Carbon and water cycling following low-severity disturbance in an Upper Great Lakes forest: Empirical and modeling results from an AmeriFlux core site

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Disturbance modifies forest physical structure and composition, which may in turn alter biogeochemical processes central to carbon (C) and water cycling. In the Upper Great Lakes region, disturbances are transitioning away from severe events that cause forest stand replacement, and toward lower-intensity disturbances that result in partial canopy defoliation or loss of selected species. These low-severity disturbances include partial harvests, wind, pathogenic insects, diseases, and age-related senescence. The response and mechanisms supporting the recovery of C and water cycles following low-intensity disturbance are poorly characterized, with most prior empirical and modeling studies examining the biogeochemical implications of severe stand-replacing disturbance.

At the University of Michigan Biological Station Ameriflux core site, we are using long-term records of C and water cycling from unmanipulated control (US-UMB) and experimentally disturbed (US-UMd) forests to quantify disturbance-related changes in biogeochemical cycling and identify the underlying mechanisms supporting their resilience to disturbance. The Forest Accelerated Succession Experiment (FASET), in which >6,700 canopy dominant Populus (aspen) and Betula (birch) trees were stem girdled within a 39 ha area, employs C and water cycling measurements within paired US-UMB and US-UMd meteorological flux tower footprints.

The C cycle at our site has exhibited striking resilience to low-intensity disturbance, with sustained net ecosystem production (NEP) following the senescence of a third of canopy trees. Disturbance-related changes in canopy physical structure are associated with improved resource-use efficiency, providing a mechanism for sustained NEP as trees die. We found that the water cycle responded to low-severity disturbance through modified transpiration. Transpiration per tree and per sap-wood area increased following disturbance, with responses varying among hydrological functional types. Maples (a diffuse porous species) exhibited greater water stress and a decrease in transpiration because hydraulic stress increased following disturbance.

We find that ecosystem models poorly simulate biogeochemical responses to low-severity disturbance. In partnership with the DOE Pacific Northwest National Laboratory, we examined whether big-leaf (Biome-BGC) and gap (ED and Zelig) models accurately simulate NEP observed in our experimentally disturbed US-UMd site. Both ED and Zelig gap models substantially over-estimated the response of NEP to low-severity disturbance, predicting large declines in C uptake. The big-leaf Biome-BGC model more accurately simulated NEP following disturbance, but its mechanistic basis for resilience was not in agreement with observation. These results have implications for biogeochemical modeling at the global scale; both Biome-BGC and ED are part of the development stream of NCAR’s Community Land Model and DOE’s forthcoming ACME.