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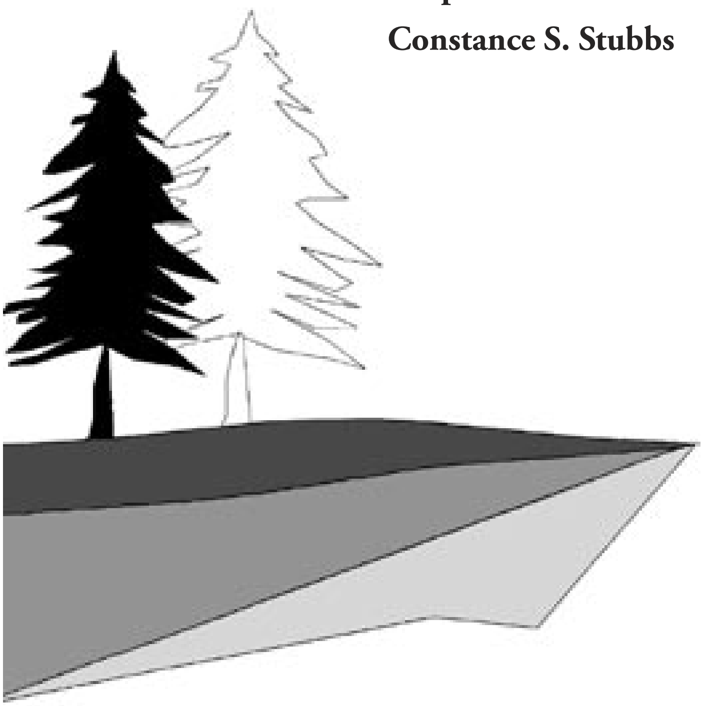

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Element Concentrations in Maine Forest Vegetation and Soils

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ABSTRACT

Bioaccumulation of trace metals in plant tissues can present a health risk to wildlife, and potentially to humans. The Passamaquoddy Tribe in Maine was concerned about health risks of cadmium (Cd) because of a health advisory for moose liver and kidney consumption due to high Cd levels. In addition to Cd, this study evaluated concentrations of aluminum (Al), calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), nickel (Ni), phosphorus (P), lead (Pb), and zinc (Zn) in four common terrestrial moose-browse species, associated forest soils, and two species of aquatic vegetation on Passamaquoddy tribal land in eastern Maine. Elements were organized into three groups (A, B, and C) based on the patterns of concentration differences in vegetation among ecosystem types. Elements in group A included the nutrients Ca, K, Mg, and P and showed a pattern of significantly higher concentrations in hardwood and aquatic vegetation compared to softwoods. Group B elements included the four metals, Cd, Cu, Mn, and Zn, and exhibited a pattern of higher concentrations in hardwoods compared to softwoods and aquatic vegetation. Group C elements did not fit the patterns of group A or group B and included the remaining four elements Al, Fe, Ni, and Pb. Total O horizon soil concentration means for all elements, except Ni and Pb, were significantly higher in hardwood compared to softwood forest types. This study provides uncommon and important baseline vegetation and soil trace metal concentrations from a remote region in Maine of interest to environmental professionals.

INTRODUCTION

Trace metals are elements found naturally in aquatic and terrestrial ecosystems at low concentrations from processes such as the weathering of parent material, volcanic eruptions, and forest fires (Nriagu and Pacyna 1988). Some trace metals, such as zinc (Zn), are essential nutrients (Taiz and Zeiger 2002) while others, such as lead (Pb), have no known biological function (Kabata-Pendias 2001). Human activities, such as mining and smelting, combustion of fossil fuels, incineration of waste, and land application of sewage sludge, have significantly increased inputs of trace metals into the environment (Nriagu and Pacyna 1988; Adriano 2001; Kabata-Pendias 2001; Pacyna and Pacyna 2001).

Trace metals tend to accumulate in surface soils because of the strong complexation of metals by organic soil materials (Herrick and Friedland 1990). Soil concentrations in the vicinity of point sources, such as smelters, are often elevated and decrease significantly with distance from the source (Lobersli and Steinnes 1988; Allen-Gil et al. 2003; Shparyk and Parpan 2004). Deposition of trace metals via precipitation or dry deposition from long-range atmospheric transport may also contribute to soil burdens (Lindberg and Harris 1981; Galloway et al. 1982; Hernandez et al. 2003). The increasing availability of trace metals in soils as a result of anthropogenic inputs has resulted in greater uptake of trace metals by plants (Tyler 1972; Kabata-Pendias 2001). Bioaccumulation of trace metals in plant foliage and branch tips presents a health risk to wildlife, and potentially to human beings, if these plant tissues and wildlife are consumed (Pacyna and Pacyna 2001).

Even though Maine is a relatively rural state, there are concerns about trace metals such as cadmium (Cd), mercury (Hg), and lead (Pb). For example, there is a health advisory in Maine for the consumption of moose livers and kidneys due to high concentrations of Cd (Gustafson et al. 2000; Maine Department of Inland Fish and Wildlife 2005). Determining the levels of risk involved and developing management and policy options to address concerns about trace metals in the environment often require background information on past and present trace metal concentrations and contents in soils. Unfortunately, these data are scarce and are often lacking for adequate temporal and spatial assessments to be carried out. As a result of research described in McGee (2006), data were developed on trace metals in a forested landscape in eastern Maine. The objectives of this publication are to provide data on element concentrations in forest soils, terrestrial foliage, tree branch tips, and aquatic vegetation for sites in eastern Maine that were

developed from a study of trace metals in the environment. These data are valuable for environmental professionals when assessing the health of an ecosystem and the levels of contamination in both point and non-point-source environments.

MATERIALS AND METHODS

Sites

Six terrestrial and two aquatic sites were established for vegetation sampling on Passamaquoddy Tribal land in T4 ND Township, henceforth T4 ND, in Hancock County, ME, in the summer of 2004. The terrestrial sites were forested uplands consisting of three hardwood and three softwood sites. Aquatic vegetation was from two lakes, Side Pistol Pond and Middle Chain Lake. The hardwood sites were all within 3 km of Middle Chain Lake and the softwood sites were within 5 km of Side Pistol Pond. Terrestrial sites were selected on the basis of forest type, stand age, stand composition, topography, and accessibility. Three species were selected to represent the hardwood forest type: red maple (*Acer rubrum*), big tooth aspen (*Populus grandidentata*), and paper birch (*Betula papyrifera*). One species was selected to represent the softwood forest type: balsam fir (*Abies balsamea*). The lakes were selected based on the presence of pondweed (*Potamogeton* spp.) and yellow water-lily (*Nuphar advena*), the target species for aquatic vegetation.

Softwood stands were two-aged, closed-canopy spruce-fir forests subjected to selective cutting between 1995 and 1998. These stands appeared to have been in a continuous softwood cover type based on existing stand characteristics. Hardwood stands were regenerated on clearcuts that resulted from harvesting a mixed beech forest with a minor component of softwoods, between 1988 and 1992. Soils were Aquic Haplorthods derived from dense basal till.

Sample Collection

At each terrestrial site, a 0.2-ha rectangular study plot was established and subdivided into a grid system of 80 numbered 5-by-5-m subplots. At each plot we sampled 15 replicates of each species from different subplots. One field duplicate was collected for each species at every plot. Subplots within the grid were randomly selected for sampling. One of each target species that met our criteria was sampled in the selected subplot. Sample tree criteria were that trees were in good health, at least 2.54 cm dbh, and had foliage on at least three branches between 1 and 2 m above ground. If a particular target tree species meeting the established criteria was

not present within the area of the selected subplot, then random subplot selection continued until the established number of samples was collected for all target tree species.

Foliage and branch tips were collected manually from at least three branches per tree at heights between 1 and 2 m. A minimum of 20 g dry weight foliar or branch tip tissue was collected. A soil sample from the O horizon was collected at each tree, mid-way between the bole and the canopy drip line. The O horizon sample was collected using a 15-by-15-cm template to guide the quantitative excavation of material to the surface of the underlying mineral soil. Soil sample depth, subplot description, time, and weather conditions were recorded in the field.

At each of the two lakes, submerged aquatic vegetation was sampled at 5-m intervals in a counter-clockwise direction from our initial access point to the lake. Aquatic vegetation was collected in the littoral zone from a canoe. Samples were collected manually with gloved hands by reaching into the water and breaking the stem of the plant approximately 20 cm below the water surface. To achieve the target dry weight of 20 g per sample, several plants of each species present at each sampling point were combined to create one sample. Sampling continued until 15 replicates were collected for both target species of aquatic vegetation.

During July and August 2004, we collected foliage from the three hardwood sites, soils from both hardwood and softwood sites, and all aquatic vegetation samples. Trees were tagged during the summer sampling season where foliage and soil samples were collected. Branch tips were sampled during the following winter. During December 2004 and January 2005, we returned to the same subplots, located the tagged trees, and collected hardwood and softwood branch tips (including needles).

Contact with samples was minimized to avoid contamination. Laboratory gloves were worn at all times during sample collection and new gloves were used for each sample. Vegetation samples (including hardwood foliage, branch tips, and aquatic vegetation) were rinsed with deionized water at the time of sampling. Coniferous branch tips were rinsed with deionized water in the laboratory. All samples were placed in new pre-labeled plastic gallon-size Ziploc® bags. All instruments used in the collection of samples were wiped clean using Kimwipes® soaked in 10% trace metal grade nitric acid (HNO_3), and then rinsed three times on each side with deionized water prior to use and between all sample collections in the field. Samples were stored on ice in coolers until delivery to the laboratory at the University of Maine, where they were stored in a laboratory refrigerator until processed for analysis.

Sample Preparation and Analyses

All samples were oven-dried at 70°C in a forced draft oven for a minimum of 24 hours. Vegetation samples were ground in a Wiley Mill using a 20-mm stainless steel mesh screen. Soil samples were sieved through a 6-mm stainless steel sieve (Fernandez et al. 1993, 2003).

Vegetation samples weighing 0.25 g were digested in 10 mL HNO_3 using a CEM® MARS microwave oven and brought up to a volume of 100 mL with deionized water (EPA Method 3051A 1998). Soil samples weighing approximately 0.4 g were microwave digested in 8 mL of 1:3 aqua regia (1 part HNO_3: 3 parts HCl) and brought up to 100 mL final volume with deionized water (EPA Method 3051A 1998). All samples were analyzed by high resolution inductively coupled plasma mass spectrometry (HR-ICP-MS, Finnigan Element 2) for aluminum (Al), Cd, copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), Pb, and Zn. Samples were also analyzed by inductively coupled plasma optical emission spectrometer (ICP-OES) for calcium (Ca), potassium (K), magnesium (Mg), and phosphorus (P).

Soil organic matter was estimated by loss-on-ignition (LOI) (Fernandez et al. 1993, 2003). Samples were dried for 24 hours in a forced draft oven at 70°C and then ignited for 12 hours at 450°C in a muffle furnace. Soil pH was determined using a ratio of 1:10 soil to 0.01 M $CaCl_2$ solution.

Quality Assurance

We analyzed at least one laboratory duplicate, one laboratory control sample (NBS SRM 1575a or MESS-3), and one laboratory blank with every 10 samples analyzed and a matrix spike with every 20 samples analyzed.

Statistical Analyses

All data were natural log transformed to approximate the assumptions of normal distribution of error and constant variance. SYSTAT® version 110 was used for the statistical analyses. Statistical comparisons of element concentrations among vegetation species and sample types (foliage, branch tips, and soil concentrations) were determined by analysis of variance (ANOVA) at a 95% confidence level. A Tukey's multiple range test was used to determine significant differences among means. Statistical relationships between soil and foliage or branch tip metal concentrations were determined by analysis of covariance (ANCOVA) at a 95% confidence level.

RESULTS AND DISCUSSION

Vegetation

Plants take up essential and non-essential elements through roots and foliage if they are present in bioavailable forms in the environment. The distribution of elements within plants varies and is highly species and element specific (Kabata-Pendias 2001). All of the elements reported in this study are essential plant mineral nutrients with the exception of Al, Cd, and Pb, which have no known essential biological function. Table 1 shows descriptive statistics for element concentrations in plant tissue by species and sample tissue type (branch tip or foliage). We found some significant differences among plant species for all elements, but no universal patterns of species difference in element concentrations. There were few elements that resulted in unique differences from all other elements, and in the assessment of these data we found that certain groups and patterns emerged. Therefore, we organized the data by evaluating aggregated categories that resulted in contrasts among three ecosystem types (hardwood vs softwood vs aquatic) and between two plant tissue types for hardwood trees (branch tip vs foliage).

We averaged element concentrations from foliage and branch tips of big tooth aspen, paper birch, and red maple to represent hardwood species, of pondweed and yellow water-lily to represent aquatic vegetation, and balsam fir was the single species representing softwoods. Analyses on balsam fir were conducted on the combined needle and branch tissue. We compared concentrations for all elements among the hardwood, softwood, and aquatic vegetation types. Figures 1 through 3 show hardwood, softwood, and aquatic vegetation means for all elements organized by three groups we called A, B, and C that reflect distinct patterns of differences among the vegetation types.

Figure 1 shows results for group A, which includes the elements Ca, K, Mg, and P. Elements in this group are all essential plant macronutrients, which include the dominant base cation nutrients Ca, K, and Mg in soil-plant systems, and the critical essential nutrient P, which is often the second most commonly limiting nutrient after nitrogen (N) in forested ecosystems. There were significantly higher concentrations of group A elements in hardwood and aquatic vegetation compared to softwoods. This pattern is consistent with the common expectation found in the ecological literature that herbaceous and deciduous vegetation is of higher ecological "quality," partly as a function of higher concentrations of essential macronutrients. For example, Ohlson and Staaland (2001) reported generally higher

Table 1. Vegetation element concentration means ± SE (mg kg^{-1} dry weight) by species and sample type.

	Al	Ca	Cd	Cu	Fe	K
Aspen branch tips	13 ± 3e	12983 ± 1392bc	1.68 ± 0.20ab	11.75 ± 0.95a	32 ± 2d	8760 ± 1187ed
Aspen foliage	22 ± 2d	17138 ± 788a	1.97 ± 0.20a	9.16 ± 0.42ab	60 ± 5c	15930 ± 731bc
Birch branch tips	11 ± 2e	8047 ± 450d	1.06 ± 0.06bc	7.92 ± 0.79ab	29 ± 2d	6311 ± 818ef
Birch foliage	21 ± 1d	13043 ± 355b	1.14 ± 0.08b	7.23 ± 0.34b	60 ± 2c	14156 ± 527c
Maple branch tips	9 ± 5e	10999 ± 763bcd	0.74 ± 0.08c	6.09 ± 0.59b	18 ± 1d	5309 ± 721f
Maple foliage	9 ± 1e	9174 ± 388d	0.37 ± 0.04d	8.93 ± 1.04ab	49 ± 4c	9412 ± 327d
Balsam Fir	196 ± 11b	5375 ± 205e	0.10 ± 0.01f	3.08 ± 0.07c	36 ± 2d	6231 ± 135e
Water Lily	53 ± 6c	17117 ± 515a	0.14 ± 0.01e	0.67 ± 0.08e	145 ± 13b	19612 ± 1355ab
Pondweed	321 ± 41a	9934 ± 322cd	0.11 ± 0.01ef	1.88 ± 0.22d	881 ± 130a	22770 ± 1016a
	Mg	**Mn**	**Ni**	**P**	**Pb**	**Zn**
Aspen branch tips	1319 ± 110d	100 ± 8g	1.45 ± 0.25abc	2164 ± 250b	0.96 ± 0.14b	126 ± 11c
Aspen foliage	2667 ± 95b	390 ± 23e	2.47 ± 0.47ab	2921 ± 112a	0.30 ± 0.08c	330 ± 25b
Birch branch tips	1091 ± 65d	425 ± 36de	7.08 ± 5.05a	2062 ± 140b	2.02 ± 0.28a	279 ± 29b
Birch foliage	2965 ± 99b	1914 ± 160a	1.66 ± 0.26bc	3199 ± 148a	0.82 ± 0.05b	431 ± 29a
Maple branch tips	752 ± 42e	552 ± 44cde	0.71 ± 0.13de	1478 ± 132b	0.73 ± 0.07b	52 ± 7de
Maple foliage	2040 ± 71c	1156 ± 142b	0.65 ± 0.08e	2943 ± 346a	0.29 ± 0.05c	61 ± 6d
Balsam Fir	1045 ± 34d	625 ± 41cd	3.63 ± 1.39a	1691 ± 51b	0.98 ± 0.24b	42 ± 2e
Water Lily	1080 ± 37d	247 ± 22f	0.46 ± 0.09e	3060 ± 261a	0.82 ± 0.06ab	22 ± 1f
Pondweed	3960 ± 190a	762 ± 86c	1.01 ± 0.07cd	2641 ± 137a	0.94 ± 0.10ab	41 ± 2e

*Means among species followed by the same letter are not significantly different at $p = 0.05$.

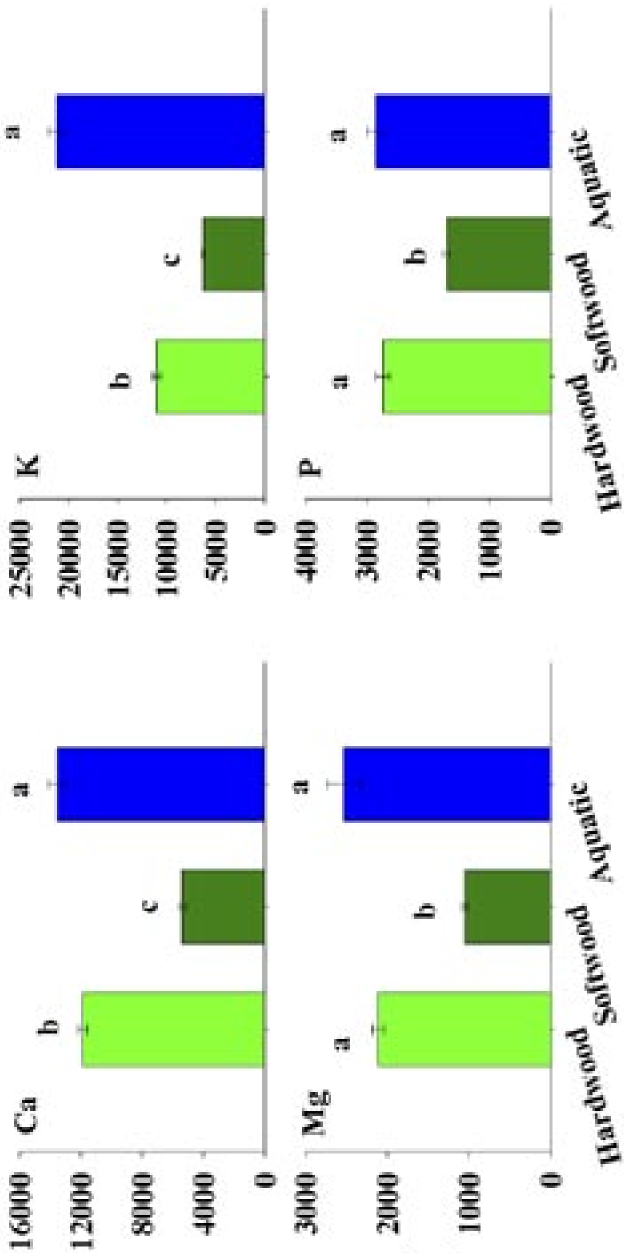

Figure 1. Group A element means ± SE (mg kg-1) that are all essential nutrients with hardwood and aquatic vegetation nutrient concentrations greater than softwoods.

element concentrations in several hardwood species, including downy birch (*Betula pubescens*) and European aspen (*Populus tremula*), compared to Scots pine (*Pinus sylvestris*) for all elements. Other examples in the literature of higher foliar nutrient concentrations in hardwoods than in softwoods can be found in Young and Guinn (1966), Alriksson and Eriksson (1998), Aerts and Chapin (2000), and Hagen-Thorn et al. (2004).

Group B elements include Cd, Cu, Mn, and Zn, and there were higher concentrations of these elements in hardwoods compared to softwoods or aquatic vegetation (Figure 2). The elements in this group differ from those in group A in that the foliar nutrient concentrations of these elements were also significantly lower in aquatic vegetation than in hardwoods. The elements in this group are often referred to as trace metals, but are also essential plant micronutrients, with the exception of Cd. They are also often considered heavy metal pollutants when concentrations are high. Although the mean concentration of Mn for hardwoods was not significantly higher than for softwoods, the numerical pattern was similar to the elements in group B. Our results for group B agree with reports of bioaccumulation of trace metals in hardwood species by other authors (Ohlson and Staaland 2001; Madejon et al. 2004).

The pattern in group B of low trace metal concentrations in aquatic vegetation, as opposed to the high nutrient concentrations evident in group A, may be due to physiological differences between aquatic and hardwood species, which results in a lower tolerance to metals by aquatic species. Trace metal concentrations in aquatic vegetation are variable among species and are dependent on factors such as available concentrations in water, sediment, and air (Sparling and Lowe 1998; Deng et al. 2004; Klink 2004). The potential for high concentrations of trace metals in some species of aquatic vegetation has been reported in laboratory and point-source studies (Deng et al. 2004; Kamal et al. 2004; Miretzky et al. 2004). At our sites, aquatic vegetation may have had less exposure to bioavailable forms of trace metals compared to terrestrial vegetation. The underlying mechanisms for these group differences deserve further study.

Figure 3 shows group C, which is the "catchall" group for elements that did not fit the patterns of groups A or B. Group C includes the remaining four elements, Al, Fe, Pb, and Ni. Aluminum and Fe are typically in high concentrations in these soils, and Fe is an essential plant nutrient. Lead and Ni are trace metals; only Ni is a micronutrient for plants.

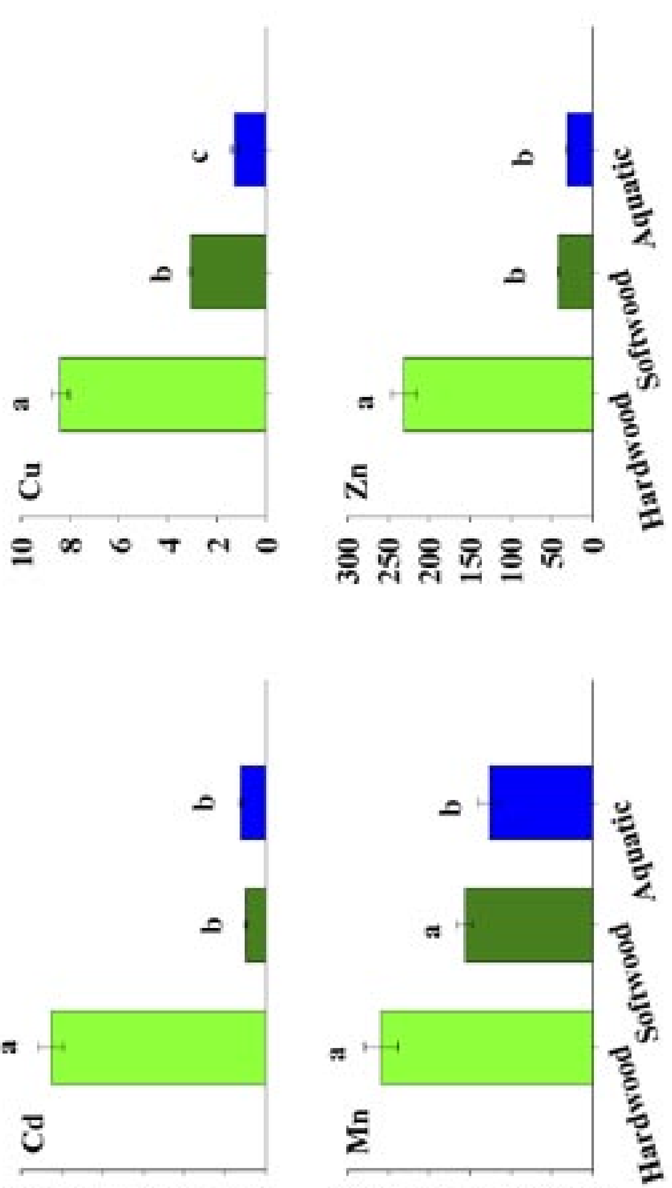

Figure 2. Group B element means ± SE (mg kg-1) that are all trace metals with hardwood vegetation concentrations greater than softwood, and aquatic vegetation.

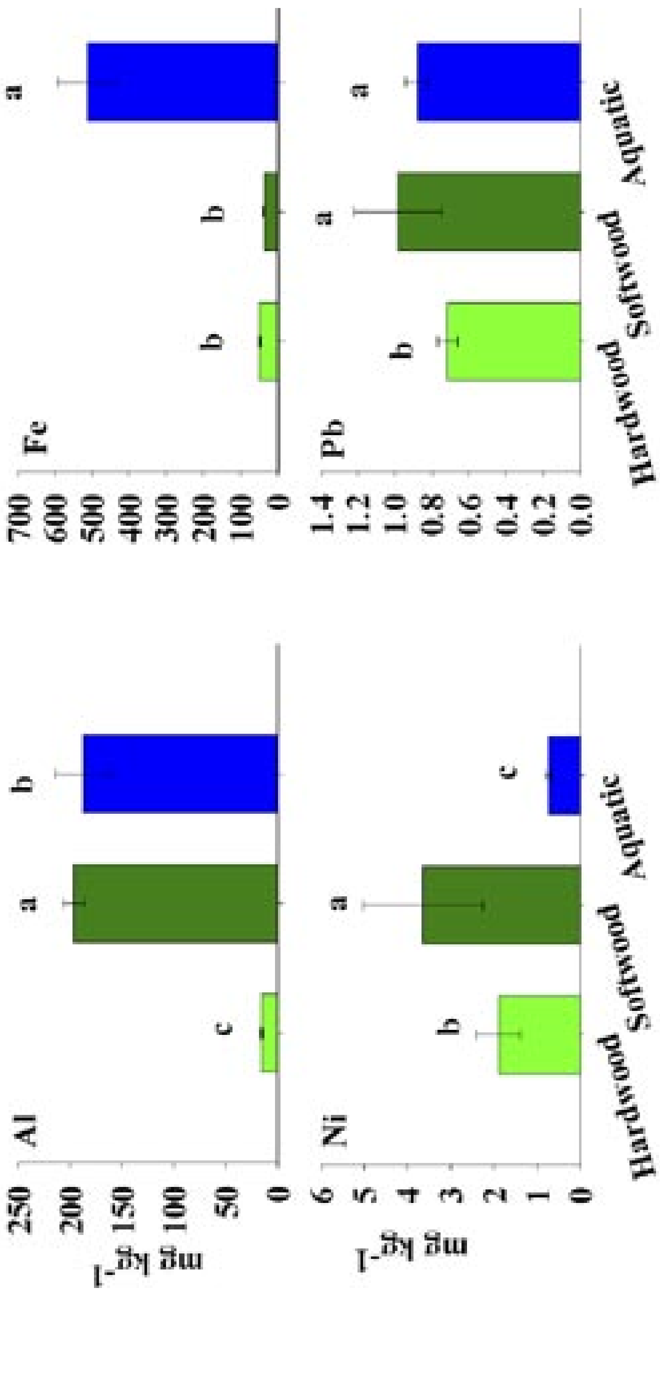

Figure 3. Group C element means ± SE (mg kg^{-1}) for hardwood, softwood, and aquatic vegetation element concentrations.

Aluminum, Pb, and Ni had a group characteristic unlike the other elements in that they exhibited significantly higher concentrations in the softwood species, balsam fir, compared to hardwoods. Softwoods in northern New England forests often exhibit higher concentrations of foliar Al, which may reflect greater mobility of Al in the highly acidic soils created by softwood forests and physiological tolerances of these species to Al uptake. Young and Guinn (1966) also observed higher concentrations of Al in balsam fir compared to white birch, aspen, and red maple foliage at sites in Maine. Higher concentrations of Ni and Pb in balsam fir, compared to hardwoods, may also indicate greater availability in soils in addition to more efficient capture of atmospheric deposition in a softwood forest canopy that results in direct incorporation of these metals into foliar tissues or soil enrichment through litterfall (Miller et al. 1993; Weathers et al. 2000).

The element Fe did not fit the pattern of the group C elements except in its difference from the patterns of either group A or group B. The significantly higher Fe concentration in aquatic vegetation compared to both hardwood and softwood vegetation was unique among all elements. This may be due to the reducing environment of aquatic sediments, which resulted in more labile forms of Fe (Kalff 2002), and thus more uptake by aquatic plants. In terrestrial ecosystems, soluble forms of Fe are generally low compared to total soil Fe content (Kabata-Pendias 2001). It is also unlikely that concentrations of Fe in aquatic vegetation in this study were the result of sediment "contamination" of the tissue samples, since the soil Fe/Al was ~0.7, whereas the aquatic vegetation Fe/Al was 2.7, clearly indicating that a different mechanism for tissue Fe accumulation was involved beyond simple uptake. Indeed, if sediments were reducing, it would be expected to deplete rather than enrich pools of Fe.

We compared element concentrations in branch tips vs foliage for big tooth aspen, paper birch, and red maple. The concentrations of many elements, including Mn, Fe, Mg, Zn, K, and P, were significantly higher in hardwood foliage than in branch tips. Aluminum and Ca were significantly higher in big tooth aspen and paper birch foliage compared to branch tips, although no significant differences were observed for red maple. Madejon et al. (2004) also observed higher concentrations of several trace elements in white poplar (*Populus alba*) foliage compared to branch tips. There were no patterns evident for Cd and Ni concentrations in foliage vs branch tips. Lead concentrations were significantly higher in branch tips than foliage for all hardwood species. Our Pb data agree with the

findings of Smith and Siccama (1981) and Friedland and Johnson (1985) who also observed higher Pb concentrations in deciduous branch tips compared to foliage in the northeastern U.S.A.

Soils

Table 2 shows descriptive statistics for soil pH, LOI, and element concentration means for all elements by forest type. Softwood soils had significantly lower soil pH than hardwoods, and significantly higher organic matter content as estimated by LOI. These relationships are consistent with the character of these forest types (Herrick and Friedland 1990), with lower pH in softwoods being driven by the larger pool of reactive functional groups on organic colloids and abundant weak organic acidity. All element concentrations, except Pb and Ni, were significantly higher in hardwood compared to softwood soils. Lead concentrations were significantly higher in softwood than hardwood soils and Ni concentrations were not significantly different between forest types.

There were likely greater litter inputs of nutrients and trace metals to soil from hardwood compared to softwood tree species (Figures 1 and 2) as a result of higher rates of mineralization and higher concentrations of these elements in litter (Lambers et al. 1998; Berg and Laskowski 2006). Some tree species appear to take up certain metals more than other tree species. For instance, bioaccumulation of Zn by birch trees has been reported in the literature (Gosz et al. 1972; Moyse and Fernandez 1987) and likely accounted for the high soil concentrations of Zn in hardwoods, since birch trees were a major component of our mixed hardwood sites. Lead concentrations in softwood soils were twice the concentrations in hardwood soils (Table 2). Higher Pb concentrations in softwoods compared to hardwoods agreed with Pb forest type differences reported by Friedland et al. (1984), but likely represents the influence of differences in atmospheric deposition rather than root uptake of Pb. As discussed for vegetation, softwood forests typically have higher rates of atmospheric deposition than hardwood forests because they have a greater foliar surface area for atmospheric interception (Miller et al. 1993). We attributed the high hardwood soil concentrations of Al and Fe to a greater mixing of mineral soil in the hardwood soil fine earth fraction (Table 2). High concentrations of both Al and Fe are expected in mineral soil particles compared to organic matter, and Table 4 shows that both elements were strongly negatively correlated with LOI for both forest types. This means that as the percentage of organic matter in the O horizon decreases, indicating more mineral soil mixing, the concentration Al and Fe increases.

Table 2. O horizon element concentration means ± SE (mg kg^{-1} dry weight) by forest type.

	pH ($CaCl_2$)	LOI (%)	Cd	Pb	Mn	Fe	Zn	Ni
Hardwood	4.6 ± 0.05	66 ± 2	1.00 ± 0.05a	21.36 ± 150a	1562 ± 104a	4900 ± 309a	167 ± 9a	4.11 ± 0.15a
Softwood	3.36 ± 0.05	88 ± 1	0.50 ± 0.02b	54.83 ± 3.48b	305 ± 47b	2462 ± 246b	55 ± 3b	4.27 ± 0.16a
			Al	Cu	Ca	K	Mg	P
Hardwood			6136 ± 390a	8.30 ± 0.19a	9638 ± 383a	1710 ± 39a	1103 ± 42a	1198 ± 26a
Softwood			3513 ± 306b	4.94 ± 0.22b	5105 ± 329b	1231 ± 72b	524 ± 49b	988 ± 42b

Table 3. O horizon element content ± SE (kg ha^{-1}) by forest type.

	Fine Earth	Organic Matter	Cd	Pb	Mn	Fe	Zn	Ni
Hardwood	29935 ± 2656a	19210 ± 1609a	0.03 ± 0.00a	0.81 ± 0.11a	43 ± 5a	162 ± 23a	4.03 ± 0.34a	0.12 ± 0.01a
Softwood	37800 ± 4311a	33834 ± 4174b	0.02 ± 0.00a	2.00 ± 0.20b	10 ± 2b	83 ± 9a	2.11 ± 0.26b	0.15 ± 0.01b
			Al	Cu	Ca	K	Mg	P
Hardwood			209 ± 33a	0.24 ± 0.02a	254 ± 22a	48 ± 4a	30 ± 3a	33 ± 3a
Softwood			121 ± 13a	0.18 ± 0.02a	188 ± 21a	43 ± 4a	18 ± 2b	35 ± 3a

Table 4. Significant correlations (r) between element concentrations (mg kg^{-1}), pH, and LOI (%).

	Hardwood		Softwood	
	LOI	pH	LOI	pH
pH			-0.64	
Al	-0.82		-0.59	
Ca		0.67		0.63
Cu	0.57			
Fe	-0.79		-0.61	0.55
K			-0.63	0.65
Mg		0.53	-0.53	0.65
Mn		0.53		0.60
Pb		-0.58		

Base cations, including Ca, K, and Mg, also were negatively correlated with LOI in both forest types (Table 4). This could indicate that mineral materials were also a greater source of base cations than organics.

In addition to concentrations, we expressed the soil results on a mass-per-unit-area basis. Table 3 shows the soil content of all elements in the fine earth fraction, which is the material that passed through the 6-mm sieve, and organic matter content. Although the concentrations of most elements in hardwood soils were significantly higher than in softwood soils and the numerical trends for content were similar, the soil contents for many elements were not significantly different between forest types. Softwood soils had a significantly larger mass of fine earth than hardwood soils, thus concentration differences between the forest types were reduced when the data were expressed on an areal basis. Given the high variability in these data, there was no significant difference between forest types in content, although concentrations were significantly different for Al, Ca, Cd, Cu, Fe, K, and P. The content of all elements were positively correlated with mass of the fine earth fraction and organic matter content (Table 3).

CONCLUSIONS

This publication documents current element concentrations in foliage, branch tips, and soils at remote forest sites in eastern Maine in 2004. Vegetation and soil element concentration data from remote regions affected by non-point source pollution are relatively uncommon in the literature, yet are essential for making sound management and policy decisions regarding ecosystem resources, tracking changes in environmental quality over time, and framing research initiatives that will address the critical environmental information needs. In the absence of large, coordinated monitoring programs across the region, we believe it is even more important to document these types of data in the public record.

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