FINAL REPORT FOR US DEPARTMENT OF ENERGY DE-SC0007041

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EFFECTS OF DISTURBANCE ON CARBON SEQUESTRATION IN THE NEW JERSEY PINE BARRENS

ABSTRACT

While carbon and water cycling of forests contribute significantly to the Earth's overall biogeochemical cycling, it may be affected by disturbance and climate change. In this research, we contributed to the body of research on leaf-level, ecosystem and regional scale effects of disturbances on forest ecosystems, in an effort to foster more mechanistic understanding, which in turn can improve modeling efforts. Here, we summarize some of the major findings in this research of physical and biogenic disturbances, such as drought, prescribed fire, and insect defoliation, on leaf and ecosystem-scale physiological responses as well as impacts on carbon and water cycling in an Atlantic Coastal Plain upland oak/pine and upland pine forest. Following we have incorporated some of our findings into a new version of the Finite-element Tree-Crown Hydrodynamics (model version 2) model, which improved timing and hysteresis of transpiration modeling for trees. Furthermore, incorporation of hydrodynamics into modeling transpiration improved latent heat flux estimates.

In our study on the physiology of the trees, we showed that during drought, stomatal conductance and canopy stomatal conductance were reduced, however, defoliation increased conductance on both leaf-level and canopy scale. Furthermore, after prescribed fire, leaf-level stomatal conductance was unchanged for pines but decreased for oaks, while canopy stomatal conductance decreased temporarily, but then rebounded the following growing season, thus exhibiting transient responses. This study suggests that forest response to disturbance varies from the leaf to ecosystem level as well as

species level and thus, these differential responses interplay to determine the fate of forest structure and functioning post disturbance. Incorporating this responses improves model outcome.

SIGNIFICANT FINDINGS

Impacts of prescribed fire on *Pinus rigida* L. in upland forests of the Atlantic Coastal Plain

Traditionally wildfire adapted systems have a fire occurrence between 5 and 50 years and due to the stochastic nature are very hard to predict to prevent major damages to life and property. Thus, in many fire prone systems, due to increasing suburbanization management commences with prescribed fires. The physiological responses of overstory trees to prescribed fire has received little attention and may differ from typical wildfires due to the lower intensity and timing of prescribed fire in the dormant season. Trees may be negatively affected by prescribed fires if injury occurs, or positively affected due to reduced competition from understory vegetation and release of nutrients from partially consumed litter. In this study, we measured sap flow and photosynthetic parameters before a late-March prescribed fires and throughout the growing season in burned and unburned pitch pine (*Pinus rigida* L.) sites in the New Jersey Pinelands to determine how water use and photosynthetic capacity were affected. Water use was similar between sites before the fire but 27 % lower in burned trees immediately following the fire. After about a month, water use in the burned site was 11-25 % higher than pines from the unburned site and these differences lasted into the summer. Photosynthetic capacity remained similar between sites but instantaneous intrinsic water use efficiency increased by 22 % and maximum Rubisco carboxylation rate (V_{cmax}) was over three times greater in the summer compared to the pre-fire period in the burned site, whereas the unburned site exhibited similar V_{cmax} and intrinsic water use efficiencies between pre-fire and summer measurements. These differences in physiology suggest that the prescribed fire altered the amount of water and nutrients that pines had access to and led to increased water use and water use efficiency; both of which are important in this water- and nutrient-limited ecosystem (see Figure 1).

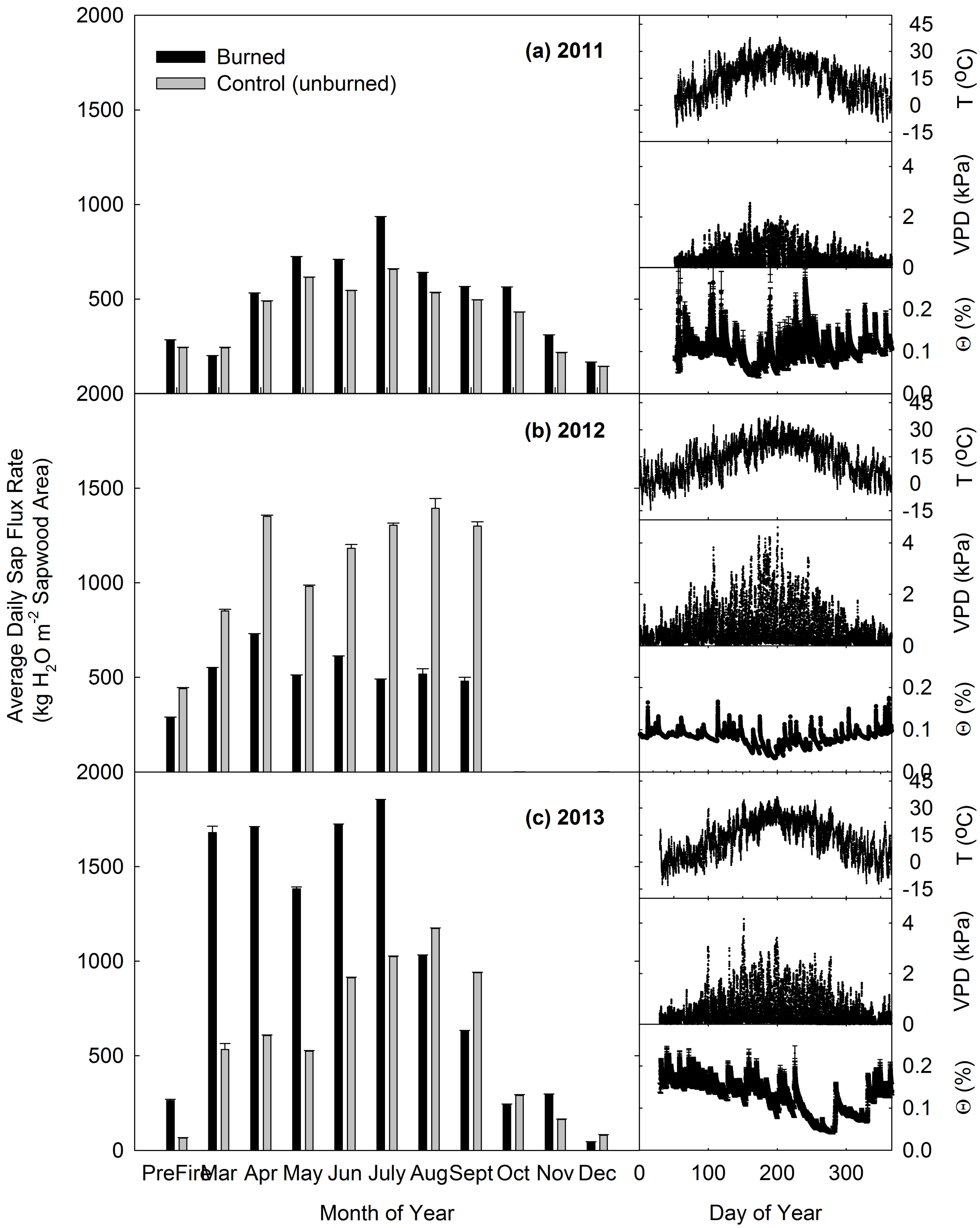

Figure 1. Daily sap-flux m^{-2} sapwood area averaged by month for all plots. Brendan T Byrne forest (BTB) (a), burned in 2011, Silas Little – oak pine forest (SL) (b), burned in

2012, and Cedar Bridge (CB) (c) burned in 2013. Only days where both burned and control (unburned) plots had sufficient data were analyzed. Beside each graph is the corresponding meteorological data for that year with air temperature (^oC) at the top, VPD (kPa) in the middle, and volumetric water content (% soil moisture) at the bottom for each year, recorded at the control (unburned) plot for each site
Note – Silas Little and Cedar Bridge are Ameriflux sites.

In the study, we found that photosynthetic capacity in terms of Rubisco-limited carboxylation rate and intrinsic water-use efficiency was unaffected, while light compensation point and dark respiration rate were significantly lower in the burned vs control plots post-fire. Furthermore, quantum yield in pines in the pine-dominated stands was less affected than pines in the mixed oak/pine stand, as there was an increase in quantum yield in the oak/pine stand post-fire compared with the control plot. We attribute this to an effect of forest type but not fire per se. Average daily sap-flux rates of the pine trees increased compared with control plots in pine-dominated stands and decreased in the oak/pine stand compared with control plots, potentially due to differences in fuel consumption and pre-fire sap-flux rates. Finally, when reference canopy stomatal conductance was analyzed, pines in the pine-dominated stands were more sensitive to changes in vapor pressure deficit (VPD), while stomatal responses of pines in the oak/pine stand were less affected by VPD. Therefore, prescribed fire affects physiological functioning and water use of pines, but the effects may be modulated by forest stand type and fuel consumption pattern, which suggests that these factors may need to be taken into account for forest management in fire-dominated systems.

Hydrological responses to defoliation and drought of an upland oak/pine forest

In this study, we analyzed the hydrologic variability during 2005–2011 in Silas Little, the upland oak/pine forest in the New Jersey Pinelands. The forest experienced defoliation by Gypsy moth (*Lymantria dispar* L.) in 2007, drought conditions in 2006 and a more severe drought in 2010. By using sap flux and eddy covariance measurements, stream discharge data from USGS, soil water changes, precipitation (P) and precipitation throughfall, a local water balance was derived. Average annual canopy transpiration (E_C) during 2005–2011 was 201 mm a−1 ± 47 mm a^{-1}. A defoliation event reduced E_C by 20% in 2007 compared with the 2005–2011 mean. During drought years in 2006 and 2010, stand transpiration was reduced by 8% in July 2006 and by 18% in 2010, respectively, compared with the overall July average. During July 2007, after the defoliation and subsequent reflushing of half of the leaves, E_C was reduced by 25%. This stand may experience higher sensitivity to drought when recovering from a defoliation event as evidenced by the higher reduction of E_C in 2010 (post-defoliation) compared with 2006 (pre-defoliation). Stream water discharge was normalized to the watershed area by dividing outflow with the watershed area. It showed the greatest correlation with transpiration for time lags of 24 days and 219 days, suggesting hydrological connectivity on the watershed scale; stream water discharge increases when transpiration decreases, coinciding with leaf-on and leaf-off conditions. Thus, any changes in transpiration or precipitation will also alter stream water discharge and therefore water availability. Under future climate change, frequency and intensity of precipitation and episodic defoliation events may alter local water balance components in this upland oak/pine forest.

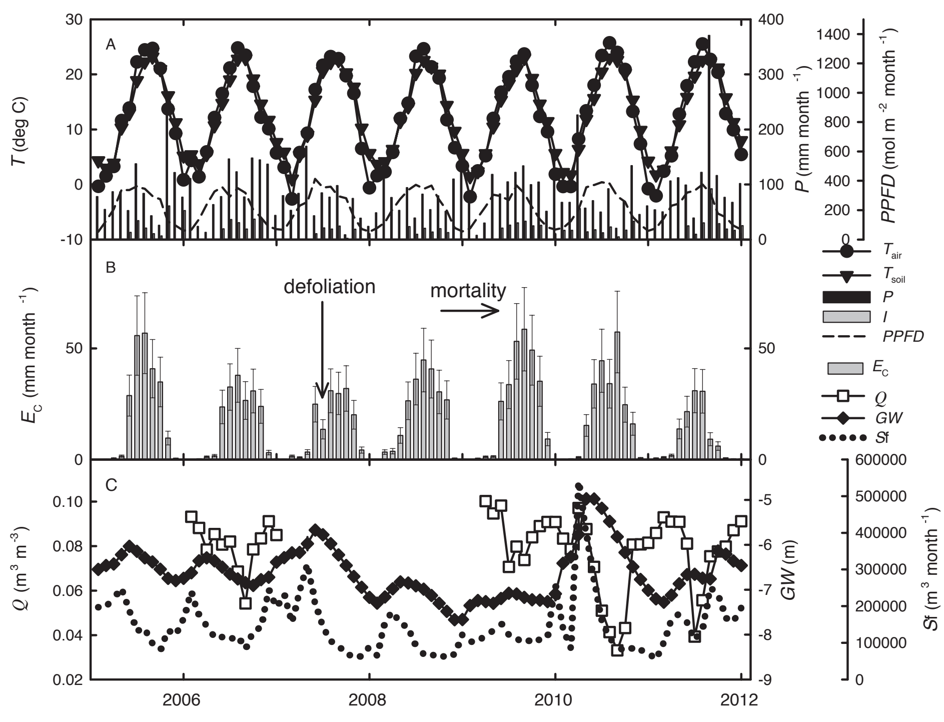

Figure 2: Top panel – soil (T_{soil}, black triangles) and air temperature (T_{air}, black circles, in °C), photon flux density (PPFD in μmol m^{-2} $month^{-1}$, dashed lines), precipitation (P, black bars) and interception (I, grey bars) middle panel – canopy transpiration (grey bars,

E_c in mm month^{-1}) with standard error of the mean (Figure 2) bottom panel – soil moisture content (Θ in m^3 m^{-3}, open squares), streamflow (Sf in m^{-3} month^{-1}, dashed-dotted line) and groundwater table (GW in m below surface, black squares)

Resource use and efficiency, and stomatal responses to environmental drivers of oak and pine species in an Atlantic Coastal Plain forest

The Pine Barrens are a pine-oak ecosystem that are also globally distributed even though differences in anatomy and leaf habit between many co-occurring oaks and pines suggest different strategies for resource use, efficiency and stomatal behavior. The New Jersey Pinelands contain sandy soils with low water- and nutrient-holding capacity providing an opportunity to examine trade-offs in resource uptake and efficiency. Therefore, in this study we compared resource use in terms of transpiration rates and leaf nitrogen content and resource-use efficiency including water-use efficiency (WUE) via gas exchange and leaf carbon isotopes and photosynthetic nitrogen-use efficiency (PNUE) between oaks (*Quercus alba*, *Q. prinus*, *Q. velutina*) and pines (*Pinus rigida*, *P. echinata*). We also determined environmental drivers (vapor pressure deficit (VPD), soil moisture, solar radiation) of canopy stomatal conductance (G_S) estimated via sap flow and stomatal sensitivity to light and soil moisture. Net assimilation rates were similar between genera, but oak leaves used about 10% more water and pine foliage contained about 20% more N per unit leaf area. Therefore, oaks exhibited greater PNUE while pines had higher WUE based on gas exchange, although WUE from carbon isotopes was not significantly different. For the environmental drivers of G_S, oaks had about 10% lower stomatal sensitivity to VPD normalized by reference stomatal conductance compared with pines. Pines exhibited a significant positive relationship between shallow soil moisture and G_S, but only G_S in *Q. velutina* was positively related to soil moisture. In contrast, stomatal sensitivity to VPD was significantly related to solar radiation in all oak species but only pines at one site. Therefore, oaks rely more heavily on groundwater resources but have lower WUE, while pines have larger leaf areas and nitrogen acquisition but lower PNUE demonstrating a trade-off between using water and nitrogen efficiently in a resource-limited ecosystem.

Physiological strategies of co-occurring oaks in a water- and nutrient-limited ecosystem

Oak species are well suited to water-limited conditions by either avoiding water stress through deep rooting or tolerating water stress through tight stomatal control. In co-occurring species where resources are limited, species may either partition resources in space and/or time or exhibit differing efficiencies in the use of limited resources. Therefore, in this study we determined whether two co-occurring oak species (*Quercus prinus* L. and *Quercus velutina* Lam.) differ in physiological parameters including photosynthesis, stomatal conductance, water-use (WUE) and nitrogen-use efficiency (NUE), as well as to characterize transpiration and average canopy stomatal responses to climatic variables in a sandy, well-drained and nutrient-limited ecosystem. The study was conducted in the New Jersey Pinelands over a 3-year period and we measured sap flux, as well as leaf gas exchange, leaf nitrogen and carbon isotope concentrations. Both oak species showed relatively steep increases in leaf-specific transpiration at low vapor pressure deficit (VPD) values before maximum transpiration rates were achieved, which were sustained over a broad range in VPD. This suggests tight stomatal control over transpiration in both species, although *Q. velutina* showed significantly higher leaf-level and canopy-level stomatal conductance than *Q. prinus*. Average daytime stomatal conductance was positively correlated with soil moisture and both oak species maintained at least 75% of their maximum canopy stomatal conductance at soil moistures in the upper soil layer (0–0.3 m) as low as 0.03 $m^3\ m^{-3}$. *Quercus velutina* had significantly higher photosynthetic rates, maximum Rubisco-limited and electron-transport-limited carboxylation rates, dark respiration rates and nitrogen concentration per unit leaf area than *Q. prinus*. However, both species exhibited similar WUEs and NUEs. Therefore, *Q. prinus* has a more conservative resource-use strategy, while *Q. velutina* may need to exploit niches that are locally higher in nutrients and water. Likewise, both species appear to tap deep, stable water sources, highlighting the importance of rooting depth in modeling transpiration and stomatal conductance in many oak ecosystems.

Tree-level hydrodynamics approach for stomatal conductance parameterization

Mirfenderesgi G, Bohrer G, Matheny AM, Fatichi S, Frasson RPdM, Schäfer KVR. (2016) Tree level hydrodynamic approach for resolving aboveground water storage and stomatal conductance and modeling the effects of tree hydraulic strategy. *Journal of Geophysical Research-Biogeosciences* 121:1792–1813 http://onlinelibrary.wiley.com/doi/10.1002/2016JG003467/abstract

The Finite-element Tree-Crown Hydrodynamics model version 2 (FETCH2) is a tree-scale hydrodynamic model of transpiration, based on the FETCH model approach [*Bohrer et al.*, 2005]. FETCH2 employs a finite difference numerical methodology and a simplified single-beam conduit system. FETCH2 simulates water flow through the tree as a continuum of porous media conduits. It explicitly resolves xylem water potential throughout the tree's vertical extent. Empirical equations relate water potential within the stem to stomatal conductance at each height throughout the crown. We utilize the assumption that stomata have evolved to minimize the risk of catastrophic levels of water stress within the vascular system and therefore, stomata are regulated by xylem water potential. While highly simplified, this approach brings additional realism to the simulation of transpiration by linking stomatal responses to stem water potential rather than directly to soil moisture, as is currently the case in the majority of models. The FETCH2 model accounts for plant hydraulic traits, such as the degree of anisohydric/isohydric response of stomata, maximal xylem conductivity, area of hydro-active xylem, vertical distribution of leaf area, and maximal and minimal xylem water content. This modeling approach enhances our understanding of the role of hydraulic limitations and short-term water stresses in regulating and limiting transpiration. We used FETCH2 along with a sap-flow data set, collected from 21 trees of two genera (oak/pine) at an experimental plot located in Silas Little Experimental Forest, NJ, USA. We used FETCH2, to conduct an analysis of the interspecific variation of hydraulic parameters that describe the genera-level transpiration and the effects of these different hydraulic strategies on diurnal and seasonal transpiration dynamics.

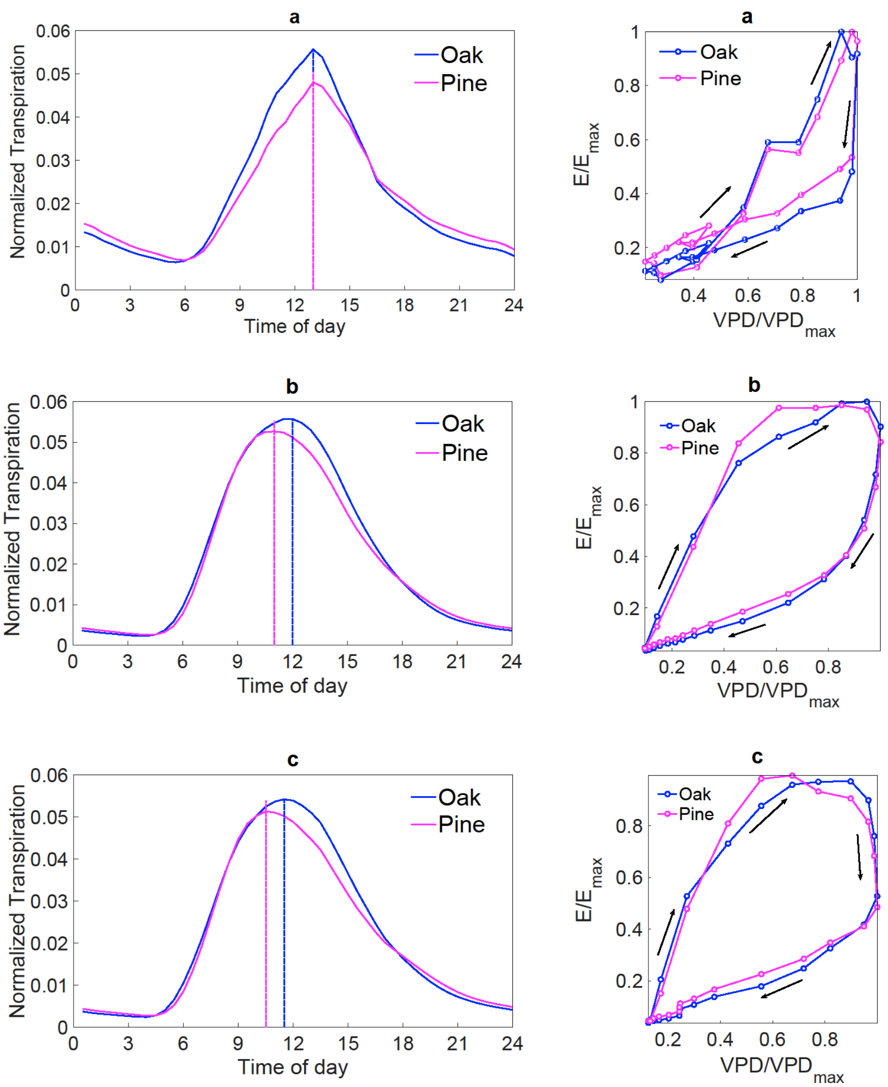

Figure 3: Normalized mean daily cycle of transpiration, during (a) wet days, (b) intermediate soil moisture, and (c) dry condition for oak (solid blue line) and pine (solid magenta line). The blue and magenta dashed lines represent the peak of normalized transpiration. Right column: Relative mean hysteresis loop of transpiration, during (a) wet days, (b) intermediate soil moisture, and (c) dry condition for oak (solid blue line) and pine (solid magenta line). Hysteresis was calculated by following transpiration to the time of peak VPD, and normalized by peak VPD and maximal daily transpiration. After normalization different days and trees where average to obtain seasonal mean hysteresis (showing here).

PRODUCTS RELATED DIRECTLY TO THIS GRANT FOR THE DURATION OF THE ENTIRE PROJECT

PUBLICATIONS

Carlo, N. J., H. J. Renninger, K. L. Clark, and K. V. R. Schäfer (2016), Impacts of prescribed fire on Pinus rigida Mill. in upland forests of the Atlantic Coastal Plain, *Tree Physiology*, *36*(8), 967-982, doi:10.1093/treephys/tpw044.

Matheny, A. M., et al. (2014), Characterizing the diurnal patterns of errors in the prediction of evapotranspiration by several land-surface models: An NACP analysis, *Journal of Geophysical Research-Biogeosciences*, *119*(7), 1458-1473, doi:Doi 10.1002/2014jg002623.

Medvigy, D., K. L. Clark, N. S. Skowronski, and K. V. R. Schäfer (2012), Simulated impacts of insect defoliation on forest carbon dynamics, *Environmental Research Letters*, *7*(4), 045703.

Medvigy, D., S.-J. Jeong, K. L. Clark, N. S. Skowronski, and K. V. R. Schäfer (2013), Effects of seasonal variation of photosynthetic capacity on the carbon fluxes of a temperate deciduous forest, *Journal of Geophysical Research: Biogeosciences*, *118*(4), 1703-1714, doi:10.1002/2013jg002421.

Mirfenderesgi, G., G. Bohrer, A. M. Matheny, S. Fatichi, R. P. de Moraes Frasson, and K. V. R. Schäfer (2016), Tree level hydrodynamic approach for resolving aboveground water storage and stomatal conductance and modeling the effects of tree hydraulic strategy, *Journal of Geophysical Research: Biogeosciences*, *121*(7), 1792-1813, doi:10.1002/2016jg003467.

Renninger, H. J., N. Carlo, K. L. Clark, and K. V. R. Schäfer (2014a), Modeling respiration from snags and coarse woody debris before and after an invasive gypsy moth disturbance, *Journal of Geophysical Research: Biogeosciences*, *119*(4), 630-644, doi:10.1002/2013jg002542.

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Renninger, H. J., K. L. Clark, N. Skowronski, and K. V. R. Schafer (2013), Effects of a prescribed fire on water use and photosynthetic capacity of pitch pines, *Trees-Structure and Function*, *27*(4), 1115-1127, doi:10.1007/s00468-013-0861-5.

Renninger, H. J., and K. V. Schafer (2012), Comparison of tissue heat balance- and thermal dissipation-derived sap flow measurements in ring-porous oaks and a pine, *Front Plant Sci*, *3*, 103, doi:10.3389/fpls.2012.00103.

Schäfer, K. V. R. (2011), Canopy stomatal conductance following drought, disturbance and death in an upland oak/pine forest of the New Jersey Pine Barrens, USA, *Frontiers in Plant Science*, *2*, 15, doi:10.3389/fpls.2011.00015.

Schäfer, K. V. R., H. J. Renninger, N. J. Carlo, and D. Vanderklein (2014a), Forest response and recovery following disturbance in upland forests of the Atlantic Coastal Plain, *Frontiers in Plant Science*, *5*, 294, doi:10.3389/fpls.2014.00294.

Schäfer, K. V. R., H. J. Renninger, K. L. Clark, and D. Medvigy (2014b), Hydrological responses to defoliation and drought of an upland oak/pine forest, *Hydrological Processes*, *28*(25), 6113-6123, doi:10.1002/hyp.10104.

CONFERENCE PRESENTATIONS

Bohrer G, Matheny AM, Mirfenderesgi G. Including tree water potential in plot-level transpiration modeling using the hydrodynamic approach. Oral presentation, 1/2016. *96th American Meteorological Society Annual Meeting*, New Orleans, LA.

Bohrer G, Matheny AM, Mirfendersgi G, Morin TH, Fatichi S. Scaling tree-level hydrodynamics to plot-level hydrology using novel model and measurements. Oral presentation, 4/2016. *European Geosciences Union General Assembly*, Vienna, Austria.

Bohrer G, Matheny AM. The Finite-Elements Tree-Crown Hydrodynamics model (FETCH): Assessing the effects of hydrodynamic strategy in different tree species, Invited Talk 7/2013. *12th U.S. National Congress on Computational Mechanics, USNCCM12*, Raleigh, NC.

Bohrer G, Maurer KD, Chatziefstratiou E, Medvigy D. Large-eddy simulations with a dynamic explicit vegetation model. Oral presentation, 12/2014. *American Geophysical Union Meeting 2014,* San Francisco, CA.

Bohrer G, Mirfenderesgi G, Matheny AM, Fatichi S. Tree to plot scaling – how individual properties and species specific traits add up to describe a forest. Poster 12/2016. *American Geophysical Union Fall Meeting 2016*, San Francisco, CA.

Chatziefstratiou E, Kenny WT, Heilman WE, Bohrer G. Resolving the effects of canopy structure on fire-emitted smoke dispersion using large eddy simulations. Oral presentation, 5/2014. *Large Wildland Fires: Social, Political and Ecological Effects Conference*, Missoula, MT.

Chatziefstratiou EK, Bohrer G. Resolving the effects of canopy structure on fire-emitted heat transport using large eddy simulations. Oral presentation, 5/2014. *31st Conference on Agricultural and Forest Meteorology.* Portland, OR.

Chen M, Keenan T, Hufkens K, Munger JW, Bohrer^ G, Brzostek E, Richardson A. Inter-annual variability of carbon fluxes in temperate forest ecosystems: effects of biotic and abiotic factors. Poster, 12/2014. *American Geophysical Union Meeting 2014,* San Francisco, CA.

Frasson RPdM, Bohrer G, Medvigy D, Matheny AM, Gough CM, Vogel CS, Curtis PS. Modeling forest carbon cycle response to tree mortality: effects of plant functional type and disturbance intensity. Poster, 1/2015. *AmeriFlux Principal Investigators Meeting*, Washington, DC.

Frasson RPdM, Bohrer G, Medvigy D, Vogel CS, Gough CM, Curtis PS. Representing sub-plot canopy heterogeneity improves model prediction of net ecosystem exchange in a mixed-deciduous forest. Oral presentation, 12/2014. *American Geophysical Union Meeting 2014,* San Francisco, CA.

Frasson RPM, Bohrer G. Exploring the influence of time and spatial resolution on the prediction of latent heat fluxes. Invited Talk 6/2014. *Ohio Supercomputer Center Statewide User Group Meeting*, Columbus, OH.

Gough CM, Bohrer G, Nadelhoffer K, Vogel CS, Curtis PS. Carbon cycle resilience to disturbance in Great Lakes forests: measurements, mechanisms, and models. Poster, 1/2015. *AmeriFlux Principal Investigators Meeting*, Washington, DC.

Keenan T, Richardson A, Gray J, Friedl M, Toomey M, Bohrer G, Hollinger D, Munger JW, Schmid HP, Wing IS, Yang B. Net carbon uptake has increased through warming-induced changes in temperate forest phenology. Invited Talk 12/2014. *American Geophysical Union Meeting 2014,* San Francisco, CA.

Matheny A, Bohrer G. Mechanistic linking of stomata conductance to soil moisture using a tree level hydrodynamic model. Poster, 9/2012. *4th International EcoSummit on Ecological Sustainability*, Columbus, OH.

Matheny AM, Bohrer G, Curtis PS, Ivanov VY, Schäfer KVR. Plot-level measurements and modeling of sap flux - providing a mechanistic link between stomata conductance and soil moisture. Poster, 4/2012. *Department of Energy, Terrestrial Ecosystem Science PI meeting*, Washington, DC

Matheny AM, Bohrer G, Fiorella R, Mirfenderesgi G. Proposed hydrodynamic model improves resolution of species-specific responses to drought and disturbance. Poster, 12/2015. *American Geophysical Union Fall Meeting 2015*, San Francisco, CA.

Matheny AM, Bohrer G, Ivanov V, Stoy P. Typical patterns of latent heat flux error – indicative of missing hydrodynamic processes in land surface models. Poster. 2/2013. *4th NACP All-Investigator Meeting*, Albuquerque, NM.

Matheny AM, Bohrer G, Mirfenderesgi G, Schäfer KVR. Proposed hydrodynamic model increases the ability of land-surface models to capture intra-daily dynamics of transpiration and canopy structure effects. Oral presentation, 12/2014. *American Geophysical Union Meeting 2014,* San Francisco, CA. (best student presentation award).

Matheny AM, Bohrer G, Mirfendersgi G. Shifting the plant functional type paradigm to reflect hydraulic properties may improve model simulations of drought and disturbance. Oral presentation 6/2016. *32nd Conference on Agricultural and Forest Meteorology*, Salt Lake City, UT (Best student presentation award, 2nd place).

Matheny AM, Bohrer G, Thomsen JE, Frasson R, Frasson CD, Ivanov VY. A framework for incorporating the effects of hydrodynamic stresses on forest photosynthesis and evaporation. Poster, 12/2012. *American Geophysical Union Meeting 2012,* San Francisco, CA.

Matheny AM, Bohrer G. Mechanistic linking of stomata conductance to soil moisture using tree-level hydrodynamic model. Oral Presentation, 6/2012. *Computational methods in Water Resources*, Urbana-Champaign, IL.

Matheny AM, Bohrer G. Multi-site model-observations comparison shows the diurnal effects of hydrodynamic stress on evapotranspiration. Poster, 12/2013. *American Geophysical Union Meeting 2013,* San Francisco, CA.

Matheny AM, Morin TH, Bohrer G, Garrity S, Vogel CS, Ivanov V, Curtis PS. Improved latent heat flux modeling through plant hydrodynamics accounts for the influence of species-specific storage and diurnal hysteresis. Poster, 1/2015. *The 2015 NACP PI Meeting,* Washington DC.

Medvigy D, Schäfer KVR, Clark KL, Skowronski NS, Defining plant functional types for xeric habitats with disturbance regimes, Ecological Society of America Meeting, Portland, OR Aug 5-10 2012.

Medvigy D; Schäfer KVR; Clark KL Impacts of insect disturbance on the structure, composition, and functioning of oak-pine forests, B31I-02. American Geophysical Union, San Francisco, CA, 4–9 December 2011

Mirfenderesgi G, Bohrer G, Fatichi S, Matheny AM, Frasson RM, Schäfer KVR. Application of a tree-level hydrodynamic model to simulate plot-level transpiration in the upland oak/pine forest in New Jersey. Oral presentation, 1/2016. *96th American Meteorological Society Annual Meeting*, New Orleans, LA.

Mirfenderesgi G, Bohrer G, Matheny AM, Fatichi S, Frasson RM, Schäfer KVR. Application of a tree-level hydrodynamic model to simulate plot-level transpiration in the upland oak/pine forest in New Jersey. Poster, 12/2015. *American Geophysical Union Fall Meeting 2015*, San Francisco, CA.

Mirfenderesgi G, Bohrer G, Matheny AM, Fatichi S, Frasson RPdM, Schafer KVR. Tree-level hydrodynamic approach for modeling aboveground water storage and stomatal conductance highlights the effects of tree hydraulic strategy. Poster 12/2016. *American Geophysical Union Fall Meeting 2016*, San Francisco, CA.

Mirfenderesgi G, Bohrer G, Matheny AM. Tree-level hydrodynamic approach for improved stomatal conductance parameterization. Poster, 12/2014. *American Geophysical Union Meeting 2014,* San Francisco, CA.

Renninger H, Schäfer K, Bohrer G, Clark K, Skowronski N. Effects of disturbance on carbon sequestration in the New Jersey Pine Barrens. Poster, 5/2014. *The 2014 Joint TES/SBR Principal Investigators Meeting*, Potomac, MD.

Renninger HJ, Clark KL, Skowronski N, Schäfer KVR Effects of a prescribed burn on the water use and photosynthetic capacity of pitch pines (*Pinus rigida* L) in the New Jersey Pine Barrens. DOE Principal Investigator meeting 23rd / 24th April 2012, Washington DC.

Renninger HJ, Schäfer KVR (2011) Comparison of heat balance (Čermák) and thermal dissipation (Granier) sap flow measurements in ring-porous oaks and a pine species. 96th Annual Meeting Ecological Society of America, Austin, TX, 7–12 August

Renninger HJ, Schäfer KVR, Clark KL, Skowronski N, Effects of a prescribed burn on the water use and photosynthetic capacity of pitch pines (*Pinus rigida* L) in the New Jersey Pine Barrens. Ecological Society of America Meeting, Portland, OR Aug 5-10 2012.

Schäfer KVR (2011) Canopy stomatal conductance under drought, disturbance and death. 96th Annual Meeting Ecological Society of America, Austin, TX, 7-12 August

Schäfer KVR, Duman T, Radwanski D, Clark K 2016 "Canopy water use efficiency before, during and after gypsy moth attack in an upland forest in the New Jersey Pine Barrens" (invited) Ecological Society of America Meeting, Fort Lauderdale, Florida, USA

Schäfer, KVR, H. Renninger, K. Clark, and D. Medvigy (2013) Hydrological response of an upland oak/pine forest on the Atlantic Coastal Plain to drought and disturbance. 98th Annual Meeting Ecological Society of America, Minneapolis, MN, 4–9 August