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Microtopography is a fundamental organizing structure of vegetation and soil chemistry in black ash wetlands

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We used a random walk study design as opposed to a hummock-hollow stratified sampling design because one of our hypotheses was that elevation above water table—not just microsite category—is an important predictor of understory richness (and overstory biomass and soil chemistry). Hence, a random walk design allowed us to sample the entire site elevation distribution instead of a potentially bimodal, clustered elevation distribution. To create the plot-level random walk design, we generated a sequence of 12 random integers between 1 and 10 that represented the number of steps to take between sampling points. Sampling point 1 was always the plot center, from which we proceeded to sample at a central point in the northern half of the plot (point 2 in S1). We then sampled at points orthogonal to this central point (e.g., points 3 and 4 in S1), and repeated this clockwise in cardinal directions (i.e., sample point at a central point along cardinal direction with two sample points orthogonal to the central point). To summarize, we randomly sampled 13 points per plot, with three plots per site, for 39 samples per site, and 390 points across all sites.

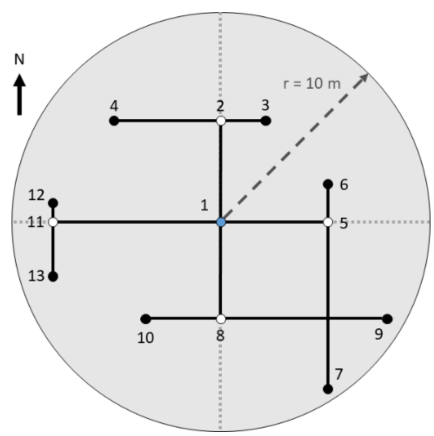


Figure S1 Example of plot-level (3 per site) quasi-random walk sampling design with 13 sampling points per plot. Points are the samples (numbers are the sequential sampling order) and black, solid line segments refer to walking path, where path length was determined by a sequence of 12 random generated integers. White points indicate central points along cardinal directions and blue point indicates plot center and first sampling point. Dotted lines demarcate circle quadrants, which this design allowed us to sample approximately equally.

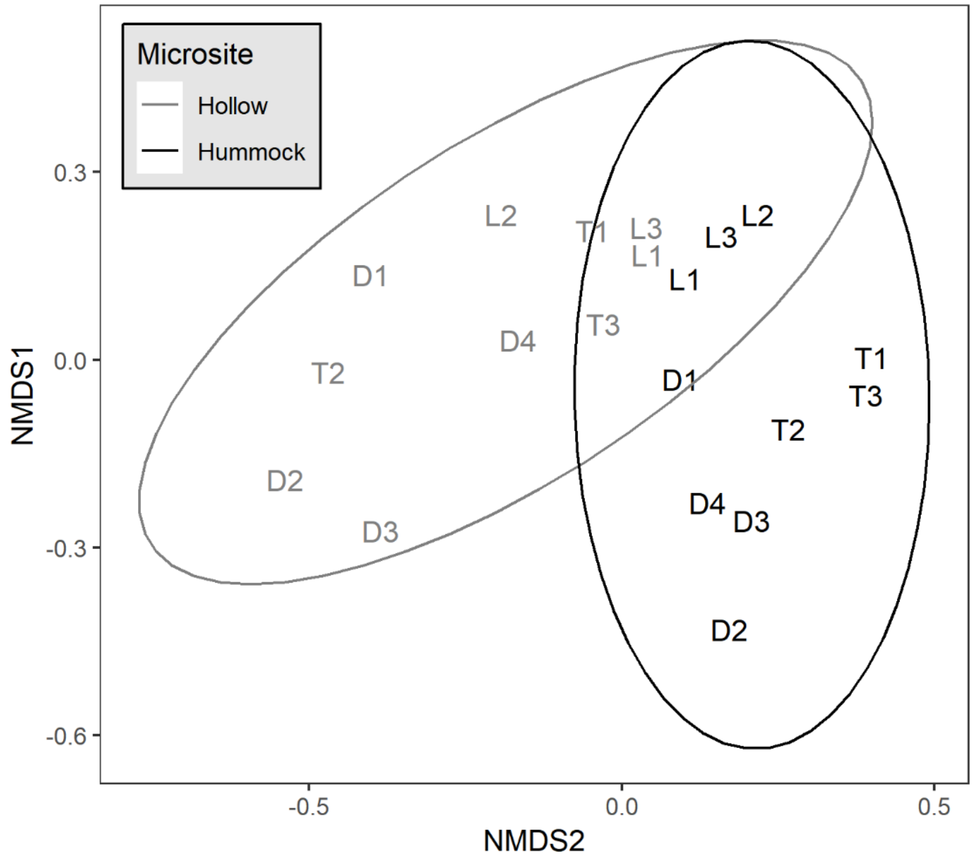
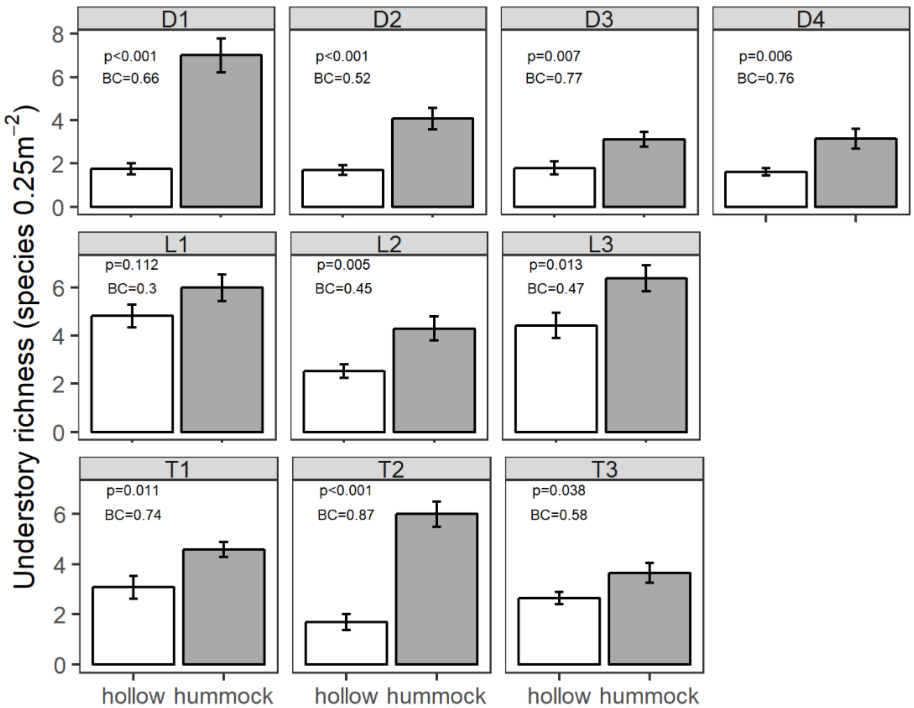


Figure S2: NMDS ordination of understory vegetation communities, grouped by sites (text labels) and microsites, with hummocks in black and hollows in grey. Ellipses indicate 95% credible intervals around the group centroid.

Table S1 Results of indicator species analysis for hummocks and hollows, including rare species

Microsite	Species	Specificity	Sensitivity	IV	p-val
Hummock	Climacium dendroides	0.91	0.59	0.53	0.001
	Rhizomnium magnifolium	0.83	0.60	0.50	0.001
	Rubus pubescens	0.83	0.42	0.35	0.001
	Funaria hygrometrica	0.84	0.40	0.34	0.001
	Carex trisperma	0.86	0.31	0.27	0.001
	Galium triflorum	0.89	0.24	0.22	0.001
	Aster lateriflorus	0.80	0.24	0.20	0.001
	Carex bromoides	0.91	0.16	0.14	0.001
	Acer rubrum	0.93	0.11	0.10	0.001
	Sphagnum angustifolium	0.97	0.11	0.10	0.001
	Maianthemum canadense	1.00	0.09	0.09	0.001
	Calla palustris	0.95	0.09	0.08	0.001
	Dryopteris carthusiana	1.00	0.08	0.08	0.001
	Pleurozium schreberi	0.98	0.08	0.08	0.001
	Carex retorsa	0.94	0.08	0.08	0.003
	Circaea alpina	0.93	0.08	0.07	0.001
	Trientalis borealis	0.89	0.05	0.04	0.005
	Corylus cornuta	0.95	0.04	0.04	0.006
	Rubus idaeus	0.99	0.04	0.04	0.004
Hollow	Calliergon cordifolium	0.72	0.61	0.44	0.001
	Lemna minor	0.98	0.27	0.27	0.001



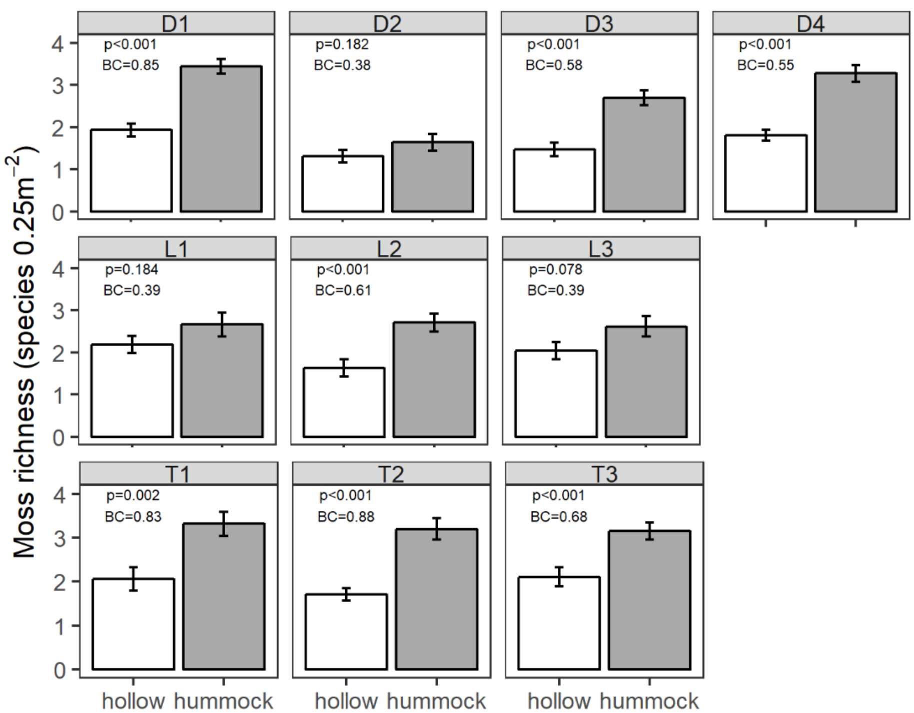


Figure S3 Understory species richness on hummocks and hollows for (top) mosses and (bottom) understory vascular plants for each study site. BC text values indicate Bray-Curtis dissimilarity, with a 0–1 range, spanning identical (0) to completely dissimilar (1) vegetation communities. p-values indicate Welch's two sample t-test significances.

Table S2 Forestry and hydrology metrics for sites

Site	Midstory basal area (m^2 ha^{-1})	Midstory Fraxinus fraction	Overstory basal area (m^2 ha^{-1})	Overstory *Fraxinus* fraction	Mean daily water table (m)	Median daily water table (m)	Mean conf. layer depth (cm)	Trees per hectare
L1	2.60	0.70	46.74	0.97	-0.26	-0.05	28.8	729
L2	1.60	0.45	44.79	0.92	-0.35	-0.05	19.6	650
L3	2.77	0.48	46.44	0.98	-0.37	-0.08	24.5	683
D1	1.12	0.4	39.59	0.98	0.01	0.09	28.9	1425
D2	2.94	0.95	39.97	0.97	-0.01	0.04	27.7	1600
D3	1.25	0.25	37.79	0.76	0.05	0.14	69.8	1067
D4	1.83	0.29	27.67	0.76	-0.01	0.00	60.6	700
T1	6.42	0.66	26.87	0.44	0.00	0.03	>150	1038
T2	1.53	0.52	25.69	0.91	-0.05	0.04	80.2	756
T3	3.10	0.48	23.31	0.74	-0.07	0.02	53.6	781

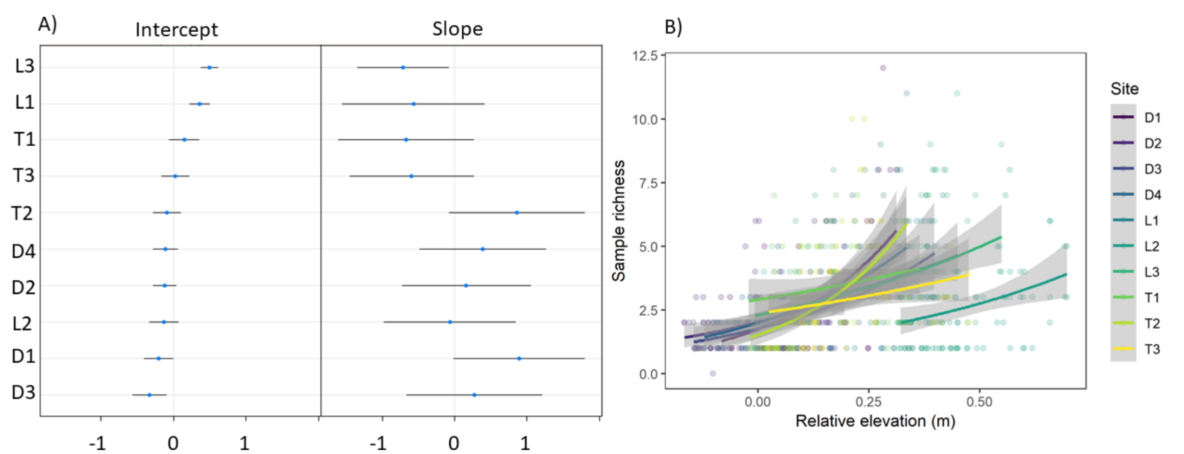


Figure S4 a) site-level random effects for intercept and slope for the richness-elevation GLMM , and b) raw data of overall (vascular and moss) richness-elevation relationships for each site with GLMMs fitted.

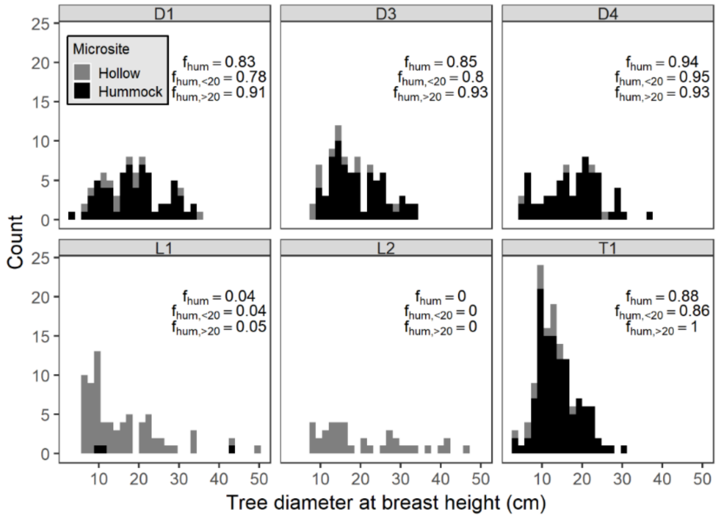


Figure S5: Stacked histograms of DBH size classes across sites. Black bars represent trees on hummocks and grey bars represent the remaining proportion of trees on hollows. Fraction of bars that are black indicate the fraction of trees that are on hummocks in that DBH size bin. Text refers to the fraction of observed trees that occupy hummocks at each sampling area for 1) the total sampling distribution (f_{hum}), 2) the sampling distribution for trees ≤ 20cm DBH ($f_{hum,<20}$), and 3) the sampling distribution for trees >20 cm DBH ($f_{hum,>20}$).

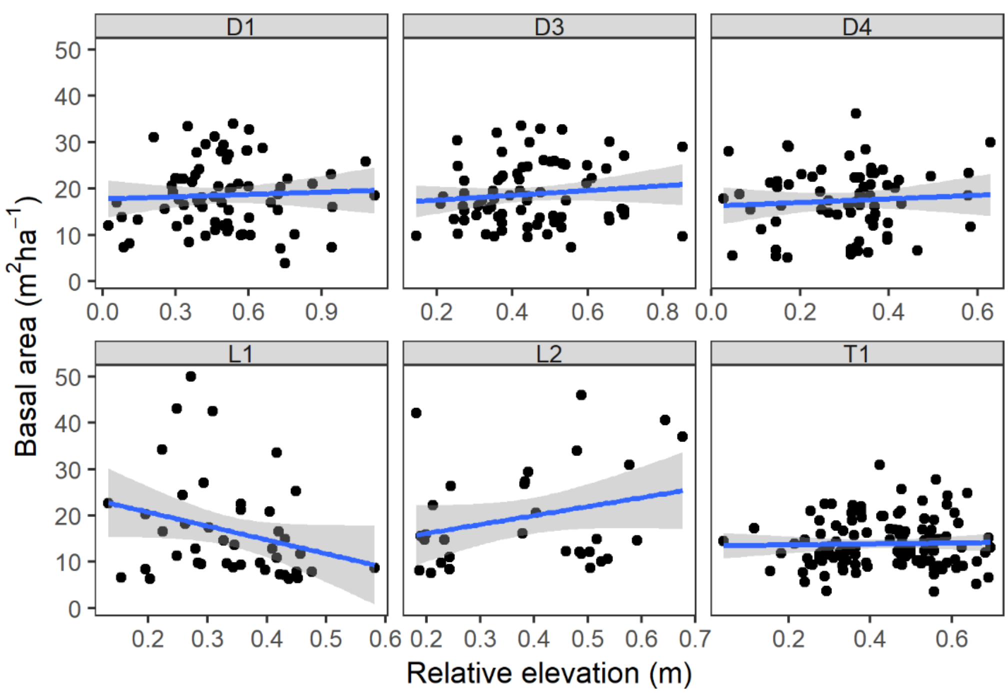


Figure S6 Site-scale individual tree base elevation versus individual tree basal area. Basal area was estimated from DBH measured with TLS using a circular model.

Table S3 Paired Levene tests for variance in soil chemistry concentrations among hydrogeomorphic categories. Bolded values are significant at p=0.05 level. Note that for most analytes, lowland sites (L) have lower variance than D or T sites.

Analyte	Comparison	Estimated differences in variances	Lower 95% confidence interval	Upper 95% confidence interval	Adjusted p-value
Ca^{2+}	L-D	-0.056	-0.931	0.819	0.987
	T-D	-0.182	-1.116	0.751	0.889
	T-L	-0.126	-1.021	0.768	0.941
Cl^{-}	L-D	-0.305	-0.473	-0.138	**0.000**
	T-D	-0.032	-0.206	0.141	0.901
	T-L	0.273	0.106	0.441	**0.000**
Mg^{2+}	L-D	0.283	-0.055	0.621	0.120
	T-D	0.771	0.418	1.125	**0.000**
	T-L	0.488	0.147	0.829	**0.002**
NO_3^{-}-N	L-D	0.505	0.324	0.687	**0.000**
	T-D	-0.069	-0.262	0.123	0.672
	T-L	-0.575	-0.754	-0.396	**0.000**
PO_4^{3-}-P	L-D	-0.453	-0.739	-0.167	**0.001**
	T-D	-0.309	-0.609	-0.009	**0.042**
	T-L	0.144	-0.144	0.432	0.467
SO_4^{2-}	L-D	0.788	0.045	1.530	**0.035**
	T-D	0.131	-0.652	0.913	0.918
	T-L	-0.657	-1.409	0.095	0.100
%C	L-D	0.900	-0.981	2.782	0.497
	T-D	-2.266	-4.240	-0.292	**0.020**
	T-L	-3.166	-5.039	-1.293	**0.000**
%N	L-D	-0.163	-0.300	-0.026	**0.015**
	T-D	-0.232	-0.374	-0.089	**0.000**
	T-L	-0.069	-0.206	0.068	0.464
C:N	L-D	-0.846	-1.266	-0.426	**0.000**
	T-D	-0.548	-0.985	-0.112	**0.009**
	T-L	0.298	-0.127	0.722	0.224

Table S4 Average (±standard deviation) soil extraction concentrations for hummocks and hollows across sites. Values are in mg L^{-1} except for %C, %N, and C:N, which are unitless.

Site	Microsite	%C	Ca^{2+}	Cl^{-}	C:N	Mg^{2+}	%N	NO_3^--N	PO_4^{3-}-P	SO_4^{2-}
D1	hol (18)	39.4±7.7	9.8±3.8	1±0.6	16.7±2.1	1.9±0.9	2.2±0.9	0.3±0.27	2.13±1.38	7.3±3.1
D1	hum (8)	38.2±11.2	10.2±5	1.3±0.7	15.8±2.4	2.2±0.8	2.3±1	0.33±0.59	2.69±1.58	7.4±3.3
D2	hol (7)	33.2±8.2	12.8±2.7	1.3±0.6	15±0.5	3.1±0.7	2.2±0.5	0.06±0.03	1.96±1.05	9.7±3.2
D2	hum (7)	38±8.1	13.2±4	1.8±0.8	15.4±1	3.2±0.8	2.5±0.6	0.06±0.05	2.9±1.03	9.6±2
D3	hol (3)	45±0.5	13.7±0.9	2.7±1.4	14.1±0.9	3.3±0.7	3.2±0.2	0.18±0.08	2.97±0.6	9.5±1.6
D3	hum (10)	45.4±2.1	14.6±2.8	2.5±0.8	17±2	4.1±1.1	2.7±0.2	0.1±0.12	3.82±0.76	9.4±2.4
D4	hol (7)	45.4±2.4	14.7±2	1.1±0.5	16.9±2.6	2.8±0.6	2.7±0.4	0.15±0.11	2.67±1.61	7.9±0.9
D4	hum (6)	48.2±1.2	12.9±3	2.5±0.7	19.2±2.2	4±0.5	2.5±0.3	0.03±0.01	5.83±1.33	7.3±2.2
L1	hol (18)	38±3.8	19.2±2.6	1.3±0.5	14.2±0.6	8±0.9	2.7±0.3	0.63±0.52	2.24±0.83	10.8±2.7
L1	hum (8)	38.7±3.1	23.4±2.6	1.3±0.3	14.1±0.5	8.9±0.7	2.7±0.2	0.53±0.25	2.62±0.83	9.8±2.4
L2	hol (12)	26.1±9.7	14.7±2.7	0.8±0.3	13.3±0.7	5.4±1	2±0.7	1.71±1.06	1.25±0.66	6.3±1.7
L2	hum (13)	32.5±12.8	15.1±6.4	1±0.4	13.3±1.1	5.5±2.1	2.1±0.6	1.51±1.33	1.33±0.82	5.4±2.6
L3	hol (17)	37.8±3.5	19.2±1.4	1.1±0.4	13.9±1	9±0.8	2.7±0.3	0.97±0.72	2.76±0.9	14.5±4.1
L3	hum (9)	39.9±5.6	20.8±2.4	1±0.3	14.8±2.2	9.4±0.9	2.7±0.2	0.5±0.54	3.09±0.82	10.5±5
T1	hol (14)	47.2±0.9	20.6±3	1.3±0.3	16.5±0.9	8.7±1.7	2.9±0.2	0.15±0.06	3.21±0.65	10.3±2.5
T1	hum (12)	46.4±1	22.6±2.5	2.6±0.6	18.2±2.4	10±2	2.5±0.4	0.15±0.13	3.65±0.93	8.6±2.1
T2	hol (15)	44.9±3.3	27.8±3.4	1.4±0.5	14.9±0.9	7.9±1.2	3±0.2	0.11±0.05	3.15±0.78	11.7±2.9
T2	hum (11)	39.4±4.5	31.7±2	2.3±0.6	15.2±0.8	9.2±1.2	2.6±0.3	0.1±0.04	4.63±1.03	10.8±2.9
T3	hol (6)	43.2±1	15.5±4.6	1.4±0.7	16±1.1	3.5±2	2.7±0.1	0.12±0.04	3.54±1.54	10.6±1.9
T3	hum (7)	43.5±1.7	16.1±1.6	1.5±0.3	17.4±1.6	5.9±2.2	2.4±0.3	0.09±0.07	3.99±0.84	9.1±1.1

Figure S7 Scaled soil extract concentrations versus relative elevation above water table for all sites and analytes. Concentrations were scaled and centered to allow easy comparison across sites and geomorphic categories. Best-fit linear regressions with 95% confidence shading are shown. Site are split by geomorphic category in columns and by analyte in rows.

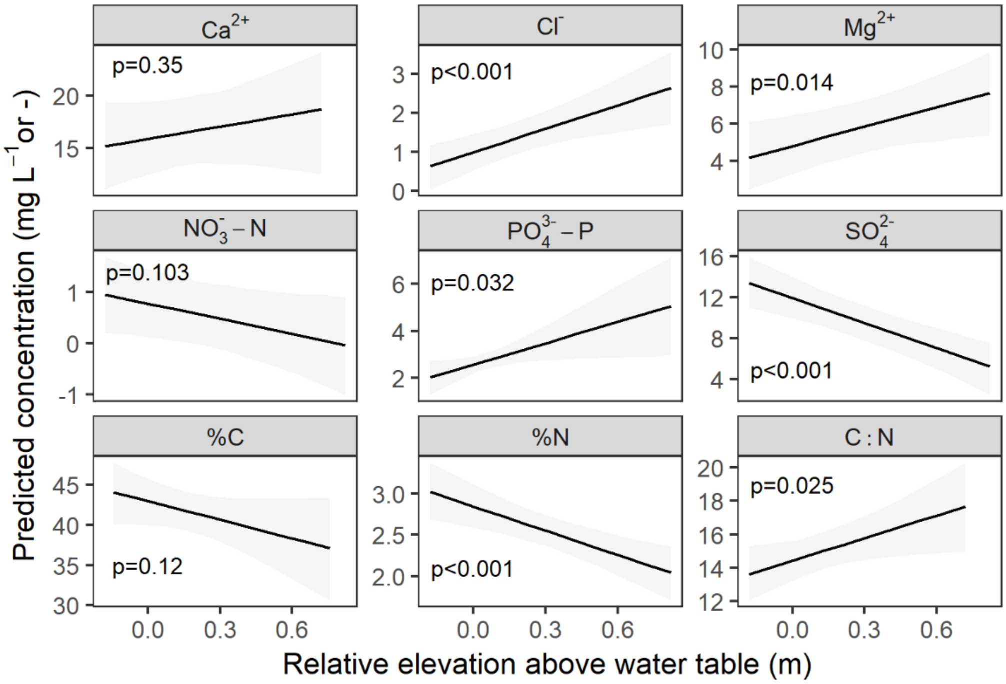


Figure S8: Linear mixed effects model-predicted soil extract concentration as a function of elevation above mean water table, split by analyte, without random site effects. Shaded ribbons indicate 95% confidence intervals about the estimate. Text are p-values for linear mixed effects model regressions.

Table S5 Linear mixed effect model results for soil chemistry analytes versus relative elevation above water table with site as a random effect.

Solute	Effect	Term	Estimate	SE	Z-score	P(Z>z)
%C	Fixed	Intercept	42.9	1.51	28.45	<0.001
		z	-7.7	4.93	-1.56	0.120
	Random	SD Intercept	2.9			
		SD z	9.6			
Ca^{2+}	Fixed	Intercept	15.9	1.73	9.19	<0.001
		z	3.9	4.19	0.94	0.350
	Random	SD Intercept	4.8			
		SD z	10.4			
Cl^{-}	Fixed	Intercept	1	0.23	4.27	<0.001
		z	2	0.6	3.36	0.001
	Random	SD Intercept	0.6			
		SD z	1.3			
C:N	Fixed	Intercept	14.4	0.61	23.72	<0.001
		z	4.5	1.99	2.27	0.025
	Random	SD Intercept	1.5			
		SD z	5.2			
Mg^{2+}	Fixed	Intercept	4.8	0.79	6.12	<0.001
		z	3.5	1.4	2.48	0.014
	Random	SD Intercept	2.3			
		SD z	3.2			
%N	Fixed	Intercept	2.8	0.13	21.71	<0.001
		z	-1.0	0.28	-3.54	0.001
	Random	SD Intercept	0.3			
		SD z	0.0			
NO_3^{-}-N	Fixed	Intercept	0.8	0.34	2.25	<0.001
		z	-1	0.6	-1.64	0.103
	Random	SD Intercept	1			
		SD z	1.4			
PO_4^{3-}-P	Fixed	Intercept	2.6	0.18	14.39	<0.001
		z	3	1.41	2.16	0.032
	Random	SD Intercept	0.2			
		SD z	4			
SO_4^{2-}	Fixed	Intercept	11.9	1.04	11.45	<0.001
		z	-8.1	1.77	-4.57	<0.001
	Random	SD Intercept	2.7			
		SD z	0			