Sylvania Wilderness - 2 Years of Carbon Uptake in an Old-Growth Forest

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Abstract

The 8,500 ha Sylvania Wilderness in the upper peninsula of Michigan (USA) is one of the few large tracts of primary old-growth forest in the Midwest. Trees range from 0-350 years old. Primary species are sugar maple, eastern hemlock and yellow birch. There is a large amount of coarse woody debris. Catastrophic disturbance is rare and only limited logging has occurred. The forest composition reflects the presettlement vegetation of much of the upper Midwest.

We established a research plot in old growth forest adjacent to the wilderness (Figure 1) in late 2001 to measure the net ecosystem exchange (NEE) of carbon using eddy-flux, component flux and biometric methods. The site is part of the Chequamegon Ecosystem Atmosphere Study (ChEAS), an affiliation of researchers conducting carbon and water research in northern Wisconsin/upper Michigan (Figure 2).

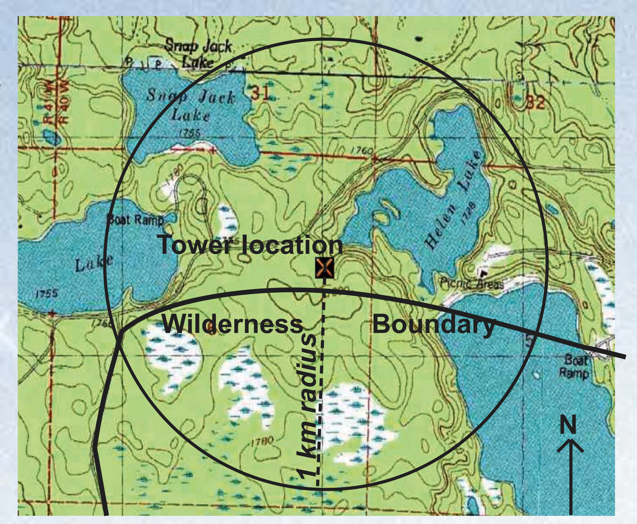


Figure 1 Map of immediate region (1 km radius) around the Sylvania flux tower. The wilderness is to the south of the boundary line.

In order to scale carbon fluxes from sites to regions, where stands of multiple ages may exist, it is necessary to measure the effect of stand age on carbon exchange. Measuring the effect of stand age on carbon exchange is also necessary when trying to predict future or past carbon exchange. Many researchers have noted that site disturbance history is a fundamental factor in determining carbon uptake by forests over time scales of decades to centuries.

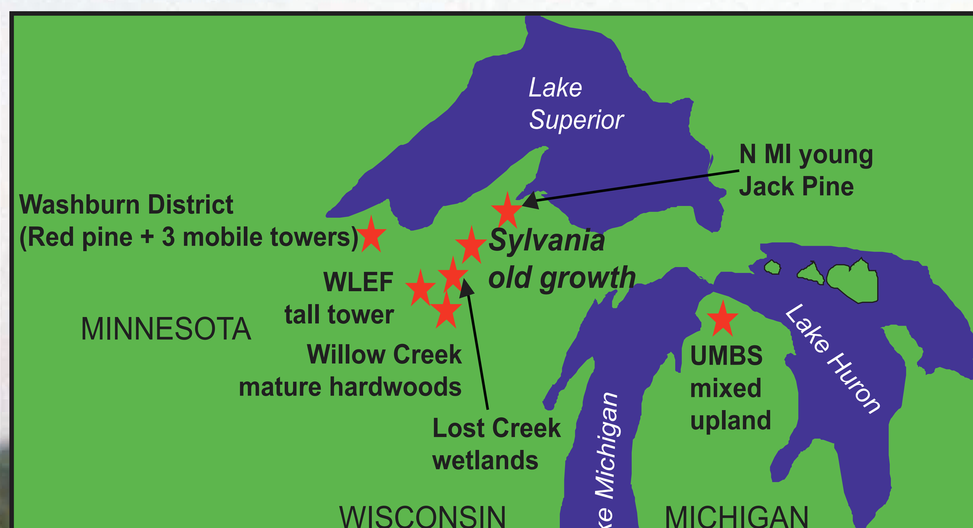


Figure 2 Chequamegon Ecosystem-Atmosphere Study (ChEAS) and nearby flux towers

Comparing Carbon Exchange Along a Successional Gradient

The Willow Creek mature uplands site (Figure 2) is about 80 years old and the primary species are sugar maple, basswood and green ash (Table 1). The site had presettlement old-growth vegetation similar to what is currently seen in the Sylvania Wilderness. Thus, carbon exchange seen at Sylvania may represent carbon uptake at Willow Creek had it not been logged in the early 20th century. Sylvania is also a successional endpoint for Willow Creek. Results from 2002 showed that both Sylvania and Willow Creek were carbon sinks, though the annual NEE of carbon at Sylvania was only -72 gC/m^2/yr, while it was -447 gC/m^2/yr at Willow Creek (Figure 3). Total annual respiration was significantly greater at Sylvania (965 gC/m^2/yr) than Willow Creek (667 gC/m^2/yr), while gross ecosystem production (GEP) at Sylvania (1045 gC/m^2/yr) was only slightly smaller than Willow Creek (1136 gC/m^2/yr) (Figures 4 and 5). These results are consistent with the theory that age-related forest carbon uptake decline is largely due to increased respiration. The largest difference in respiration between the two sites occurred in early summer, whereas the largest difference in GEP occurred in late summer.

Table 1
Site descriptions

Site descriptions	Sylvania	Willow Creek
Location	46 14' 31.3" N, 89 20 51.5 W Ottawa National Forest, MI	45 48' 28.2" N, 90 4' 43.2" W Chequamegon National Forest, WI
Elevation	500 m above sea level	520 m above sea level
Annual Average		
Precipitation	77.1 cm	81.8 cm
Temperature	3.9 C	4.8 C
Stand age	0-350 years	80 years
Species composition	sugar maple (*Acer saccharum*) eastern hemlock (*Tsuga canadensis*) basswood (*Tilia americana*) yellow birch (*Betula alleghaniensis*)	sugar maple (*Acer saccharum*) green ash (*Fraxinus pennsylvanica*) basswood (*Tilia americana*)
Canopy height	26-27 m (37 m flux tower)	24 m (30 m flux tower)
Leaf Area Index (LAI)	4.0	5.3
Established	August 2001	May 1998

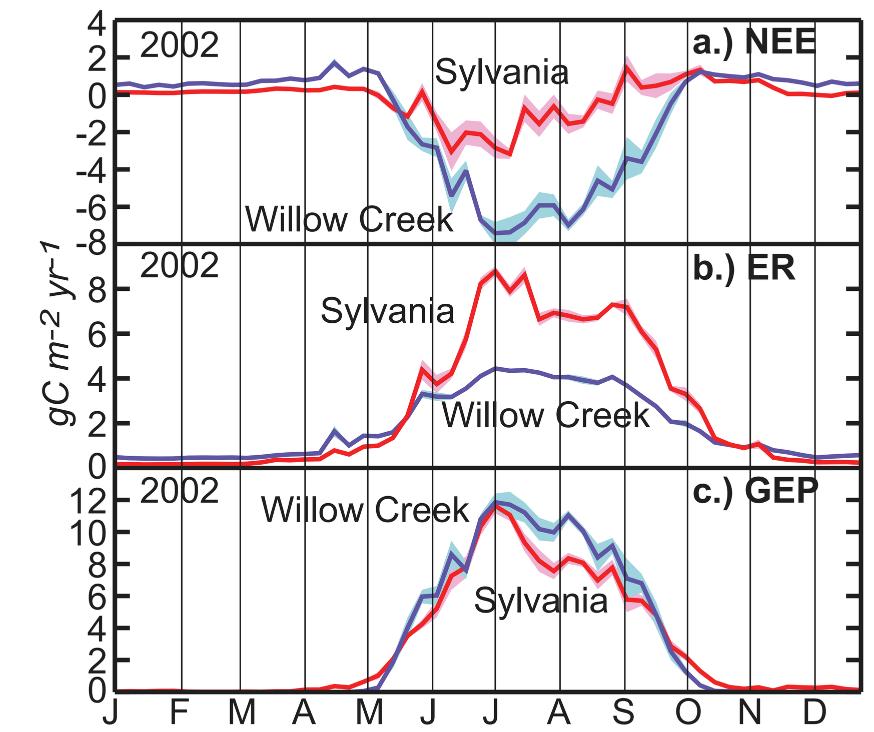


Figure 3 (above) 2002 7-day smoothed annual time series of daily total a.) net ecosystem exchange of carbon (NEE), b.) ecosystem respiration (ER) computed using a moving window Arrhenius style relationship of nighttime NEE to soil temperature, and c.) gross ecosystem production (GEP = ER-NEE) at Willow Creek (blue) and Sylvania (red). 7-day standard error is also shown.

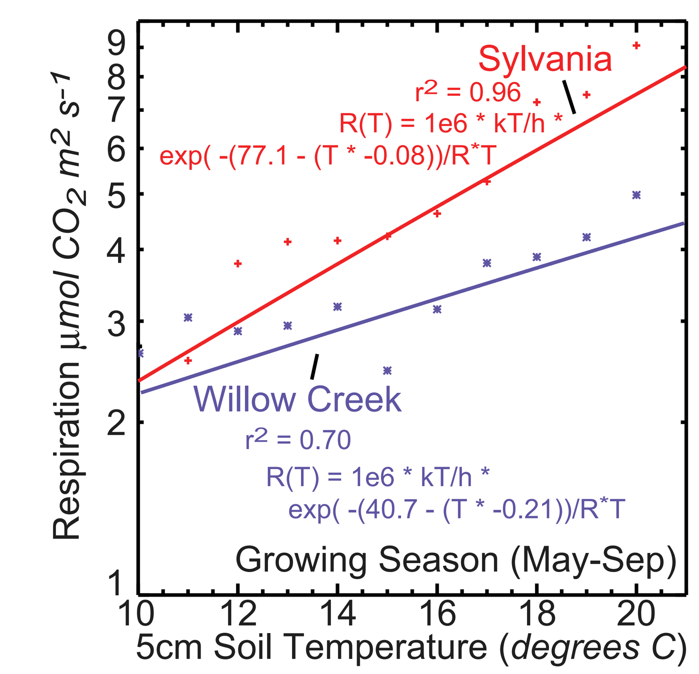


Figure 4 (above, right) 2002 June-August flux tower observed nighttime NEE versus 5 cm soil temperature. Sylvania had a greater temperature sensitivity to soil temperature than Willow Creek.

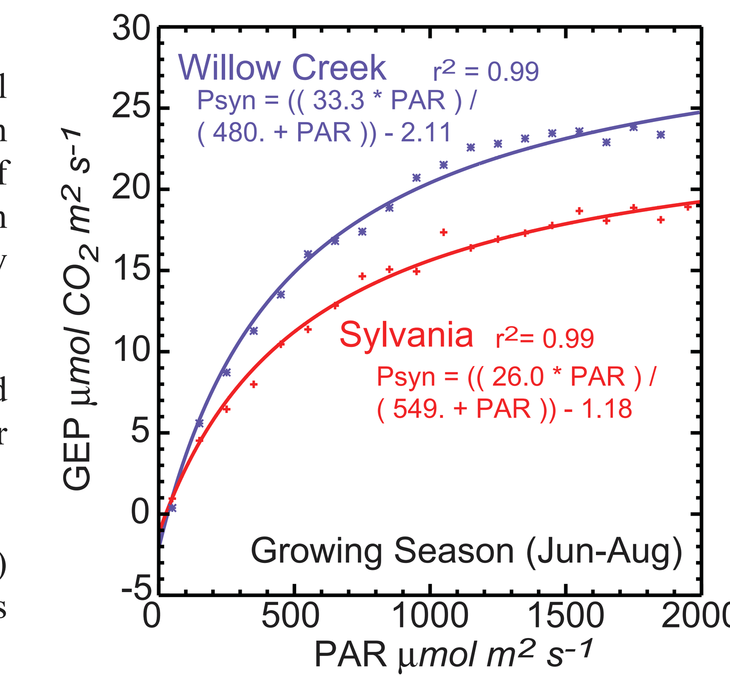


Figure 5 (right) 2002 June-August flux tower observed GEP (NEE-ER) as a function of photosynthetic active radiation (PAR). Sylvania had less uptake than Willow Creek for the same PAR.

Contrasting Carbon Exchange in Wet (2002) and Dry (2003) Years

Initial results from the growing season (June-August) of 2003 at Sylvania showed 61% greater net ecosystem exchange (NEE) of carbon compared to 2002, due to a 25% decrease in total ecosystem respiration (ER) and an 8% decline in gross ecosystem production (GEP) as measured by the flux tower (Figure 6). Soil chamber observations also showed a decline in soil respiration temperature sensitivity (Figure 7), leading to a 13% decline in total soil respiration (Table 2). This 13% decline in soil respiration explains 32% of the decline in ecosystem respiration; thus, leaf, stem and coarse woody debris respiration must also have declined. Average leaf light response curves also showed a decline in leaf carbon assimilation (Figure 8).

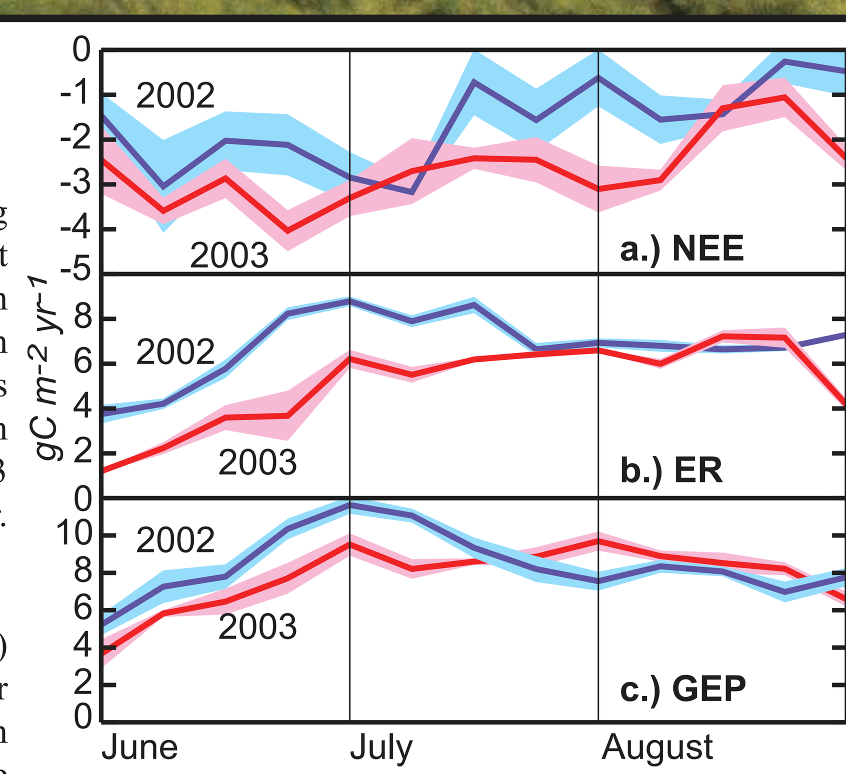
We hypothesize that these differences in carbon exchange occurred due to site water stress in 2003 from decreased winter/spring precipitation in 2003 (51% of normal) compared to 2002 (148% of normal). We believe this water stress had a greater impact on respiration than GEP because trees were able to tap water from deeper reservoirs, whereas soil respiration occurs primarily in the upper soil layers. Trees were also slightly water stressed in 2003, as evidenced by decreased sapflux (Table 2). Dry weather throughout the summer of 2003 led to very low soil moisture by late August (Table 2). However, this impact was not seen immediately on carbon fluxes. The summer month with the largest decline in soil moisture and precipitation (August) had the least decline in respiration and an increase in GEP. There appears to be a 1-2 month lag between precipitation and its impact on ER and GEP. These results provide insight into how an old-growth forest responds to climate variability.

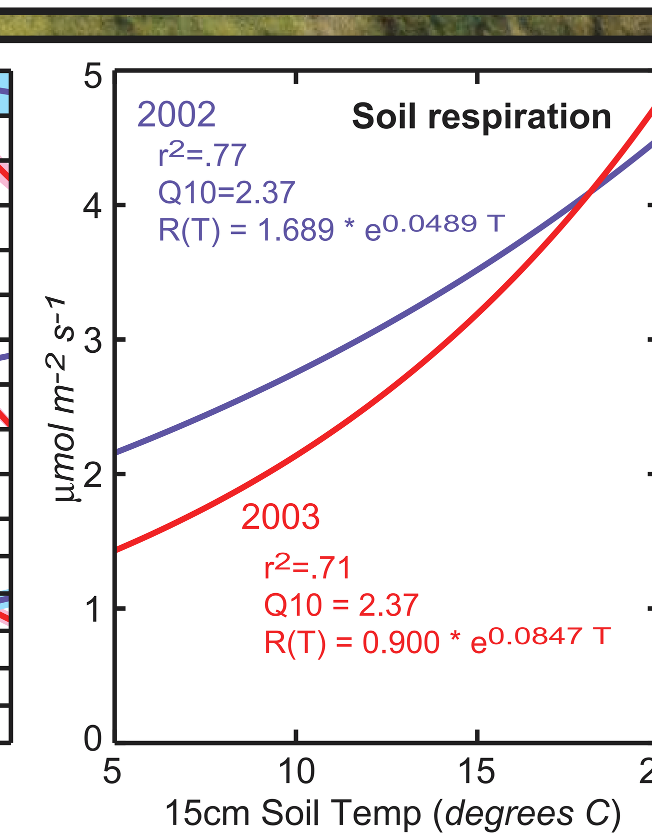
Figure 6 (near right) Jun-Aug weekly average daily total a.) net ecosystem exchange of carbon (NEE), b.) total ecosystem respiration (ER) and c.) gross ecosystem production (GEP) in 2002 (blue; wet year) and 2003 (red; dry year) from flux tower. 7-day standard error is shown.

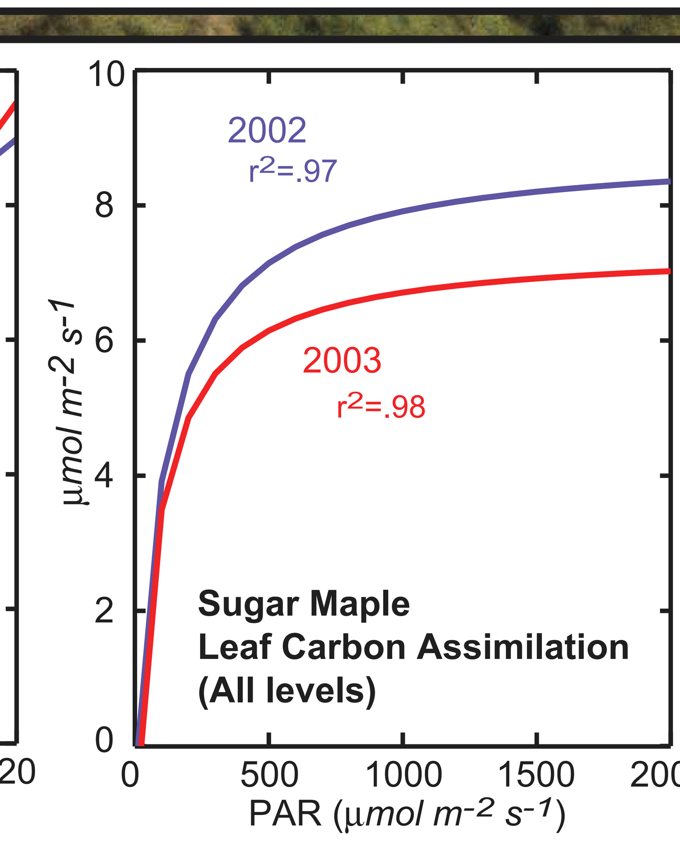
Figure 7 (right, center) Regression of soil chamber carbon flux measurements to in situ 15 cm soil temperature (n=40) in 2002 and 2003.

Figure 8 (far right) Average observed leaf light response curves for sugar maple in 2002 and 2003 (~16% decline).

Table 2 Average flux and micrometeorology values for 2002 and 2003. NEE increased in 2003 because ER declined greater than GEP. Precipitation, soil moisture, and latent heat fluxes all declined in summer 2003 compared to 2002. Sapflux declined for hemlock and sugar maple.







	Winter-Spring 2002	Winter-Spring 2003	June 02	June 03	Change	July 02	July 03	Change	Aug 02	Aug 03	Change
NEE (*gC m^{-2} month^{-1}*)			-61	-96	*57%*	-58	-83	*43%*	-34	-68	*98%*
Mean total respiration (*µmol m^{-2} s^{-1}*)			5.0	2.5	*-49%*	7.7	5.8	*-25%*	6.5	6.1	*-7%*
Mean soil respiration (*µmol m^{-2} s^{-1}*)			3.3	2.7	*-19%*	4.1	3.3	*-19%*	3.8	3.8	*0%*
Mean GEP (*µmol m^{-2} s^{-1}*)			7.0	5.6	*-19%*	9.5	8.4	*-12%*	7.6	8.2	*8%*
Mean sugar maple leaf assimilation* (*µmol m^{-2} s^{-1}*) ***for at 1500 µmol m^{-2} s^{-1} PAR**			6.8	5.4	*-19%*	9.6	6.1	*-36%*	7.6	8.4	*11%*
Total precipitation (*cm*) and % normal (1971-2000)	37 (148%)	13 (51%)	10 (116%)	8 (86%)	*-26%*	9 (112%)	9 (114%)	*2%*	7 (78%)	4 (41%)	*-47%*
Volumetric 5cm soil moisture (%)			23%	22%	*-5%*	21%	18%	*-13%*	21%	14%	*-31%*
Column soil moisture, 0-100 cm (*cm*)			25	24	*-4%*	23	20	*-12%*	22	16	*-29%*
% change in daily sapflux — hemlock					*-19%*			*-13%*			*-13%*
sugar maple					*-6%*			*-17%*			*-12%*
yellow birch					*20%*			*22%*			*26%*
Mean daily noontime latent heat flux (*W m^{-2}*)			179	160	*-10%*	216	176	*-19%*	185	161	*-13%*
Above canopy air temperature (*degrees C*)	-2.7	-3.4	16	15	*-7%*	21	18	*-13%*	17	19	*8%*
5cm soil temperature (*degrees C*)			14	13	*-8%*	18	16	*-14%*	17	17	*3%*
Mean daily noontime PAR (*µmol m^{-2} s^{-1}*)			1293	1445	*12%*	1623	1452	*-11%*	1449	1368	*-6%*

Future Work

- Characterize impact of lakes and/or anomalous SW respiration source on NEE (Figure 9).
- Calculate biometric NPP and upscale component fluxes to assess tower fluxes.
- Compare component fluxes to Willow Creek component fluxes to help explain mechanisms for age-related carbon uptake decline.
- Apply BIOME-BGC and Ecosystem Demographics (ED) models at Sylvania.

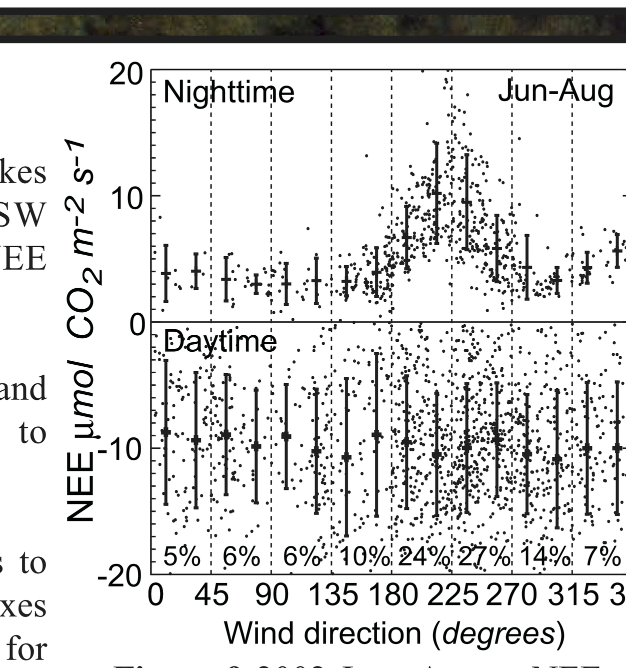


Figure 9 2002 June-August NEE of carbon versus wind direction. Nighttime fluxes when wind is from the southwest were twice those compared to other directions where fluxes may be diluted by lakes.

The Sylvania flux tower is affiliated with the Chequamegon Ecosystem Atmosphere Study (ChEAS, http://cheas.psu.edu) and the Ameriflux network.

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