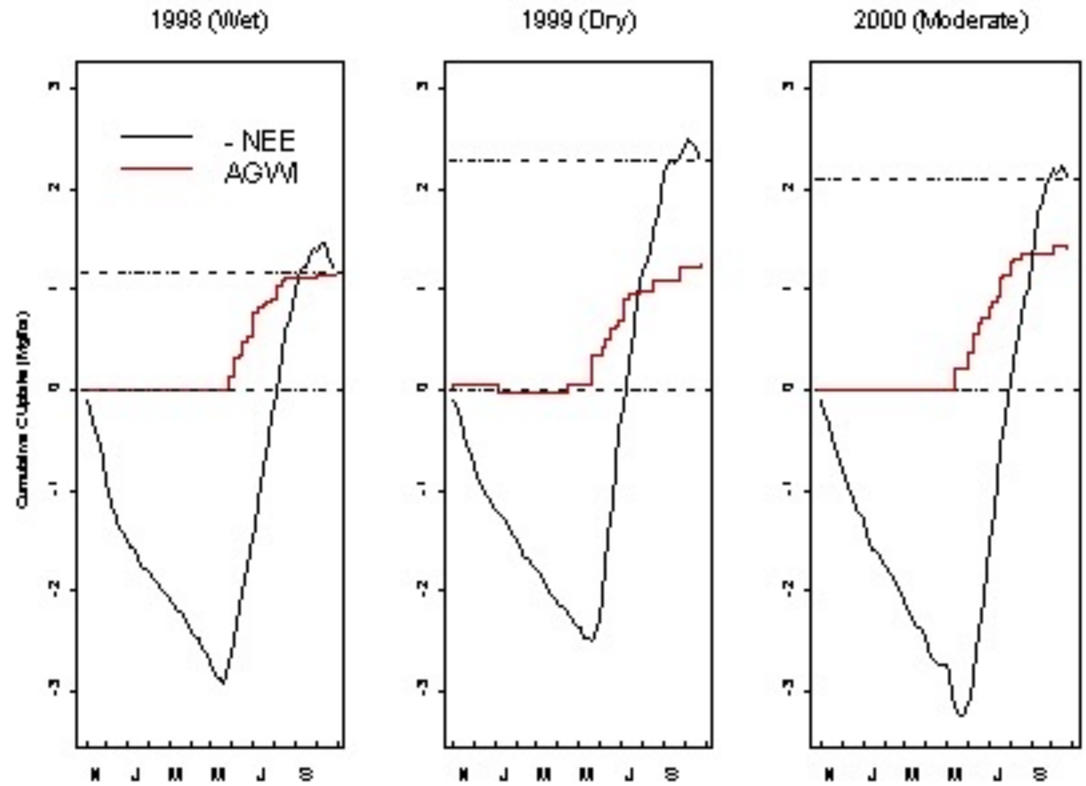
- Above-ground wood increment (AGWI)
  - 800+ trees dendrometry (since 1998)
  - Standard allometries used to calculate biomass
- Coarse woody debris (CWD)
  - 400+ pieces (since 1999)
  - Survey method of Harmon & Sexton (1996)
- Leaf litter (120 baskets)
- Other: phenology, soil respiration

Biometry and NEE (mean of 1993-2000)

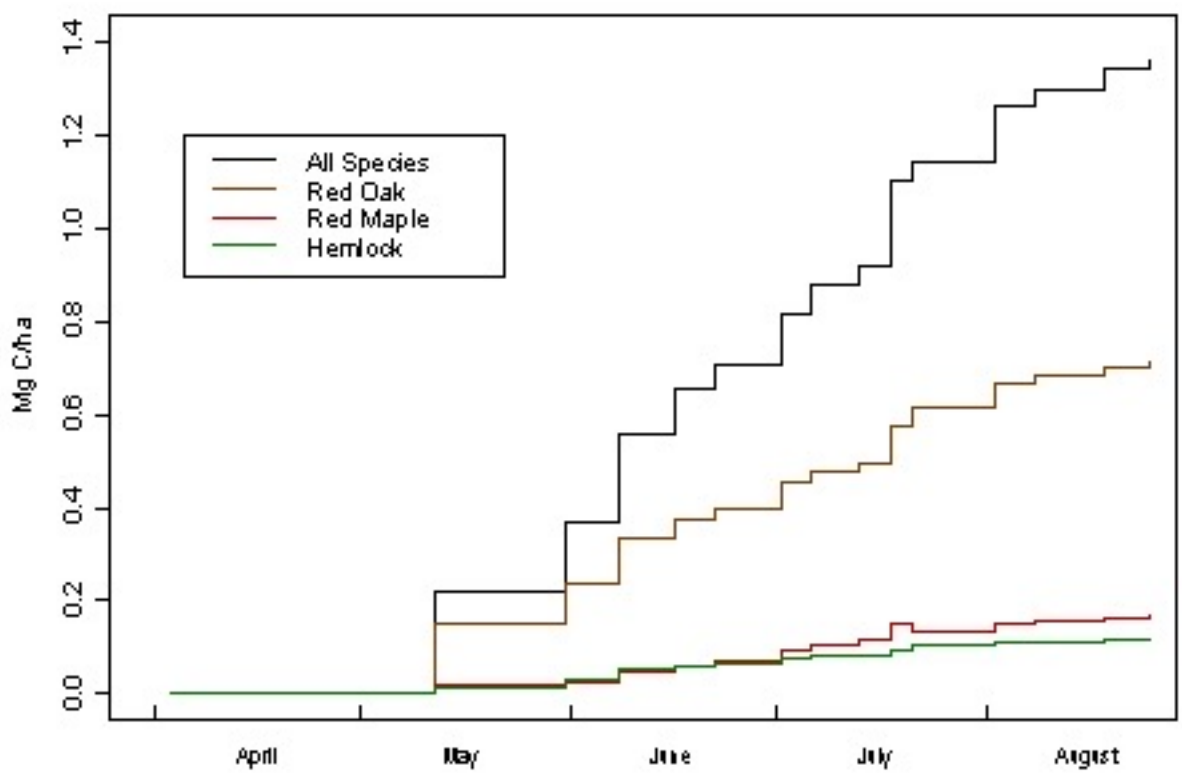
	Mg C ha^{-1} yr^{-1} †
? Live Biomass	1.0 ± 0.4
? CWD	0.4 ± 0.6
? Soil C*	0.2 ± 0.1
" Carbon Budget	1.6 ± 0.7
NEE (×-1)	1.9 ± 0.4

* Gaudinski *et al.*, 2000. † Mean ± 95% c.i.

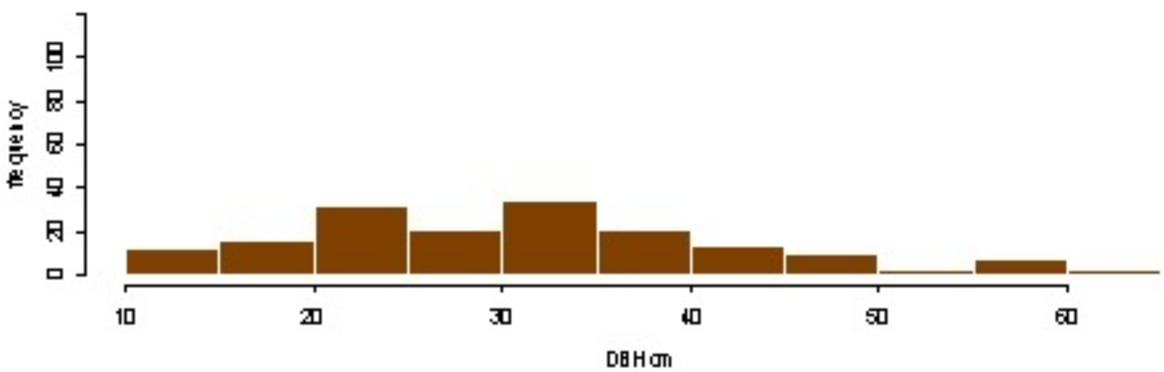
Ecosystem C Uptake and AGWI



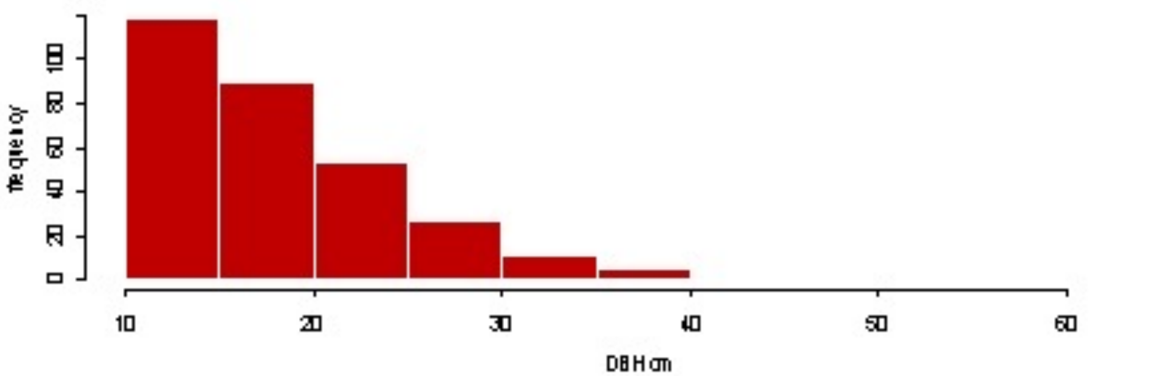
Wood Increment EcoYear 2000



Tree Size Distribution - Oaks



Tree Size Distribution - Maples



New Studies for 2001

- Litter mass & turnover study
- Tree coring (to measure past growth rates)
- Dendrometer settling experiment
- Harvest experiment (near HF)
  - Pre-harvest measurements complete
  - Harvest in progress
  - Post-harvest C cycling study beginning now

Conclusions

- Stand age and composition determines multi-year mean NEE.
- Carbon storage at HF is likely to decrease over the coming decades.
- Several years' data are required to construct carbon budget.
- Tree mortality contributes uncertainty.
- Flux and biometric measurements compare well.