PS 48 Forest Habitats: #52848 Interspecific ecological and meteorological controls on forest canopy-derived hydrology and biogeochemistry in the southeastern United States

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ECOLOGICAL SCIENCE AT THE FRONTIER
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ABSTRACT (#52848)

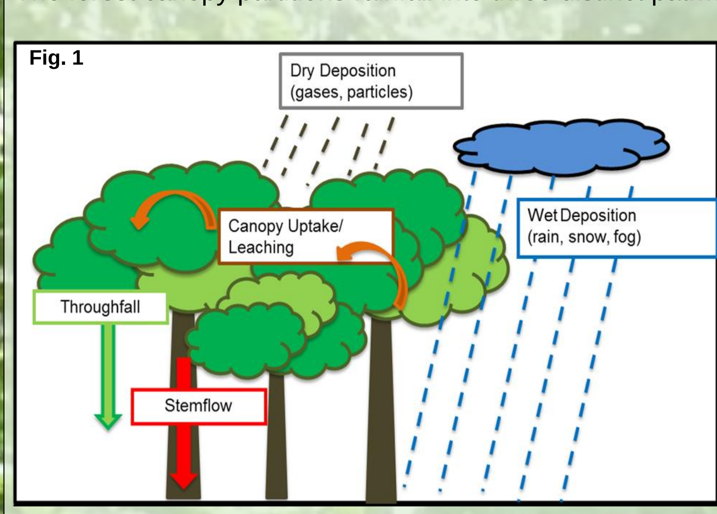
Background/Questions/Methods: During storm events, as precipitation moves through the forest canopy it is transformed in both quantity and quality, thus delivering highly enriched water to the forest floor. Throughfall is spatially distributed beneath the forest canopy while stemflow is localized to the roots and soils in the immediate vicinity of individual tree trunks. Previous research has demonstrated that storm characteristics (e.g., intensity, duration, and magnitude), canopy structural parameters, and species composition have a significant control on canopy-derived nutrient fluxes. However, in the southeastern United States, contributions of the forest canopy to nutrient cycling have largely been overlooked, although the magnitude of tree biodiversity in the region separates these forests from their more-studied counterparts. Therefore, a field study was established in an oak-hickory forest in Mississippi to categorize the interspecific control on canopy-mediated nutrient cycling during precipitation events. Throughfall collectors and stemflow collars were located underneath the canopies of four oak (Shumard, Southern Red, Post, and White) and two hickory species (Shagbark and Pignut), with three replicates for each species. Hydrologic flux and nutrient samples were collected following individual precipitation events beginning in Fall 2014 and continue to present. Meteorological characteristics and precipitation chemistry were collected at a nearby open site.

Results/Conclusions: Preliminary results indicate interspecific differences were statistically significant for both throughfall and stemflow hydrologic partitioning (p=0.045 and p=0.021, respectively). Shumard oak, of the red oak family, partitioned an average of 78.7% of incident precipitation into throughfall and 1.3% into stemflow, the largest among all species. Mean concentrations of total nitrogen in throughfall were greatest in Shumard oak (1.44 mg/L) and post oak (1.39 mg/L) while stemflow concentrations were greatest in shagbark hickory (1.84 mg/L) and white oak (1.56 mg/L) and intermediate in Shumard oak (0.92 mg/L). These differences were not significant across species (throughfall: p=0.301, stemflow: p=0.459), but were significant across storm events (throughfall: p<0.001, stemflow: p=0.326). Results suggest that Shumard oak canopies facilitate the largest hydrologic fluxes in oak-hickory forests that correspond to intermediate biogeochemical fluxes of nitrogen, enabling this species to directly modify the substrata and its growing conditions. Additionally, the significant temporal differences in throughfall biogeochemistry highlight the importance of interspecific ecological traits in the phyllosphere to nutrient cycling in oak-hickory forests. Improved understanding of species-specific roles in nutrient cycles in highly diverse southern forests is critical to developing effective management strategies to mitigate shifts in species composition and ecosystem functions as regional climates change.

INTRODUCTION

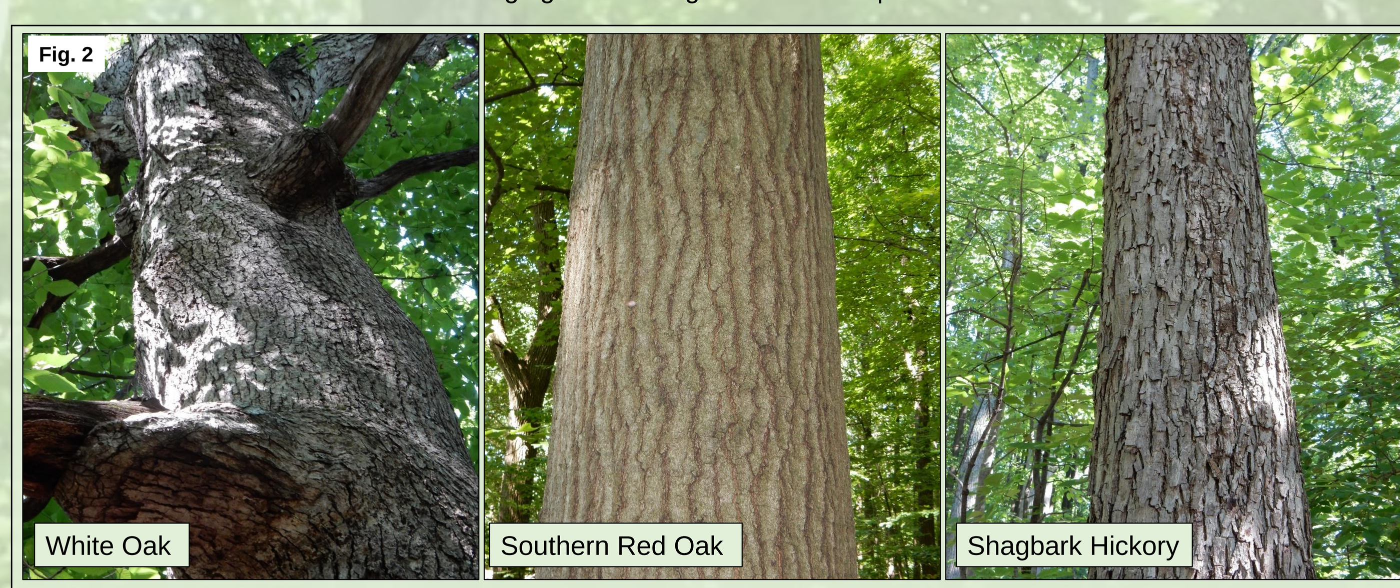
The biogeography of oak species in forests across the United States is changing due to anthropogenic management of fire regimes (Brose et al. 2001; Nowacki and Abrams 2008), accelerated mammalian browsing (Abrams 2003; Cote et al. 2004), insects (Stephen et al. 2001), disease (Bruhn et al. 2000), and climatic disturbances leading to a broad decline of oaks (Clinton et al. 1993; Voelker et al. 2008; McEwan et al. 2011). As such, oaks are a crucial component of forest hydrology and biogeochemical cycling, influencing both the temporal and spatial distribution of water and nutrients in forests. Ecosystem services (*e.g.*, carbon sequestration, water and air purification, storm water management, recreational retreats) are constrained by forest health, which can be measured via several parameters including net primary production and biomass accumulation, evapotranspiration, resiliency to disturbance, and forest nutrient balances. These services are ultimately controlled by the external climate from which forests derive water and nutrients.

The forest canopy partitions rainfall into three distinct pathways (Fig. 1):

Fig. 1


1. **Throughfall-** passes through the forest canopy, and may or may not contact canopy surfaces before being deposited heterogeneously across the forest floor.
2. **Stemflow-** is captured by the forest canopy, channeled down tree trunks, and deposited locally to root systems.
3. **Interception-** is captured by the forest canopy and evaporated back to the atmosphere, thus removing this portion of rainfall from the surface water budget.

Throughfall and stemflow hydrology are largely influenced by species-specific characteristics (*e.g.*, bark morphology (Fig. 2), branching geometry, leaf characteristics) (Levia and Frost 2003, 2006), the presence/absence of deciduous foliage, and storm meteorological conditions (Siegert and Levia 2014). These pathways may become enriched with nutrients and other solutes via washoff of dry deposition during antecedent dry periods or canopy leaching (Lovett and Lindberg 1984). Changes in precipitation characteristics (e.g. magnitude, duration, and intensity) or in overall storm tracks as a result of changing climatic regimes have the potential to alter the movement of water and nutrients in forests.

Fig. 2


Additionally, the absence of oaks in historically oak-dominated forests will have many implications including alterations to: hydrologic and biogeochemical cycling; soil nutrient status, carbon storage, and microbial populations; streamwater and groundwater chemistry; and timing and intensity of fire regimes. In order to predict and manage oak decline, it is first necessary to understand and quantify the role of oaks to forest nutrient cycling.

STUDY SITE

The field site was located at Sessums Natural Area in Oktibbeha County, MS (33°25'27.8"N 88°45'36.6"W) in a 15 hectare catchment (Fig. 6). The site is located at the contact point between the Demopolis chalk formation to the northeast and the Ripley formation to the southwest. Soils at the site are silty clay loams ranging from somewhat poorly drained (Kipling) to well drained (Sumpter) depending on landscape position. The climate is warm, humid with average temperatures of 8.0°C in January and 27.4°C in July. Annual average precipitation is 129.1 cm, with almost all occurring as rainfall.

Fig. 3

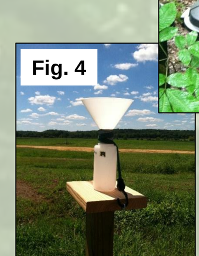

Fig. 4


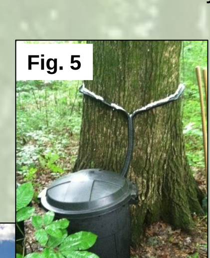
Fig. 5


Fig. 6


METHODS

Four oak species and two hickory species (see Table 1) were selected for the study. Three trees from each species were outfitted with stemflow collars by longitudinally cutting high density polypropylene (HDPE) tubing, which was sealed to the trees with silicone caulk and drained into large collection bins (Fig. 4). Following rainfall events greater than 5 mm, stemflow bins were measured to determine total stemflow volume and samples were collected for nitrogen analysis. Open precipitation was measured and samples were collected at the nearby MSU Dairy Farm (Fig. 5, 6).

Tree Species		DBH (cm)	Basal Area (m²)	Canopy Area (m²)	Stemflow (%)	TN (mg L⁻¹)	NO_3^{-1} (mg L⁻¹)
Quercus shumardii	Shumard Oak	48.5 70.9 76.7	0.18 0.39 0.46	24.1 65.7 53.1	2.6 1.5 1.0	0.78	0.18
Quercus pagoda	Southern Red Oak	61.5 65.5 78.7	0.30 0.34 0.49	60.7 170.5 306.1	0.1 1.0 0.5	0.50	0.22
Quercus stellata	Post Oak	49.3 58.7 69.3	0.19 0.27 0.38	151.3 126.7 164.3	0.3 0.5 0.2	0.79	0.14
Quercus alba	White Oak	49.5 61.5 88.9	0.19 0.30 0.62	77.1 122.5 198.1	0.1 0.2 0.2	1.06	0.14
Carya glabra	Pignut Hickory	18.0 36.3 77.5	0.03 0.10 0.47	23.3 11.8 194.6	0.9 0.1 2.4	0.40	0.14
Carya ovata	Shagbark Hickory	25.9 31.5 49.8	0.05 0.08 0.19	1.5 56.9 74.8	- 0.3 0.2	1.60	0.21

Table 1. Summary of species characteristics.

Stemflow volumes were converted to depth equivalents based on the canopy area of each collecting tree. Depth equivalents were then compared to rainfall amounts to determine each tree's stemflow partitioning. Funneling Ratios (FR) (Herwitz 1986) were determined by

$$FR = \frac{SF}{P_g \times BA}$$

where *SF* is stemflow volume (mL), P_g is precipitation (cm), and *BA* is the basal area of each tree (cm²).

Samples were returned to the laboratory, filtered to remove particulates greater than 0.45µm, and stored at 4°C within 24 hours. Total nitrogen (TN) concentrations were determined using colorimetric methods on a Bran+Luebbe Autoanalyzer and nitrate (NO_3^{-1}) concentrations were determined on a Dionex DX-500 Ion Chromatograph. To determine the volume-weighted flux of nitrogen in each sample relative to precipitation, enrichment ratios (ER) (Levia and Herwitz 2000) were determined by

$$ER = \frac{SF \times [SF_i]}{P_g \times [P_{gi}] \times CA}$$

where *SF* is stemflow volume (mL), $[SF_i]$ is the concentration of nutrient *i* in stemflow (mg L⁻¹), P_g is precipitation (cm), $[P_{gi}]$ is the concentration of nutrient *i* in precipitation (mg L⁻¹), and *CA* is the canopy area of each tree (cm²).

RESULTS: STEMFLOW HYDROLOGY

Event	Precipitation (cm)	Event	Precipitation (cm)
18-NOV-2014	1.46	03-APR-2015	0.68
13-JAN-2015	1.37	04-APR-2015	0.88
23-JAN-2015	3.16	07-APR-2015	1.28
02-FEB-2015	1.06	10-APR-2015	0.75
17-FEB-2015	1.18	14-APR-2015	0.96
16-MAR-2015	3.65	18-APR-2015	3.74
23-MAR-2015	2.50	19-APR-2015	3.54
01-APR-2015	0.55	25-APR-2015	2.38

Table 2. Summary of sampled rainfall events.

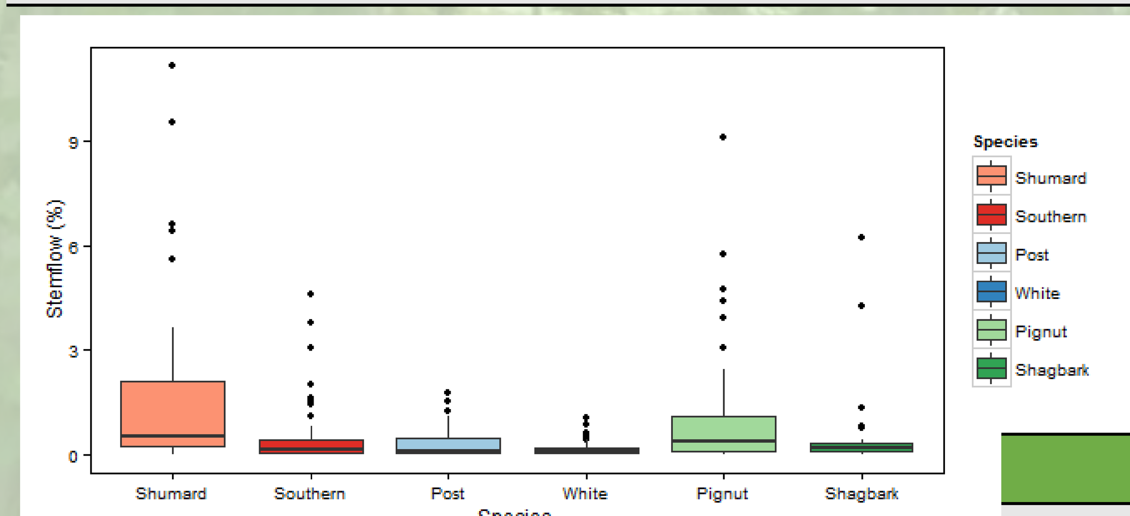


Fig 7. Stemflow partitioning as a percentage of incident rainfall for individual trees during rainfall events (see Table 2).

	D.F.	Sum of Squares	Mean Square	F Value	Pr(>F)
Species	5	76.9	15.37	8.062	**<0.001**
Event	1	42.0	42.04	22.052	**<0.001**
Residuals	267	509.1	1.91		

Table 3. ANOVA results for stemflow partitioning between species and rainfall events.

	Shumard Oak	Southern Red Oak	Post Oak	White Oak	Pignut Hickory
Southern Red Oak	**<0.001**	-	-	-	-
Post Oak	**<0.001**	0.448	-	-	-
White Oak	**<0.001**	0.209	0.617	-	-
Pignut Hickory	0.054	0.052	**0.007**	**0.002**	-
Shagbark Hickory	**<0.001**	0.946	0.529	0.277	0.064

Table 4. Pairwise t-test results for stemflow partitioning between species for individual rainfall events. Values in bold represent species pairs with significantly different mean partitioning rates at α=0.05.

RESULTS: STEMFLOW BIOGEOCHEMISTRY

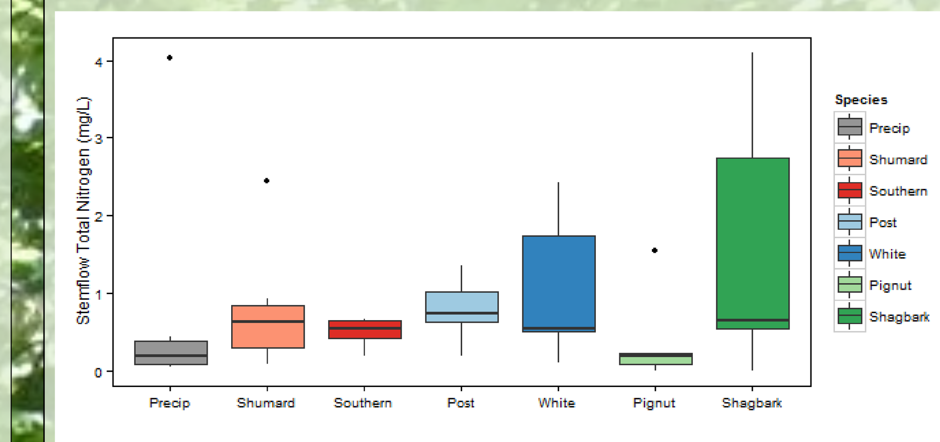


Fig 8. Total nitrogen concentrations in rainfall and stemflow from 7 rainfall events.

	D.F.	Sum of Squares	Mean Square	F Value	Pr(>F)
Species	6	4.86	0.8106	0.810	0.570
Event	1	2.82	2.8181	2.816	0.103
Residuals	32	32.03	1.0008		

Table 5. ANOVA results for TN concentrations in rainfall and stemflow between species and rainfall events.

	D.F.	Sum of Squares	Mean Square	F Value	Pr(>F)
Species	5	949	189.7	0.771	0.584
Event	1	1601.4	1601.4	10.287	**0.006**
Residuals	15	2335.2	155.7		

Table 6. ANOVA results for TN enrichment in stemflow relative to rainfall between species and rainfall events.

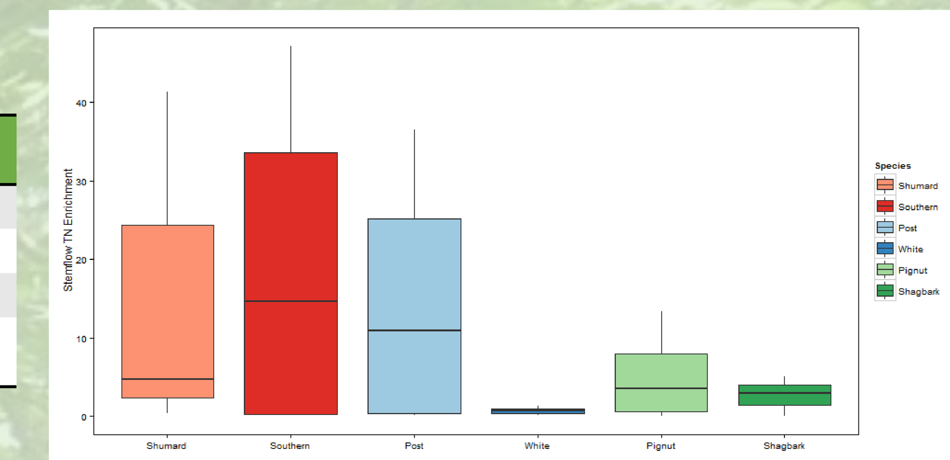


Fig 9. Total nitrogen flux-based enrichment in stemflow relative to rainfall from 7 rainfall events.

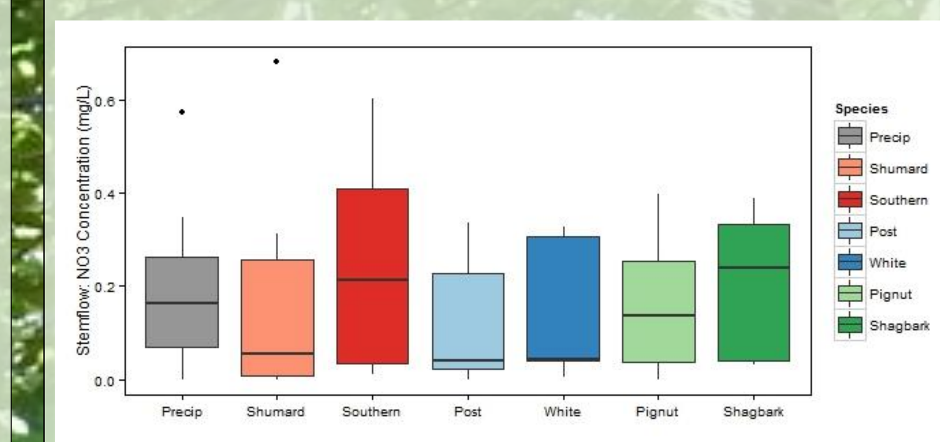


Fig 10. Nitrate concentrations in rainfall and stemflow from 8 rainfall events.

	D.F.	Sum of Squares	Mean Square	F Value	Pr(>F)
Species	6	0.0633	0.0106	0.292	0.937
Event	1	0.0940	0.0940	2.602	0.115
Residuals	37	1.337	0.036		

Table 7. ANOVA results for NO_3^- concentrations in rainfall and stemflow between species and rainfall events.

	D.F.	Sum of Squares	Mean Square	F Value	Pr(>F)
Species	5	217.0	43.4	0.598	0.702
Event	1	701.1	701.1	9.663	**0.006**
Residuals	18	1306.1	72.6		

Table 8. ANOVA results for NO_3^- enrichment in stemflow relative to rainfall between species and rainfall events.

Fig 11. Nitrate flux-based enrichment in stemflow relative to rainfall from 8 rainfall events.

CONCLUSIONS

A small number of rainfall events revealed differences between oak and non-oak species relative to stemflow hydrology and biogeochemistry. Future sampling and analysis should reveal additional relationships as more data are available, but at present the following findings indicate:

- Stemflow hydrology was significantly different between oak and non-oak species (Fig. 7, Tables 3-4).
- The largest stemflow fluxes were observed in Shumard oak and pignut hickory—both species with relatively smooth bark morphology while the smallest hydrologic fluxes were observed in species with the roughest bark morphology– white oak and shagbark hickory (Fig. 7).
- Total nitrogen concentrations were not statistically different between species (Table 5), although TN concentration variability was quite different (Fig. 8).
- TN enrichment relative to precipitation was significantly different between rainfall events (Fig. 9, Table 6).
- Nitrate concentrations were not statistically different between species (Fig. 10, Table 7).
- Nitrate enrichment relative to precipitation was significantly different between rainfall events (Fig. 11, Table 8).

THROUGHFALL RESULTS

Results of throughfall hydrology and biogeochemistry are being presented by Katy Limpert on Monday, August 10th 4:30-6:30PM in PS 15-149 "Ecological significance of phyllosphere leaf traits on throughfall hydrology, biogeochemistry, and leaf litter among Quercus species in the southeastern United States."

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