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NET CARBON EXCHANGE AND BIOMASS ACCUMULATION AS A FUNCTION OF SPECIES COMPOSITION AND STAND AGE AT THE HARVARD FOREST IN CENTRAL MASSACHUSETTS

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1. INTRODUCTION

Forests in New England include a mixture of deciduous and coniferous species and a range of disturbance history from intensive agriculture abandoned in the late 1800s to permanent woodlots that were managed for forest products but never cleared. In order to better understand the role of land-use history and species composition on carbon budgets a group of sites at the Harvard Forest Long-term Ecological Research Site (HF-LTER) have been established for Net Ecosystem Exchange (NEE) eddy flux and biomass measurements. These sites capture the range of forest types that typify central Massachusetts. The Environmental Measurement Site (EMS) is in a stand dominated by red oak and red maple with the oldest trees established prior to 1895 on abandoned pasture. Scattered pines and patches of hemlock make up as much as 44% of the basal area in the area northwest of the tower and are present as small saplings in the understory throughout the stand. The Hemlock (HEM) tower is sited adjacent to a nearly pure stand of eastern hemlock with some individuals up to 230 years old. The site has not been affected by any stand-clearing disturbance since European settlement. A third tower, Little Prospect Hill (LPH), is in a stand also dominated by red oak and red maple on abandoned pasture, but with fewer conifers and younger trees that have regenerated since a fire in 1957. Towers at each site are instrumented for eddy-covariance measurements of CO_2, H_2O, energy, and meteorological variables. Ancillary measurements near each tower track biomass and leaf area. Near the EMS tower 34 10m radius plots are arrayed along 500m transects in the dominant upwind direction from the tower. Trees greater than 10cm diameter are observed for growth, mortality, and recruitment from smaller size classes. The plots were first measured in 1993 and have been re-measured annually since 1998. A mapped plot near the hemlock stand was established in 1990, with stems > 5cm diameter tracked over time. The plot has been resampled about every 10 years. Stem diameters are converted to biomass using species specific allometric equations.

2. RESULTS

The instantaneous CO_2 fluxes for each tower site throughout calendar year 2010 (Figure 1) highlight the similarities and differences in stand physiology. The peak CO_2 uptake rates (largest absolute value negative fluxes) in mid summer are greater for the two

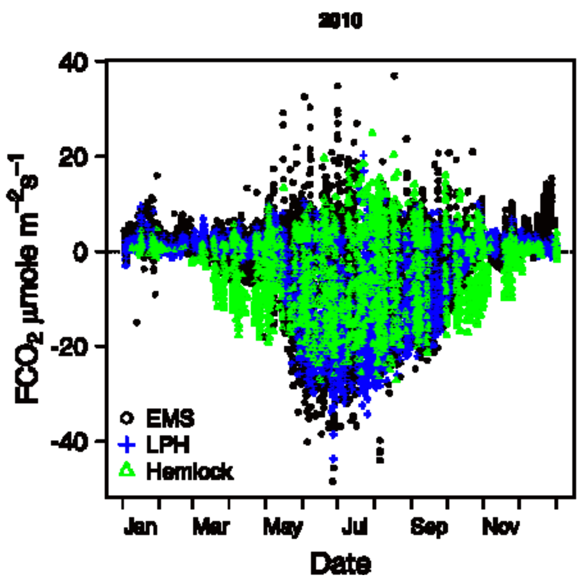

Figure 1 Hourly fluxes of CO_2 in 2010 for the 3 Harvard Forest tower sites are plotted against time. The 3 tower sites are distinguished by different symbols, and in addition the fluxes measured at EMS tower when surface winds blew from the northwest direction, which has more hemlock present, are distinguished by blue circles. Negative values indicate flux from the atmosphere to the forest

deciduous-dominated sites. CO_2 fluxes at the older EMS site slightly exceed those at the younger site, LPH. The reduced magnitude of CO_2 uptake during summer months in the Hemlock stand is offset by a much longer growing season that adds 1.5 – 2 month in the spring and fall compared to the active season for deciduous stands. The scattered conifer patches and subcanopy hemlocks near the EMS tower generate a modest CO_2 uptake during April before the deciduous leaves emerge; this is especially noticeable for periods when the tower footprint encompasses the area to the northwest of the tower where there are more hemlocks present. Light response curves for the Hemlock and EMS stands show clearly that the conifers are actively photosynthesizing in early spring as soon as the soils have thawed (Figure 2), but CO_2 uptake at the deciduous dominated stand lags behind. During the mid summer months the EMS stand has generally larger (more negative) CO_2 uptake for a given light input (Figure 3) than the hemlock stand does. Over the years 2005-2010 mean CO_2 uptake rates in April for photosynthetically active photon flux densities (PPFD) above 1000 μmole $m^{-2}s^{-1}$ were between 0 and 2

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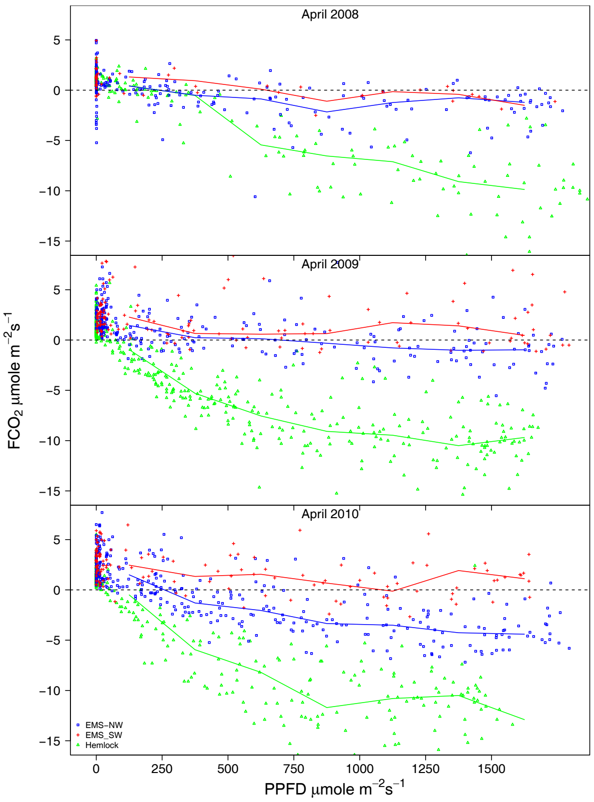

Figure 2 Hourly CO_2 fluxes for the NW and SW sectors at EMS tower and for the Hemlock tower in April for 2008-2010 are shown as a function of Photosynthetically-active Photon Flux Density. Points show the individual hourly observations with lines indicating the trends as median values within incremental bins of PPFD.

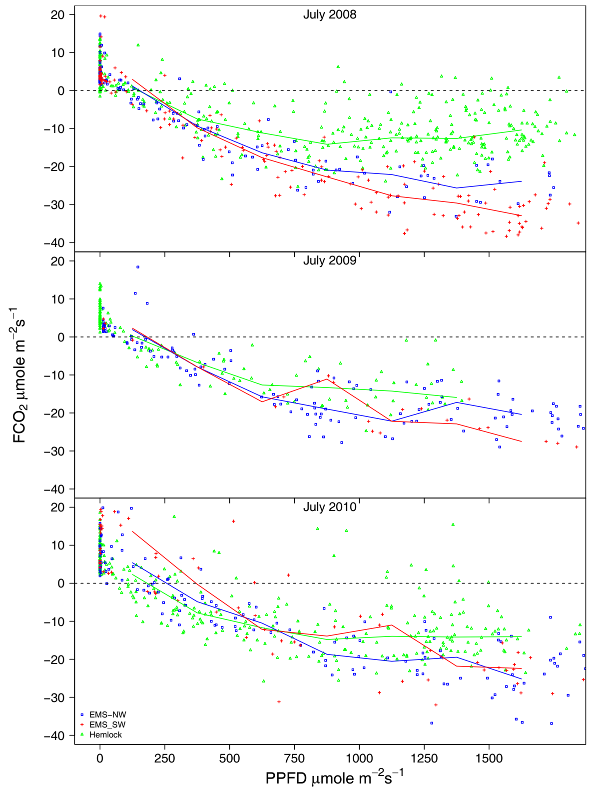

Figure 3 Hourly CO_2 fluxes for the NW and SW sectors at EMS tower and for the Hemlock tower in July for 2008-2010 are shown as a function of Photosynthetically-active Photon Flux Density. Points show the individual hourly observations with lines indicating the trends as median values within incremental bins of PPFD.

μmole CO_2 $m^{-2}s^{-1}$, while the CO_2 uptake at the hemlock stand was always greater than 10 μmole CO_2 $m^{-2}s^{-1}$ (Fig. 4). In July the CO_2 uptake fluxes for the Hemlock stand were only slightly higher, with mean values between 10 and 15 μmole $m^{-2}s^{-1}$, whereas the CO_2 uptake rates at EMS exceeded 20 μmole $m^{-2}s^{-1}$. In October as the deciduous canopy senesced, the fluxes at EMS declined, but at the Hemlock they remained constant.

Biomass accumulation trends at the EMS and Hemlock stands are remarkably similar (Figure 5). Despite distinct differences in physiology and mean age for the two stands the net outcomes for biomass accumulation are comparable.

3. CONCLUSIONS AND IMPLICATIONS

Because the evergreen hemlock stand is able to begin photosynthesizing as soon as the temperature warms in the spring and continues in the late fall until it is too cold these stands are able to capitalize on warmer temperatures that extend the frost-free season. The deciduous stand is not able to respond as quickly to warm temperatures in early spring and late autumn since it has to grow new leaves and cannot resume photosynthesizing once the leaves begin to senesce and change color. The reduced magnitude of CO_2 uptake during summer months by hemlock is partly offset by the 1.5 – 2 month longer growing season that starts earlier and ends later compared to the active season for deciduous stands. Despite different strategies the two stands both accumulating carbon in live biomass at about the same rate.

Even a small component of evergreens can have a significant impact on overall carbon budget for a stand. The conifers in the northwest sector at EMS and small hemlock saplings that comprise less than 10% of the total biomass contribute to overall hourly CO_2 uptake rates at the EMS stand that are 30% of the corresponding rates at the Hemlock site during the early spring months when the subcanopy is exposed to nearly full sunlight.

The prognosis for continued carbon accumulation by the hemlock stand is clouded, however, by the recent infestation at this site by Hemlock Wooly Adelgid, an invasive pest that is spreading northward through the hemlock forests in eastern North America. Infected trees invariably die within 5-10 years. Ongoing research will quantify the changes in carbon, water, and energy exchange as hemlock canopy dies and new species emerge.

4. ACKNOWLEDGEMENTS

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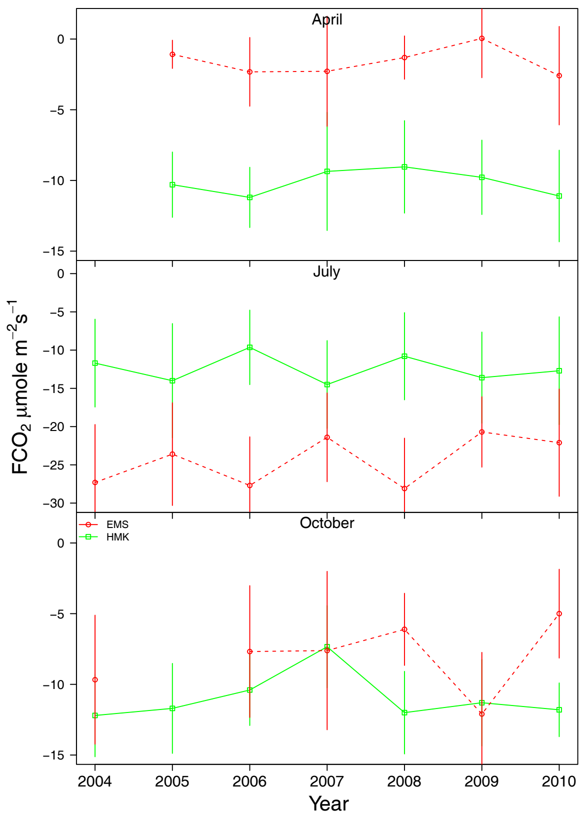

Figure 4 Mean values and standard deviation of CO_2 flux for PPFD values >1000 are shown for the months of April, July, and October in each year from 2005 to 2010.

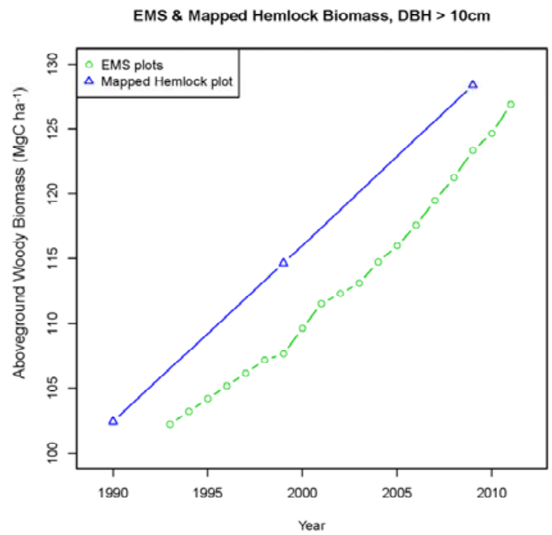

Figure 5 Total above-ground live woody biomass in the EMS and Hemlock plots are shown as a function of time.