THROUGHFALL PH IN A MIXED DECIDUOUS-CONIFEROUS FOREST, ONTARIO, CANADA: THE EFFECT OF OVERSTORY SPECIES COMPOSITION

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ABSTRACT

Throughfall and precipitation pH were observed for one growing season in an undisturbed mixed deciduous-conifer forest on the east shore of Lake Superior in Ontario. Rainfall and throughfall were collected for pH analysis from late-May through mid-August under the dominant tree species. From a total of 18 measureable rainfall events, pH of deciduous (sugar maple and paper birch) and coniferous (white spruce and balsam fir) throughfall was significantly less acidic than the incident rainfall for nine of the events; particularly for events following deciduous canopy leafout. Deciduous and coniferous throughfall pH differed significantly from each other for four of the 18 rain events throughout the middle of the growing season. Paper birch had the least acidic throughfall and sugar maple, white spruce, and balsam fir throughfall were generally similar and more acidic. The spatial heterogeneity of throughfall chemistry as controlled by overstory species composition, in addition to numerous other environmental factors that differ at fine spatial scales in forest understories, may play an important role in mediating germination, growth rates, carbon assimilation rates, and mortality of understory tree seedlings.

Keywords: *Acer saccharum*, deciduous forest, coniferous forest, throughfall, soil pH

INTRODUCTION

Understory environmental conditions play an important role in mediating a wide array of ecological processes. A large body of ecological research has focused on how light, edaphic conditions, temperature, relative humidity and a long list of other physical factors control biodiversity, growth rates, mortality rates, and regeneration. These and other environmental variables exert a strong influence on understory plant communities (Barbier et al. 2008).

In some ecosystems, atmospheric deposition of acidic compounds has been identified as contributing to forest decline (Shibata and Sakuma 1996) as base cations are leached from the soil (Shibata et al. 1995). This is the case for large areas of the forests of Ontario, Canada including the forests on the eastern shore of Lake Superior (Morrison et al. 1992, Morrison 2004) as the soils in these forests lack the ability to buffer acid deposition (Morrison et al. 1992). Acid deposition in both dry and wet forms collect on leaves in the forest canopy, poten-

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tially leading to canopy exchange (washoff of deposited particles and gases) (Lovett and Lindberg 1984), which following a precipitation event may eventually drip onto the forest floor as throughfall. As a result, throughfall is frequently enriched with base cations and strong acid anions (Neary and Gizyn 1994), and may be less acidic than rainfall pH (Moore 1983).

The degree to which the forest canopy alters throughfall is dependent on the species composition of the adult tree layer (Mahendrappa 1989). In a mixed canopy forest it is possible that throughfall chemistry can be highly spatially heterogeneous (Keim et al. 2005) potentially altering water and soil resources at fine spatial scales that might favor one species over others (Wallrup et al. 2006). This project is part of a larger ongoing assessment of the degree to which canopy overstory conditions affect growth, carbon assimilation, and mortality rates of sugar maple seedlings due to varying light levels under coniferous and deciduous canopies, moisture and temperature regimes, and nutrient additions through stemflow and throughfall.

As summarized by Morris et al. (2003) a number of studies have recently explored spatial patterns of throughfall chemistry in mixed forests, but studies of temporal variability are generally lacking. Thus, for a mixed deciduous-conifer forest in central Ontario we address the following objectives: 1) does throughfall pH and rainfall pH vary significantly during the growing season and 2) to what extent does overstory species composition affect throughfall pH.

MATERIALS AND METHODS

Study Area

This research was conducted in a mixed temperate deciduous-conifer forest in Lake Superior Provincial Park (LSPP), Ontario, Canada (47°44′N, 84°49′W). The park is located at the ecotone between the temperate deciduous forest (found to the south) and boreal forest (dominant from the study area north) on the northeastern shore of Lake Superior, approximately 300–400 m above sea level (Barras and Kellman 1998; Goldblum and Rigg 2002; 2005). The forests are dominated by two coniferous species: white spruce (*Picea glauca*) and balsam fir (*Abies balsamea*); and three deciduous species: sugar maple (*Acer saccharum*), the rare yellow birch (*Betula alleghaniensis*), and paper birch (*Betula papyrifera*) (Goldblum and Rigg 2005).

On the upland hills, little soil development has occurred; therefore most of the plants growing in these areas are rooted in the surface organic material that is covering the rocky surface below (Kellman 2004). Soil pH ranges from 3.7 to 4.4 in the areas in which mineral soil is present (Goldblum and Rigg 2002).

The study site is a 1 ha area approximately 5 km south of the sugar maple northern limit in this region of Ontario. Previous stand structure analysis at the site indicated a total tree (>5 cm dbh) density of 1175 trees/ha. (Goldblum and Rigg 2002) The only tree seedlings (<30 cm ht.) and saplings (>30 cm ht, <5 cm dbh) in the study site are sugar maple with a seedling density of 29.9/m^2, and a relatively high sapling density of 10000/ha (Goldblum and Rigg 2002).

The Environment Canada weather station in Wawa, Ontario (25 km north of LSPP) maintains the closest long-term weather records to the study area (Kellman 2004; Goldblum and Rigg 2005). According to Environment Canada (2002), Wawa has a mean January temperature of –14.8 °C (std. dev. = 3.2) and a mean July temperature of 14.8 °C (std. dev. = 1.5). The annual average rainfall in Wawa is 727.4 mm, while the annual average snowfall is 328.6 cm, with the largest average snow depth occurring in February (67 cm) (Environment Canada 2002).

For comparison with the sampled forest, LSPP collects rainfall twice daily at the park headquarters (≈1 km S of the study site). Rainfall amounts were collected in the field site with a Decagon Devices ECRN-100 double-spoon tipping bucket rain gauge (resolution ±0.02 mm) and logged every 30 minutes with a Decagon Devices EM-50 data logger.

Field data collection

At the beginning of the 2008 growing season (prior to canopy leafout) we distributed 50 bulk throughfall collectors throughout the mixed deciduous-conifer forest of the study site. The understory at the fieldsite is open, and collectors were located so as not to receive throughfall from understory vegetation. We recorded the species composition of the immediate overstory for each throughfall collector into one of five mutually exclusive categories: sugar maple (n=14), white birch (n=4), balsam fir (n=7), white spruce (n=6), or partially open canopy (n=15), which were located in small gaps. The larger field objective was not only to quantify throughfall pH by overstory species, but to characterize the overall pattern of throughfall pH for the study area. This design provides ecologically meaningful information as understory plants are found throughout the understory under a variety of overstory conditions. Four throughfall collectors were ultimately excluded from analyses as they were under dead canopies or mixed canopies (which only became apparent after leaf out). Two collectors were placed outside the forest (≈ 2 km from the study site) to help quantify precipitation pH.

Following each measureable (> 1 mm) precipitation event, we collected water from the bulk collectors and measured pH in the field with an Oakton 310 Series pH Meter, and rinsed the collector with distilled water. The pH meter was calibrated twice during each set of field measurements. In the few cases where foreign biological material (e.g. leaves, slugs, insects) was found in the collector, no measurement was taken.

Standard statistical tests were used to address the scientific objectives. Tests used included: one-sample t-test, unpaired t-test, Spearman rank correlation, ANOVA, and Kruskal-Wallis. In the event that an ANOVA test identified a significant difference, we performed a post-hoc Tukey test. Given the risk of committing a Type I statistical error, all tests were conducted with a significance threshold of at least $p<0.01$.

RESULTS

During the 2008 growing season (May 25–August 15) there were 18 distinct measureable rain events distributed evenly throughout the summer (Table 1). Rainfall amounts measured in the field site and at the park headquarters were highly correlated (Spearman rank correlation; $r = 0.86$; $p<0.0001$); thus, rain amounts reported below are from the rain gauge in the field site. The mean rainfall event during the study period was 8.54 mm, but events were highly variable (SD = 8.78 mm). Individual precipitation events ranged from 1.27–32.51 mm. Total measured rainfall was 153.67 mm. We were able to collect rainfall samples for pH analysis outside of the forest, for 11 of the 18 events (in general, we were unable to collect an adequate sample for the smaller rain totals to perform field-based pH testing).

Overall, average rainfall pH measured outside the forest during the study period was 4.85 (SD = 0.50), with the most acidic event (June 13) being 3.71 (coinciding with the largest rain event; 32.51 mm) and the least acidic event (June 10) being 5.56 (coinciding with a 5.33 mm event). Average overall throughfall pH measured in the forest during the study period was 5.25 (SD = 0.61), with the most acidic event (May 31) being 4.22 and the least acidic event (June 26) being 6.12. There were significant differences (one-sample t test; $p<0.01$) between precipitation pH (measured outside the forest) and forest canopy throughfall (both deciduous throughfall and coniferous throughfall) for nine of the 12 comparable precipitation events (Table 1). In all cases, precipitation pH was significantly (Kruskal-Wallis, $p<0.01$) lower than either deciduous or coniferous throughfall (Table 1). Deciduous throughfall and coniferous throughfall pH were similar for

TABLE 1. Each rainfall event (by date) for the 2008 growing season is presented with amount (mm) and pH of precipitation (measured outside the forest). Throughfall pH (mean and standard deviation [SD]) as measured under deciduous canopy, coniferous canopy, and partially open canopy are presented for each event. Asterisks in the "D vs C" differences column represent significant ($P < 0.01$) differences between deciduous and coniferous throughfall pH. Asterisks in the "C/D vs P" differences column represent events in which both coniferous throughfall pH and deciduous throughfall pH differed significantly ($P < 0.01$) from precipitation pH.

				Throughfall							
	Precip	Precipitation pH		Deciduous pH		Coniferous pH		Partial canopy pH		Differences	
Date (2008)	mm	mean	SD	mean	SD	mean	SD	mean	SD	D vs C	C/D vs P
May 26	2.29	n/a		4.25	0.15	4.31	0.17	4.18	0.10		
May 27	1.27	n/a		4.29	0.32	4.11	0.39	4.30	0.26		
May 31	9.65	n/a		4.25	0.17	4.21	0.17	4.23	0.23		
June 8	1.78	n/a		5.95	0.20	5.82	0.23	5.78	0.30		
June 10	5.33	5.56	0.54	5.35	0.36	5.27	0.24	5.32	0.20		
June 13	32.51	3.71	0.06	4.69	0.41	4.45	0.40	4.19	0.18		*
June 17	3.05	4.82	0.02	6.06	0.29	5.86	0.48	5.82	0.36		*
June 25	4.32	n/a		5.86	0.23	5.61	0.33	5.75	0.22		
June 26	5.33	n/a		6.21	0.19	5.95	0.33	6.17	0.14	*	
June 28	20.32	5.02	1.04	5.47	0.36	5.40	0.30	5.45	0.21		*
July 2	7.87	5.22	0.17	5.74	0.27	5.78	0.24	5.63	0.18		*
July 9	9.14	4.75	0.15	5.99	0.44	5.79	0.34	5.73	0.30		*
July 13	25.65	5.23	0.56	5.29	0.35	4.96	0.42	4.93	0.32	*	
July 17	8.64	4.70	n/a	5.70	0.29	5.43	0.23	5.44	0.28	*	*
July 21	7.87	4.56	0.84	5.49	0.34	5.36	0.56	4.97	0.25		*
July 26	2.03	5.46	0.45	5.54	0.42	5.90	0.55	5.27	0.56		
July 30	3.81	4.79	0.06	5.83	0.34	5.36	0.42	5.45	0.48	*	*
August 9	2.79	4.45	0.10	5.18	0.57	4.94	0.53	4.64	0.34		*

all but four of the censuses. However, for the four census dates with differences (unpaired t-test, $P < 0.01$), coniferous throughfall was more acidic than deciduous throughfall (Table 1).

There were no significant relationships (Spearman-rank correlation) between throughfall pH and precipitation amount or time interval between precipitation events. However, pH was lower (unpaired t-test; $P < 0.001$) in the early portion of the growing season prior to full canopy leaf out which occurred on June 6–7, 2008 in the study site.

Similar to comparison of throughfall with rainfall, the comparison of throughfall pH based on overstory categories: coniferous (n=13), deciduous (n=18), and partially open canopy (n=15) also found significant differences (based on 18 individual ANOVA tests, $P < 0.0001$; post-hoc Tukey tests) for nine of the 18 rain events; three dates in mid-summer (June 13, 25, and 26) and the final six rain events during the study period (July 13–August 9, inclusive). The post-hoc tests showed that for all cases with significant differences, pH of the deciduous throughfall was least acidic; in five cases partially open canopy throughfall was most acidic, and in four cases coniferous throughfall was most acidic.

Species-specific throughfall pH values were generally similar throughout the growing season (Kruskal-Wallis, with Holm's [1979] correction method), with differences ($P < 0.01$) evident for only four (June 13, 26, July 21 and 26) of the 18 rainfall events. In general for those censuses with significant differences, two groups existed (with considerable overlap). Sugar maple throughfall, white spruce throughfall and balsam fir throughfall were statistically more acidic then paper birch throughfall, which was consistently higher than the other species. However, overall the pattern of differences was not consistent throughout the growing season.

DISCUSSION

For all measured rainfall events, precipitation pH in the study site was considerably more acidic than non-polluted rain (pH = 5.6) (Moore 1983), and slightly less acidic than the 4.3 reported for the early 1980s in a study site ≈130 km south of the present study (Morrison et al. 1992). As reported by Moore (1983), coniferous species generally increase throughfall acidity, while deciduous trees generally decrease throughfall acidity. The results from this study suggest that this may not always be the case; in half of the rainfall events both deciduous and coniferous canopies significantly increased pH, a pattern observed by Mahendrappa (1989). However, in the four rainfall events when deciduous and coniferous throughfall pH differed significantly from each other, the coniferous throughfall was more acidic than deciduous throughfall.

Moore (1983) observed that during long intervals between precipitation events deciduous canopies had a high buffering capacity and throughfall pH remained high. Such a pattern was not observed during the period of our study. This may be due to the fact the longest interval during the study period was 10 days, and the average period between rain events was 4.4 days, likely not enough time for dry deposition to accumulate. The marked decrease in throughfall acidity following full canopy leafout has been observed elsewhere (Shibata and Sakuma 1996), but typically the decrease in acidity following leafout would be most pronounced under deciduous canopies as leafless trees would not buffer rain water as it passes through a leafless canopy. Despite our lack of precipitation pH for the late-May events, clearly this pre-growing season pattern is worthy of further exploration as it may be an important variable affecting seed germination and first year seedling survivorship and growth particularly given the generally poorly buffered soils found in this region (Hutchinson et al. 1998).

Differences in throughfall acidity, controlled by overstory species composition, may be an important factor in creating a highly heterogeneous understory environment which might partly explain understory biodiversity (Wallrup et al. 2006). This is particularly the case given that understory light levels differ under conifer and deciduous canopies (Aubin et al. 2000, Bartemucci et al. 2006), differences exist between deciduous and conifer litter chemistry (Barras and Kellman 1998), and stemflow may be an important contributor to nutrient enrichment at the base of trees which would vary from species to species (Levia and Herwitz 2000). Ongoing research is investigating relative growth rates, carbon assimilation, and mortality rates of sugar maple under various canopy types in the study area.

ACKNOWLEDGEMENTS

For assistance in the field we are grateful to: Valerie Arkell, Christine Carrier, Josh Halpern-Givens, Ian Kenney, Jeff Krueger, Matt Kwit, Alicia Lisowski, and Shannon McCarragher. The authors would like to thank Ontario Parks and especially Bob Elliott and Carol Dersch at Lake Superior Provincial Park. Funding for this project was through a National Science Foundation grant (0724256) to DG and LR.

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