DETECTING CHANGES IN TREE TISSUES CHEMISTRY OVER TIME IN NORTHERN HARDWOODS

by

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Keywords: Laboratory precision, within the tree, among trees, inter-annual, sampling effort.

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Chapter 1: Introduction

Background

In the early 1800s in Europe, De Saussure (1804) identified various chemical elements that are essential for plant growth. Plant tissue analysis then developed as a means of measuring the essential nutrients in a sample of plant tissue by Von Leibig (1840). Later, Weinhold (1862) began to use plant nutrient analysis as an index of available nutrient element supply. Since then, plant tissue analysis has been widely adopted by other researchers, and has been widely utilized in crop production for purposes such as making decisions on fertilization use and crop type. In forested ecosystems, the balance of nutrient concentrations in trees is important to the growth, reproduction and development of trees. Plant tissue analysis can help correct deficiencies (Beede et al., 2005) and the time to harvest appropriately (Crow et al., 1991).

In the mid-19th century, the term "acid rain" was coined by Robert Angus Smith after deterioration of forests was discovered near industrial areas, coinciding with observations of damage to plants experiencing acidic precipitation. Acid rain has been found to add nitrogen and sulfur to ecosystems; oxidized mobile anion forms depletes base cations from soils, thereby altering the nutrient concentrations and contents in trees (Aber et al., 2003). This change in tree nutrients may pose a potential threat to forest health and productivity, impairing the sustainability of forests over the long-term. Thus, the description of changes in tissue chemistry is important to detecting long-term trends of impacts on forest productivity (Yanai et al., 1999).

Roles of nutrients in trees

Macronutrients such as N, P, Ca, Mg and K are required in large amounts by trees. Nitrogen and P, which form covalent bonds with CHO skeletons, and a component of essential molecules such as proteins and nucleic acids. Nitrogen, part of carbon compounds, is required by plants in the greatest amounts (Gauch 1972; Dickson 1989). Phosphorus, important in energy

storage and structural integrity, is the key for respiration and photosynthesis (Taiz and Zeiger, 2006).

Base cations, such as Ca, Mg and K, which are derived from parent material, soil minerals, and atmospheric deposition also play important physiological roles in trees. Ca and K contribute to the ionic and osmotic balances of protoplasm and vacuoles, whereas Mg is essential to energy transfers involving ATP and ADP in trees. Calcium, Mg and K are also the activators for various enzymes associated with photosynthesis in leaves (Gauch 1972). Leachability from the foliage and bark is highest for K, relatively low for Ca and Mg, and lowest for N and P (Carlisle et al. 1966, 1967; Day et al, 1977; Gosz et al, 1975).

Natural variation of nutrient concentrations in trees

Multiple factors can cause the natural variability of nutrient concentrations in trees. 1. Time and age. Nutrient concentrations in trees can vary during a day, within a year, between years and at different tree ages. 2. Physiology and morphology. Nutrient concentrations in trees also vary by tree species, crow class, tissue types, and tissue position. 3. Tree location and environment. Nutrient concentrations in trees differ in different geographical locations and soils (site quality).

Some sources of variability in nutrient concentrations have been quantified in foliage for hardwood species. Within the tree, vertical patterns of macronutrient concentrations in foliage through the canopy have been summarized as either a decrease from bottom to upper canopy or from upper to bottom canopy, or no vertical pattern (Van den Driessche 1974). The coefficient of variation (CV) of foliar nutrient concentrations was within 5% for N and P and 5~10% for cations for European beech (*Fagus sylvatica* L.) (Le Tacon and Toutain 1973), sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), black cherry (*Prunus serotina*

Ehrh.), yellow birch (*Betula alleghaniensis* Britton.) (Ellis 1975; Morrison 1985), and red maple (*Acer rubrum* L.) (Erdmann et al., 1988). Effects of foliage directional aspect on nutrient concentrations in the northern hemisphere differ by species within and among sites. Mount Tabor oak (*Quercus ithaburensis* Mich.) had higher foliar P in eastern and southern aspects (Oppenheimer and Halfon-Meiri, 1961), silver birch (*Betula verrucosa* ehrh.) trees had higher foliar N in northern aspects than other aspects (Tamm 1951) and Freeman maple (*Acer x freemanii*) had lower foliar N in northern aspects and higher foliar Ca in southern aspects (Mickelbart 2010), with all CVs within 5%. Within the stand, variability in nutrient concentrations from tree-to-tree was in the similar range (8 ~15% CV for N and P, and 16 ~ 31% CV for Ca, Mg and K) for red maple, yellow birch and ash (*Fraxinus*) in Northern Michigan (Erdmann et al., 1988), and Ontario (Morrison 1985; Ellis 1975). For red maple across sites with Spodosols, foliar P, Ca and Mg had higher concentrations in a more fertile site with a CV of 9% for foliar P and more than 20% for foliar Ca and Mg (Erdmann et al., 1988). European beech foliage had a CV of 5% for N, 7% for P, 11~15% for Ca, Mg and K inter-annually (Duquesnay et al., 2000).

Variability in nutrient concentration of non-leaf tissues are less studied. Within a tree, nutrient concentrations in branches decreased with increased branch diameter. For quaking aspen (*Populus tremuloides* Michx.) and yellow birch, branch wood had a CV of 56% for N, 49% for Ca, 37% for Mg and 44% for K, and branch bark had a CV of 28% for N, 33% for Ca, 16% for Mg and 28% for K from 0-75 mm of branch in Ontario (Hendrickson 1987). For sugar maple, yellow birch and American beech (*Fagus grandifolia*Ehrh.), branch wood and bark had a CV of 38% for N and K from 0-30 mm of branch in New Hampshire, USA (Whittaker et al., 1979). Nutrient concentrations in stem wood varied radially with higher concentrations of N, P and K in

sapwood than in heartwood. For a meta-analysis of 50 hardwood species across 42 stands, concentration of N and P (27% CV for N, 62% CV for P) had a higher radial variability in wood disk samples than Ca, Mg and K (1% for Ca, 10% for Mg and 26% for K) within a tree (Meerts 2002). Within the stand, the variability in nutrient concentrations among individual trees of the same species was smaller for N (CV=4~11%) compared with P, Ca, Mg and K (CV=11~33% for P, 14~27% for Ca, 12~29% for Mg and 11~16% for K) for ash, European beech, yellow birch and oak (*Quercus*) in European countries (Hagen-Thorn et al., 2004).

Studies on long-term changes in tree nutrients

Over a long-term period, cation depletion in tree tissues, especially in foliage, has been caused by acidic deposition ("acid rain") (Lovett et al., 1985; Johnson et al., 1985) accompanied by an increase of nitrogen (Flückiger and Braun, 1998; Duquesnay et al., 2000; McNeil et al., 2007) and a decrease of phosphorus (Flückiger and Braun, 1998; Duquesnay et al., 2000).

Methods of sampling tissues can affect the variability of nutrient concentrations. For foliage, sampling on the southern and eastern sides of a tree is recommended due to the lower variation in nutrient concentrations at these locations (Mickelbart 2010). Branch diameters are rarely recorded or reported when sampled. One study sampled branches in a range of diameters (1-4 cm) to exclude the variation caused by branch diameter (Santa et al., 1997). For wood samples, two methods, coring and disk sampling, are commonly used. Cores of the tree bole are taken using an increment borer; this method is more popular than disk sampling because it is more efficient and does little damage to the tree (Arthur et al, 1999); However, this method underestimated the concentrations of N-P-K in the sapwood and overestimated the Ca-Mg concentrations in the heartwood compared to disk sampling for maritime pine (*Pinus pinaster* Ait.) in south-western France (Augusto and Bert, 2005). Considering the inter-tree variability, a

sampling intensity of 5~ 10 replicate trees per plot is commonly employed for intensive monitoring projects to produce a relatively smaller variation (CV ≤ 10%; De Vries et al., 1998). Collection of tree tissues is usually conducted in late summer when seasonal variations in nutrients are lower and nutrients are relatively stable (Alban 1985).

A comparison of errors from various uncertainty sources has not been conducted, especially within the same forest region. To study long-term changes in tree nutrients, guidelines need to be developed for sampling efforts within the tree, among trees, and within the stand. To detect change in tree nutrients over decades requires information about previous sampling site, sampling methods, analyzing methods and the associated inter-annual variation data. Missing documents or vague descriptions of sampling methods may introduce bias to sampling schemes repeated from previous studies. The changes in tissue chemistry over time should be reported with known statistical confidence in the future.

Chapter 2: Sources of variability in tissue chemistry in northern hardwood species

Abstract

Various sources of uncertainty should be considered in evaluating changes in tree nutrients over a long-term period. Variability was characterized in laboratory analyses, different sampling positions within trees, different trees, and variation from year to year, using tissue samples of northern hardwood species. Uncertainty associated with laboratory analyses differed among elements with potassium concentration exhibiting the least accuracy and precision. Within trees, foliage and bark were less variable in nutrient concentration than branches and wood ($P < 0.001$). For tree to tree, nitrogen and phosphorus concentrations in leaves were the least variable resulting in a significant interaction of tissue and element ($P = 0.02$). From year to year, nitrogen concentrations in leaves were the least variable ($P = 0.03$). In monitoring long-term changes in tree nutrients, a lower sampling intensity is needed to detect a given rate of change in foliar nitrogen or phosphorus than other elements or tissues.

Keywords: Laboratory precision, within the tree, among trees, inter-annual, sampling effort.

1 Introduction

Acidic deposition has added nitrogen and sulfur to ecosystems but has depleted nutrient base cations from soils due to the importance of nitrate and sulfate serving as mobile anions, posing a potential threat to forest health and productivity (Aber et al., 2003). Nutrient concentrations in tree tissues affect forest growth and can be used to diagnose the nutritional disturbances. The abnormal changes of nutrient concentrations under acidic deposition have been well documented for foliage. In France, increases in foliar N concentration and decreases in foliar P, Ca, Mg, and K have been reported for European beech (*Fagus sylvatica* L.) over 26 years (Duquesnay et al., 2000). A similar pattern has been observed in beech and oak over 16

years in Belgium-Wallonia and Luxemburg (Jonard et al., 2009), and in beech over an 11 year period in Switzerland (Flückiger and Braun, 1998). Throughout the United States and Canada, higher concentration of foliar N and lower concentration of foliar Ca and Mg have been reported in American beech (*Fagus grandifolia* Ehrh.), sugar maple, and yellow birch at locations with greater rates of N deposition (Boggs et al., 2005). Non-leaf tissues such as boles and branches, are rarely studied because they are more difficult to sample repeatedly, though these tissues contain a larger amount of nutrients than leaves due to the former's much greater biomass (Whittaker et al., 1979). More description of changes in nutrient concentrations in these tissues over time is essential to detecting long-term trends and understanding the effects of environmental stresses on forested ecosystems.

Reports of long-term change in tree nutrients should contain errors from 2 sources of uncertainty. Measurement error comes from the procedures of collecting samples and analyzing them in the laboratory. Changes in methods of sample collection could contribute to differences in nutrient concentrations measured at two different times. Differences in laboratory methods and accuracy used to quantify nutrient concentrations could also potentially contribute variation in nutrient concentrations; these differences may be mistakenly attributed to the actual differences in the nutrient concentrations of samples, but can be minimized with proper use of the standard reference materials. Another source of uncertainty, sampling error, comes from the location and time of sampling, Nutrient concentrations in foliage varied by crown class, position in crown, time of year, site properties (Van den Driessche, 1974; Luyssaert et al., 2002). Thus, samples collected in different positions with a tree, for different individuals of the same species and at different time period could result in differences that could be mistaken for detecting long-term change. The magnitude of these two sources of uncertainty, measurement error and

sampling error, have not been well characterized for foliage, much less for non-leaf tissues of different forest types. A comparison of uncertainty from multiple stands, individual trees by species, tissue types and elements, would help determine which sources most affect the accuracy of the results and need more sampling effort.

This study took advantage of nutrient datasets at six sampling years and three sites. Nutrient concentrations (N, P, Ca, Mg and K) of four tissue types (bark, branch, foliage and wood) were investigated in six dominant species, American beech, red maple, sugar maple, white birch (*Betula papyrifera* Marshall.), yellow birch, and pin cherry (*Prunus pensylvanica* L.f.), in the BEF (Bartlett Experimental Forest) in 2005; in the HWF (Huntington Wildlife Forest) in 1985, 1986, 1987, 2012 and 2013; and in the HBEF (Hubbard Brook Experimental Forest) in 2013. The main purpose of this study was to compare the magnitude of different sources of uncertainty in studying long-term changes in nutrient concentrations in northern hardwoods. Four sources of uncertainty were characterized using different datasets (Table 1): Laboratory accuracy and precision, within the tree, tree to tree, and year to year. The effects of tissue type and element on the uncertainty were reported in this study as well.

2 Materials and methods

2.1 Study site

The HBEF and BEF are located in the White Mountain National Forest in central New Hampshire. One old stand (> 100 yrs old) was selected for this study at the HBEF, and six stands were selected at the BEF consisting of two stands for each of three stand ages (young at 15 yrs old, middle at 30 yrs old and old at 100 yrs old). The HWF is located in the Adirondack Mountains of northern New York. The old stand selected for this study at the HWF is near the Integrated Forest Study site (IFS; Johnson and Lindberg, 1992) and outside of the Arbutus

Watershed (Mitchell et al., 2002). For all three sites, young and middle-aged stands were dominated by American beech, yellow birch, red maple, white birch and pin cherry. Old stands were dominated by American beech, sugar maple and yellow birch. The annual mean temperature is 4.4 ˚C in all three sites with an annual precipitation of 130 cm at HBEF and BEF and 101 cm at HWF (Likens et al., 1977; Bailey et al., 2003; Shepard et al., 1989). Well-drained Spodosol (Haplorthords) developed from glacial drifts are mainly loam at all three sites (Huntington et al., 1988; Vadeboncoeur et al., 2014; Somers, 1986).

2.2 Field sampling

Sampling at HBEF: To address the variability of nutrient concentrations within the tree, one tree of each of three species (American beech, sugar maple and yellow birch) with DBH about 30 cm was selected and cut down in June 2013 near watershed 7. Branch samples were collected at four branch diameters (0.5, 1, 2, and 3 cm). Thirty leaves without petioles and free from disease and insect herbivory were collected at three canopy positions (bottom, middle and upper). Disks were collected from the bole of each tree at three heights (Figure 1).

Sampling at BEF: To report the variability of nutrient concentrations among trees, a total of 101 trees of 6 species were cut down in 2005 (American beech, red maple, sugar maple, white birch, yellow birch and pin cherry) (Fatemi, 2007). In young and middle age stands, cut trees had DBH ranging from 2 to 12 cm. Leaves with petioles from the canopy, branches and disk samples along the stem were collected in the field. In old stands, trees with DBH larger than 12 cm were selected for three species (American beech, sugar maple and yellow birch). Bark was collected from the stem at 1.5 m with a chisel and hammer. Leaves with petioles were sampled using a 12-gauge shotgun. Two tree cores deep to the pith were also taken from each tree at approximately 1.0 m height.

Sampling at HWF: In 1985, a survey line was established around the Integrated Forest Study site consisting of 39 points encompassing 4.7 ha (Johnson and Lindberg, 1992). The same survey line was re-established prior to every sampling period. In August of 1985, 1986, 1987, 2012 and 2013, at least five trees of each of four species (American beech, sugar maple, red maple and yellow birch) with DBH > 10 cm were selected for sampling along the survey line. Trees nearest each sample point were selected in the 1980s. Because of destructive sampling for allometric analysis (Briggs et al., 1989), not all the sampled trees were the same in 1985-1987 and 2012-2013, but were the same in 2012 and 2013.

Bark was collected from the stem at 1.3 m with a chisel and hammer. Two branches from each tree were cut from the base of the crown, at least 1 m from the trunk, using a ladder and pruner. Twenty to thirty pathogen-free leaves with petiole attached were collected from the cut branches of each tree. Three cores were collected from each tree at breast height using a Pressler's increment borer (5 mm diameter).

2.3 Sample processing and analysis

Samples from HBEF and HWF: Three disks of each of three trees collected from the HBEF were dissected into bark and wood in the laboratory. Wood samples were separated into lightwood and darkwood based on color using a clean chisel. Bark samples collected from the HBEF and the HWF were examined and washed in a phosphorous-free detergent solution (1% Alconox) if lichens or algae existed, and then rinsed three times in deionized water (Likens and Bormann, 1970).

All the foliage, branch, bark and wood samples from two sites were dried at 60 ˚C and ground in a Wiley mill to pass a 20 mm mesh screen. Total N was analyzed using a Kjeldahl digestion method in the 1980s and a carbon-nitrogen elemental analyzer (Thermo Electron

Corporation, EA1112 elemental analyzer, SUNY-ESF) in 2012 and 2013. Subsamples were ground to pass 40 mm mesh screen, ashed at 470 ˚C and dissolved in 5 mL of 6 molar HNO_3 on a hot plate (Siccama et al., 1994). Concentrations of P, Ca, Mg and K were determined by Perkin-Elmer Optima 3300DV ® inductively coupled plasma optical emission spectroscopy (ICP-OES) for all samples. National Institute of Standards and Technology (NIST) solid standard reference material (NIST 1515, apple leaves) was analyzed along with all samples, and was also run after every ten samples. The recovery of NIST standards was controlled within 5%. Samples were re-processed and the analyzer was recalibrated when the recovery was larger than 5%.

Samples from BEF: Samples were oven-dried at 60 ˚C and ground in a Wiley mill to pass a 20 mm mesh screen (Fatemi, 2007). Total N was determined using the carbon-nitrogen elemental analyzer. Subsamples were ground to 40 mm using a Wig-L-Bug®, and were ashed at 470 ˚C and digested in either a microwave oven (9 mL of 6M HNO_3) or by using the hot-plate procedure (5 mL of 6M HNO_3). Concentrations of P, Ca, Mg and K were determined by ICP-OES. NIST 1515 apple leaves were used as the standard reference material every 10 samples to check for machine accuracy and precision.

2.4 Data analysis

To describe the laboratory precision, the coefficient of variation (CV, the standard deviation as a percentage of the mean) in nutrient concentrations was calculated among duplicates using data from the HWF in the 2010s. A general linear model was used to test the effects of element and tissue type on CV in nutrients among duplicates treating CV as the dependent variable. I reported my values of certified standards (NIST 1515, apple leaves) to ascertain laboratory accuracy. The bias of the recovery (the differences between actual recovery

and 100%) was calculated, and a t–test was used to determine whether the bias was different from zero. Coefficients of variation were log transformed in all of the analysis to meet the assumption of normality of the residuals.

Coefficient of variation in nutrients across different tissue positions was reported within the tree by element and tissue type using data from the HBEF. A general linear model was used to test the effects of element and tissue type on CV in nutrients within the tree. To describe variability of nutrients among individuals for the same species, data from the BEF in 2005 was used and tree-to-tree CV in nutrient concentrations was calculated by element, tissue type and species for each stand. A general linear model for nest-stand selection (Table 2) was used to test the main effects of element, tissue type, species, stand age and their interactions on CV in nutrients among trees.

Samples collected in 1985, 1986 and 1987 at the HWF were used to describe the inter-annual variation in nutrient concentrations by tissue type, element and species. Coefficient of variation in nutrients across the three sampling years was calculated, and a general linear model was used to test the effects of element, tissue type and species and their interactions on inter-annual CV with Tukey's honestly significant differences. Long-term changes in nutrient concentrations between the two sampling periods at HWF (1980s and 2010s) were reported. Median nutrient concentrations of replicate individuals by element, tissue type and species at each of five sampling years were used to analyze the long-term changes in tree nutrients using an unequal two sample t-test (three years in the 1980s and two years in the 2010s). Significance for statistical analysis was set at $\alpha = 0.05$, and statistical analysis was conducted with SAS 9.4 (SAS Institute, Raleigh, NC).

3 Results

3.1 Accuracy and precision in laboratory

Accuracy and precision were calculated using data from the HWF in 2010s. The accuracy of tissue element concentrations were within the range of 95~104% (Table 3) compared with the reference sample (NIST1515-apple leaves). Values were 3% higher than the reference values for N and Ca, and 4% lower for K ($P = 0.01$).

The precision were within 8% by tissue and element in the laboratory, in unit of CV. Tissue type differed among duplicates ($P = 0.05$) with bark showing the largest variability (CV = 3.2%) and foliage showing the smallest (CV = 1.55%). Elements differed in CV in laboratory analysis ($P = 0.01$) with K exhibiting the largest variability (CV = 5.2 %) and N showing the smallest (CV = 1.3 %).

3.2 Variability within the tree and among trees

Coefficient of variation in nutrient concentrations due to sampling position was calculated using data from the HBEF in 2013. Tissue types differed in CV ($P < 0.001$) within the tree with darkwood showing the largest variability (CV= 44%) and foliage and bark exhibiting the smallest (CV= 12%) (Figure 3). Elements also differed in CV ($P = 0.08$) with K having the largest variability (CV = 29%) and N having the smallest (CV = 18%).

Coefficient of variation in nutrient concentrations among trees was calculated using data from the BEF in 2005. Species had similar tree-to-tree CVs (CV = 21~25%) among stands at the Bartlett site ($P = 0.19$) (Figure 4). Tree-to-tree CV depended on the tissue type ($P < 0.001$), with wood having the largest variability (CV = 30%) and foliage having the smallest (CV = 16%) (Figure 4). Tree-to-tree CV also varied by element ($P = 0.03$) with K showing the largest (CV = 24%) and N showing the smallest (CV = 19%) (Figure 4). Stand age had a significant effect on

tree-to-tree CV (P = 0.002) in that old stands had higher variability (CV = 26%) and young stands had the least (CV = 21%). Wood N was especially variable (CV = 35%) and foliage N and P were the least variable (CV = 11%), resulting in a significant interaction of tissue and element (P =0.02). Different individuals of sugar maple in old stands varied most (CV = 29%) in nutrient concentrations and American beech in young stands varied the least (CV= 19%), resulting in a significant interaction of stand age and species (P=0.05).

3.3 Inter-annual variability and long-term changes

Inter-annual CV in nutrient concentrations was calculated using data from the HWF in 1980s. Species differed significantly in inter-annual CV (P = 0.06), with red maple exhibiting the largest variability (CV = 28%) and yellow birch showing the smallest (CV = 17%) (Figure 5). Elements also differed in inter-annual CV (P = 0.001), with Ca exhibiting the largest variability (CV = 28%) and N again showing the smallest (CV = 13%) (Figure 5). Tissue type differed in inter-annual CV (P = 0.001) with bark showing the largest variability (CV = 28%) and foliage showing the smallest (CV = 12%). Wood P was especially variable (CV = 51%) and foliar N was the least variable (CV = 6%), resulting in a significant interaction of tissue and element (P =0.03).

Compared with nutrient concentrations in trees in 1980s, concentrations of foliar N ($P \leq 0.03$) reported in red maple, sugar maple and yellow birch was higher, and concentration of foliar K (P = 0.02) reported in American beech was lower in 2010s (Table 8). For non-leave tissues, concentration of bark N (P = 0.02) in American beech (Table 6), and concentrations of branch Ca ($P \leq 0.02$) in red maple and sugar maple were both higher in 2010s than in 1980s (Table 7). Concentrations of wood Ca and Mg ($P \leq 0.02$) reported in red maple (Table 9), and concentration of branch K (P = 0.04) reported in yellow birch were both lower in 2010s than in 1980s (Table 7).

4 Discussion

4.1 Effects of element on laboratory precision

For laboratory precision (CV in nutrient concentrations among duplicates), element was the main factor driving the difference (Figure 2). Concentration of K was the least precise, having the largest CV among replicates compared with other elements in this study. Since K suffers from ionization effects in the presence of other alkali metals, it is necessary to quantify K in a radial mode (torch positioned vertically in relation to the optical system) (Method 200.7, USEPA 2004). Concentrations of P, Ca and Mg were quantified in an axial mode (which is about ten times more sensitive as radial mode). Thus K suffers from poor precision due to very low signal magnitude. In ICP-OES, potassium (~5 ppb) had a relatively higher detection limits than P (~1.55 ppb), Ca (~0.003 ppb) and Mg (~0.01 ppb) in ICP-OES. However, the measured concentrations of actual samples were at least 500 times higher than the detection limits which suggested that the difference in detection limits of elements might not be a reason to cause K to be less precise.

4.2 Effects of element on tree-to-tree and inter-annual CVs

Element was the main factor driving the differences among tree-to-tree (Figure 4) and inter-annual (Figure 5) CVs in nutrient concentrations. Potassium was found to be the most variable element from tree to tree (Figure 4) which might be due to the varying degrees of leaching for different individual trees. Leachability is the highest for K, relatively low for Ca and Mg, and lowest for N and P especially in bark and foliage (Carlisle et al. 1966, 1967; Day et al, 1977; Gosz et al, 1975). Nitrogen was found to be the most stable element from tree to tree (Figure 4) and inter-annually (Figure 5) which might be attributed to the specific amounts of N needed for biochemical function in trees at one time period (Canadell and Vilà, 1992).

4.3 Effects of tissue type on CVs within the tree, tree-to-tree and inter-annually

Tissue type was mainly driving the differences of CVs in nutrient concentration within the tree (Figure 3), tree-to-tree (Figure 4) and inter-annually (Figure 5). Within the tree, nutrient concentrations within the same tissue type varied by position. Coefficient of variation in nutrient concentrations was 32% greater in darkwood than in foliage, in units of CV (Figure 3). Within the tree, the upper stem is composed of the newly formed darkwood, whereas the lower stem has relatively older darkwood. Accumulation of secondary metabolites, formation of tyloses (Taylor et al., 2002), and fungal infection (Ostrofsky et al., 1997) vary by the age of the darkwood, resulting in differences in nutrient concentrations. Nutrients from newly formed heartwood would recycle back into the sapwood (Bamber and Fukazawa, 1985) which might result in this great difference in nutrient concentrations for darkwood at different vertical sampling positions. The variation in foliar nutrient concentrations across the three canopy positions was the smallest in this study (CV=12%). In sugar maple (Wallihan 1944) and red maple (Erdmann et al., 1988), similar concentrations of foliar N, P, K and Ca were found in sun leaves and shade leaves. Foliar K was found to be higher in sun leaves than shade leaves in sugar maple, yellow birch and American beech; however, there was no difference based on leaf position for Ca or Mg concentrations (Likens and Bormann 1970). For tree-to-tree and inter-annual CVs in nutrient concentrations, foliar nutrient concentrations were found to be less variable than nutrient concentrations in non-leaf tissues (Figure 4 and 5), with reasons unknown.

4.4 Comparing magnitudes of different sources of variability

To study long-term changes in tree tissue chemistry, laboratory analyses introduced only slight variation, compared to other sources in this study (Table 4). Treating tissue types as replicates, variation of nutrient concentrations for five elements was smallest among duplicates

in the laboratory (CV ≤ 5%). Treating elements as replicates, variation of nutrient concentrations for four tissue types was also the smallest (CV≤ 3%). Bark and wood (CV = 3~35%) had relatively larger variation for four uncertainty sources than branch and foliage, and foliage had the smallest variation (CV = 2~16%).

Within the tree, the variability observed in nutrient concentrations in foliage across canopy position (5% in N and P, and 12% in Ca, Mg and K) (Figure 3) was similar to that reported in other studies (Table 5. Ellis 1975; Morrison 1985; Erdmann et al., 1988). Tree-to-tree CV of foliar N and P was 11% in this study, which was similar to studies for maple, birch and ash (CV = 8~15%) (Table 5. Erdmann et al., 1988; Morrison 1985; Ellis 1975). Similar inter-annual variability in concentrations of N and P in foliage (CV=5~7%) was also found in other studies (Ljungström and Nihlgård, 1995; Duquesnay et al., 2000).

4.5 Long-term changes in tree nutrients

Over extended periods, concentration of K reported in foliage and concentrations of Ca and Mg reported in wood in the studied species were lower in the 2010s (Table 8, Table 9). The CV in concentration of K (27%) in foliage across 25 years was higher than the CV within the tree (12%) and tree-to-tree (16%) in this study. The CV in concentrations of Ca (40%) and Mg (54%) in wood in red maple across 25 years was again higher than the CV within the tree (35%) and tree-to-tree (30%). It is possible that the decreased concentration of K in foliage and concentration of Ca and Mg in wood was a real trend since the long-term variation of nutrients was larger than the possible sampling error. The decreasing trend of cation concentrations was also found in other studies but only for foliage (Lovett et al., 1985; Johnson et al., 1985). Concentration of branch Ca in maple was reported higher in the 2010s (Table 7), probably because the study site (HWF) is a base rich site.

Concentration of foliar N in red maple, sugar maple and yellow birch was reported higher in 2010s (Table 8) though the rate of nitrogen deposition occurring at Huntington decreased from 4.9 kg ha^{-1} $year^{-1}$ in 1980s to 3.3 kg ha^{-1} $year^{-1}$ (National Atmospheric Deposition Program Network). Only the CV in concentration of foliar N (21%) across 25 years in sugar maple, was higher than the CV within the tree (6%) and tree-to-tree (11%). This did not occur in yellow birch or red maple. Thus, only the increased concentration of foliar N in sugar maple might be real in this study.

5 Conclusions

Among all the uncertainty sources described here, variability within the tree, among trees and inter-annually was relatively larger than variability among duplicates in the laboratory. Sampling position within the tree should be consistent for repeated samplings, and replicated individual trees or years is also necessary due to the large uncertainty. Though variability in the laboratory analysis was the smallest among all uncertainty sources, there is a concern over analytical determination of K concentration since it had the largest variability in the laboratory. To detect long-term changes in tree nutrient concentration, wood should be sampled more intensively than foliage, bark or branches, with darkwood and lightwood separated for analysis. Foliage is the easiest tissue to monitor for changes over time, because it exhibits the least variability among samples. For elements, N and P had the smallest variability within the tree, inter-tree and inter-annually. To detect different elements in various tissue types of trees, foliar N and P would require less sampling effort compared with cation elements in non-leaf tissues.

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Chapter 3: Summary

To detect long-term changes in tree nutrients in different sites, it is necessary to keep the sampling protocol consistent over time. The initial design of sampling methods for long-term monitoring should be based on the observed variation in the current study site and in similar earlier studies. Variability within the tree, among trees, and inter-annually has been examined separately in the past, but all factors were not considered. Researchers have often studied foliage but there are fewer studies on non-leaf tissues.

It is not possible to quantify all sources of uncertainty when reporting long-term changes in tree nutrients. Some other related uncertainty sources, such as seasonal nutrient variation, were not considered in this study. Among all the uncertainty sources studied here, variability in the laboratory was the smallest; however, special attention should be given to enhancing quality control through the use of standard reference materials. Variability in nutrient concentrations was relatively smaller in foliage than in non-leaf tissue within the tree, among trees and inter-annually. Concentrations of foliar N and P were the least variable for all the uncertainty sources in this study. Sampling efforts could be allocated more efficiently if the sample size necessary to detect differences were estimated in advance. Sample size should be calculated based on the variability at different scales (within a tree, within a stand, across stands) and the objectives of the study. This research provided a comprehensive study of different sources of variability in tree tissue analysis. Future research should focus on calculating the actual required sampling effort according to the sources of uncertainty in northern hardwood species.

Tables and Figures

Table 1. Background information of the datasets used in this study, and the types of uncertainty sources quantified by different researchers.

Location	Year of sampling	Species	Sample size	Type of uncertainty to be quantified	People who analyzed the samples
Bartlett Experiment Forest	2005	American beech, red maple, sugar maple, white birch, yellow birch, and pin cherry	3 ~5 trees per species	Variability among individual trees	Farrah Fatemi
Huntington Wildlife Forest	1985,1986,1987, 2012,2013	American beech, red maple, sugar maple, yellow birch	5 ~ 6 trees per species	Laboratory accuracy and precision, temporal variability.	Russell Briggs Yang Yang
Hubbard Brook Experimental Forest	2013	American beech, sugar maple, yellow birch	1 tree per species	Variability within the tree	Yang Yang

Table 2. Example of ANOVA table for the general linear model for nest-stand selection comparing CV in nutrient concentrations across element, tissue type, species and stand age. DF denotes degrees of freedom. * indicates stand was nested in the model for the experimental design.

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Model	17	9.81	0.58	5.34	< 0.0001
Error	552	59.71	0.11		
Corrected Total	569	69.52			
Stand age	2	1.39	0.69	6.40	0.002
Species	5	1.17	0.23	2.16	0.06
Tissue	3	5.35	1.78	16.50	<0.0001
Element	4	1.20	0.30	2.78	0.03
*Stand	3	0.70	0.23	2.16	0.09

Table 3. A comparison of analysis with the reference (NIST 1515, apple leaves) values using data from HWF in 2010s. Sample size equals three for P, Ca, Mg and K, and 20 for N. Standard error for my values and reference values represents the deviation of nutrient concentrations among replicated samples.

	N	P	Ca	Mg	K
Our value (%)	2.33 ±0.02	0.16 ±0.004	1.58 ±0.04	0.27 ±0.08	1.54 ±0.32
Reference value (%)	2.25 ±0.2	0.16 ±0.02	1.53 ±0.2	0.27 ±0.03	1.61 ±0.2
Recovery (%)	103.6 ±1.0	101.9 ±1.4	103.4 ±1.4	100.7 ±1.8	95.7 ±1.0
CV (%)	2.47 ±0.2	1.31 ±0.04	2.41 ±0.1	0.52 ±0.05	3.14 ±0.2

Table 4. Summary of CV in concentrations for different types of variablity. Coefficient of variation for nutrient element was treating tissue types as replicates. Coefficient of variation for tissue type was treating nutrient elements as replicates.

Type of variability	Coefficient of variation (%)								
	Nutrient element					Tissue type			
	N	P	Ca	Mg	K	Bark	Branch	Foliage	Wood
Laboratory precision	1	3	2	2	5	3	3	2	3
Within the tree	18	27	25	20	29	12	23	12	35
Tree-to-tree	24	19	21	24	24	23	22	16	30
Inter-annual	13	25	28	16	23	28	23	12	22

Table 5. Summary of variability in foliar nutrient concentrations (%) within the tree, among trees and inter-annually for different tree species at different areas.

			Variability of nutrient element in foliage (%)					
Type of variability	Location	Species	N	P	Ca	Mg	K	Sources
Within the tree	Ontario	Sugar maple, yellow birch	3	3	13	10	7	Morrison 1984
	Michigan	Red maple	2	4	12	11	14	Erdmann et al., 1988
	Southern Ontario	Maple and Ash	2	2	12	13	11	Ellis 1975
Tree-to-tree	Southern Ontario	Maple and Ash	11	12	12	14	17	Ellis 1975
Inter-annual	France	European beech	6	8	18	27	15	Duquesnay et al., 2000

Table 6. Median nutrient concentrations in bark at five sampled years in four species. Coefficient of variation (%) was calculated to show the changes in nutrient concentrations across two sampling periods (1980s vs. 2010s). * indicates p value for unequal two sample t-test is less than 0.05.

Species	Nutrient element	Sampled years					CV (%)	Species	Nutrient element	Sampled years					CV (%)
		1985	1986	1987	2012	2013				1985	1986	1987	2012	2013	
American beech	N	6.88	8.01	6.12	12.63	10.64	35*	Sugar maple	N	5.45	5.34	6.50	10.76	7.47	32
	P	0.30	0.37	0.25	0.39	0.39	17		P	0.31	0.33	0.25	0.37	0.36	14
	Ca	37.32	33.70	29.52	31.22	27.79	9		Ca	21.93	26.56	37.80	24.20	28.97	6
	Mg	0.46	0.39	0.49	0.66	0.54	21		Mg	0.80	0.78	0.36	1.33	1.16	45
	K	1.49	1.72	1.15	1.77	2.06	20		K	2.62	3.32	1.19	1.96	2.22	9
Yellow birch	N	5.74	5.22	6.87	7.57	6.64	13	Red maple	N	6.03	5.44	9.30	8.34	5.98	2
	P	0.25	0.31	0.30	0.25	0.25	11		P	0.34	0.34	0.45	0.37	0.37	1
	Ca	9.83	10.05	38.71	6.63	13.37	46		Ca	15.23	12.19	36.67	20.65	18.21	7
	Mg	0.42	0.49	0.57	0.51	0.50	1		Mg	0.30	0.40	0.82	0.49	0.47	4
	K	0.87	1.14	1.04	0.62	0.78	26		K	0.85	1.23	3.22	0.77	1.61	28

Table 7. Median nutrient concentrations in branch at five sampled years in four species

Species	Nutrient element	Sampled years					CV (%)	Species	Nutrient element	Sampled years					CV (%)
		1985	1986	1987	2012	2013				1985	1986	1987	2012	2013	
American beech	N	2.41	4.56	4.20	6.56	6.02	36	Sugar maple	N	3.15	4.62	3.95	6.77	6.44	36*
	P	0.15	0.37	0.38	0.28	0.30	1		P	0.25	0.41	0.32	0.49	0.45	26
	Ca	3.80	10.32	9.63	10.30	8.35	12		Ca	6.86	8.83	5.96	7.53	7.20	1
	Mg	0.35	0.59	0.51	0.60	0.44	5		Mg	0.33	0.49	0.36	0.56	0.44	17
	K	1.18	1.20	1.65	1.22	1.11	10		K	1.42	2.18	1.95	2.40	1.87	10
Yellow birch	N	4.58	5.04	5.20	6.69	5.59	15	Red maple	N	3.45	2.40	4.55	5.60	5.73	34
	P	0.36	0.40	0.50	0.35	0.39	9		P	0.30	0.24	0.38	0.41	0.39	18
	Ca	6.29	5.44	8.51	9.44	8.35	19		Ca	7.14	4.87	2.72	11.87	13.17	62*
	Mg	0.53	0.56	0.69	0.63	0.56	1		Mg	0.35	0.39	0.42	0.48	0.45	13
	K	1.06	1.23	1.25	0.87	0.92	20*		K	1.42	1.09	2.14	1.51	1.73	3

Table 8. Median nutrient concentrations in foliage at five sampled years in four species

Species	Nutrient element	Sampled years					CV (%)	Species	Nutrient element	Sampled years					CV (%)
		1985	1986	1987	2012	2013				1985	1986	1987	2012	2013	
American beech	N	24.14	26.52	22.00	26.21	25.07	4	Sugar maple	N	19.66	19.01	16.50	24.90	24.50	21*
	P	1.26	1.51	1.19	1.18	1.19	8		P	1.13	1.10	0.94	1.46	1.23	17
	Ca	6.66	8.56	1.65	9.61	8.56	33		Ca	8.63	6.65	1.11	8.19	6.88	22
	Mg	1.32	1.80	1.67	2.00	1.81	12		Mg	1.72	1.16	1.04	1.11	1.21	23
	K	7.84	7.74	7.08	5.56	4.65	27*		K	7.68	6.08	6.05	5.23	4.46	9
Yellow birch	N	25.20	26.01	25.20	26.96	26.77	4*	Red maple	N	19.24	20.26	18.50	22.47	22.47	11*
	P	1.43	1.70	1.49	1.26	1.29	13		P	1.15	1.38	1.05	1.23	1.23	2
	Ca	11.97	11.46	2.82	12.84	11.19	22		Ca	8.32	6.92	1.60	8.46	8.46	29
	Mg	3.09	2.88	3.22	2.74	2.47	11		Mg	1.86	1.73	1.46	1.90	1.90	8
	K	14.37	8.56	8.83	8.04	5.85	29		K	6.35	7.71	6.00	4.84	4.84	23

Table 9. Median nutrient concentrations in wood at five sampled years in four species

Species	Nutrient element	Sampled years					CV (%)	Species	Nutrient element	Sampled years					CV (%)
		1985	1986	1987	2012	2013				1985	1986	1987	2012	2013	
American beech	N	1.27	1.28	1.10	1.31	1.95	21	Sugar maple	N	0.98	0.89	1.00	1.05	1.65	24
	P	0.07	0.06	0.02	0.03	0.04	16		P	0.07	0.05	0.05	0.05	0.06	1
	Ca	0.77	1.03	2.20	0.95	1.51	6		Ca	1.66	1.54	2.34	1.43	1.17	24
	Mg	0.22	0.20	0.23	0.16	0.17	20*		Mg	0.22	0.21	0.23	0.20	0.21	6
	K	0.76	0.55	0.88	0.34	0.39	48		K	0.49	0.58	0.65	0.39	0.45	22
Yellow birch	N	0.81	0.94	0.90	1.14	1.79	35	Red maple	N	0.87	0.90	0.70	1.03	1.51	30
	P	0.04	0.05	N/A	0.03	0.03	26		P	0.04	0.09	0.01	0.05	0.05	11
	Ca	0.84	0.89	1.06	1.01	1.04	7		Ca	1.93	1.47	2.08	0.82	0.81	40*
	Mg	0.18	0.15	0.17	0.18	0.16	2		Mg	0.26	0.22	0.27	0.13	0.15	54*
	K	0.36	0.21	0.32	0.13	0.28	25		K	0.77	1.14	1.68	0.74	0.59	40

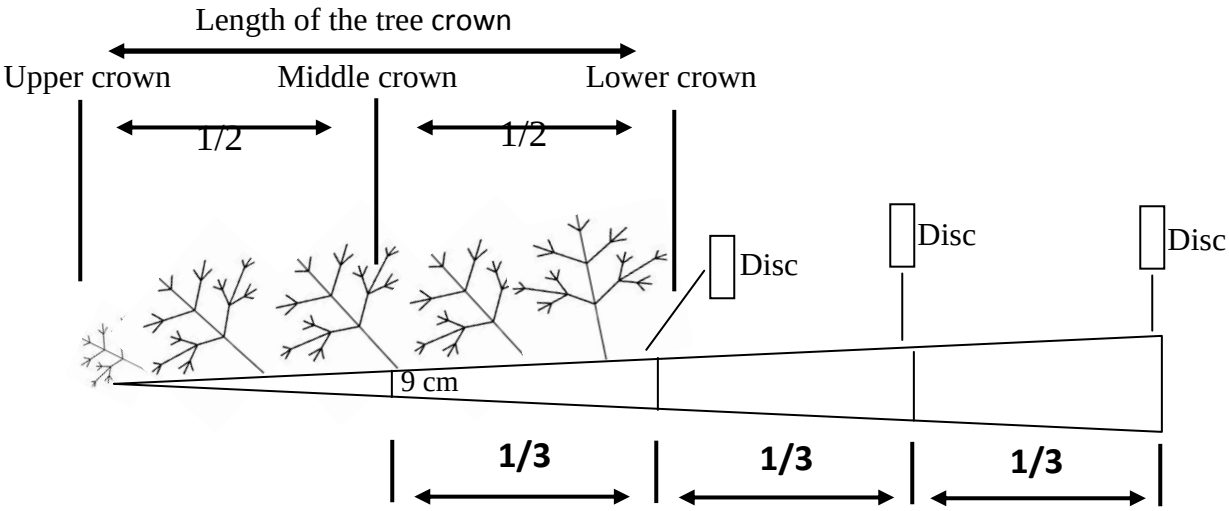

Figure 1. Sampling strategy for studying variability in nutrient concentrations with the tree by tissue position at HBEF in 2013.

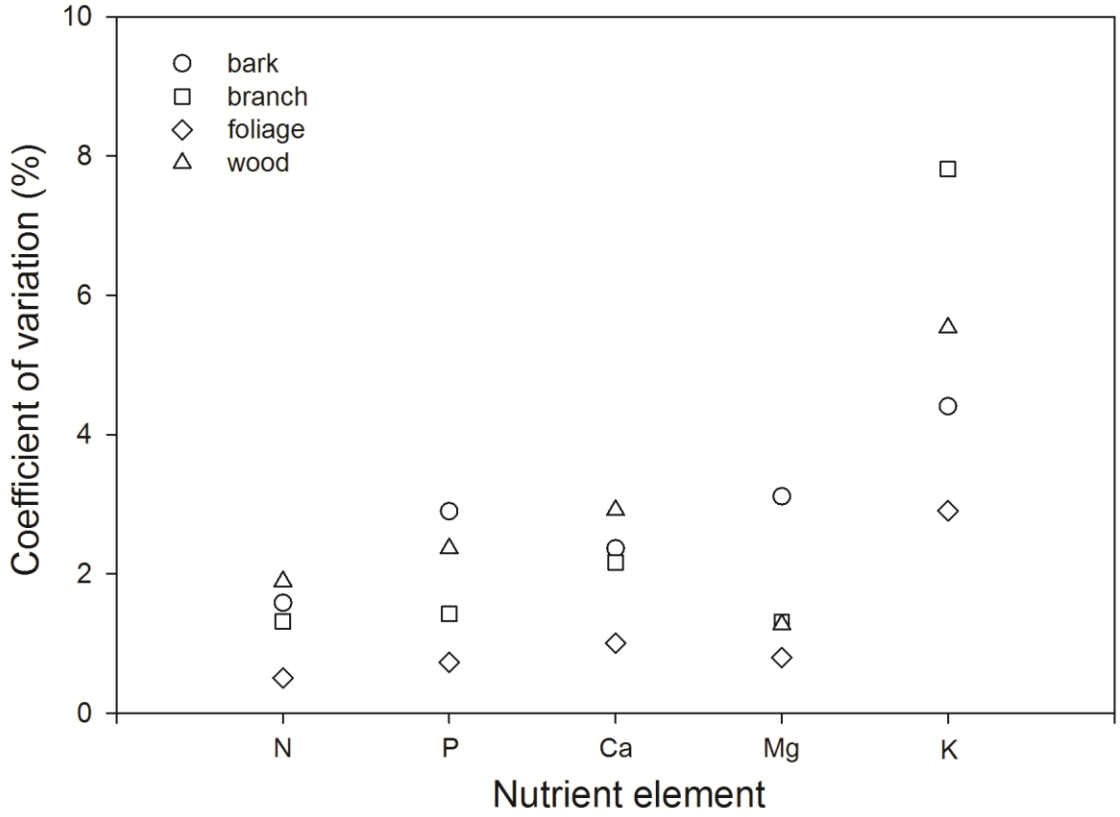

Figure 2. CV of nutrient concentrations among replicates in the laboratory using data from HWF in 2010s. Sample size equals three.

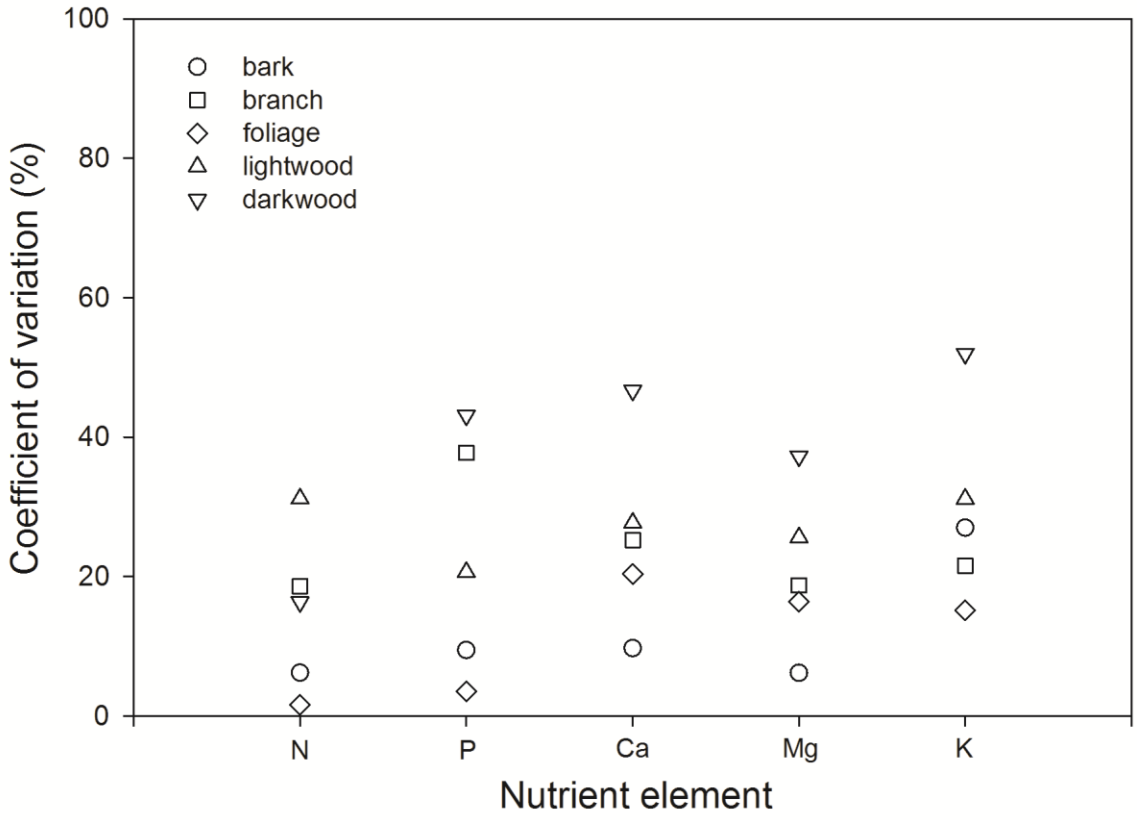

Figure 3. CV of nutrient concentrations within the tree (American beech, sugar maple and yellow birch) using datsets from HBEF in 2013. Nutrient concentrations used for calculating the CV are in the Appendices.

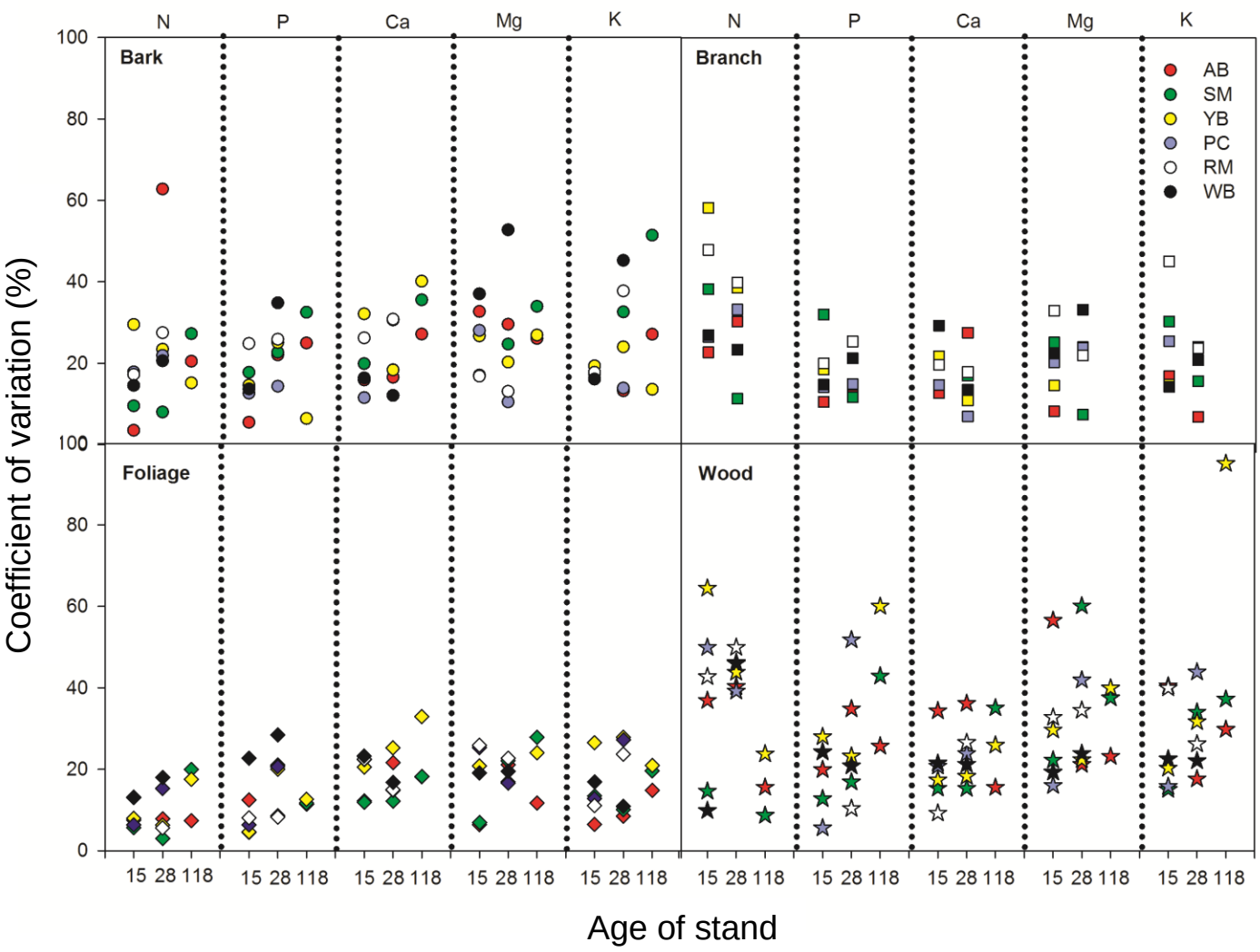

Figure 4. Tree-to-tree CV in nutrient concentrations of stands at different stand age using data from BEF in 2005 (Circle for bark, square for branch, diamond for foliage, and star for wood). The age of stands is given in years in x axis (15 represents young age stands, 28 represent middle age stands, and 118 represents old age stands). Species codes are AB for American beech, SM for sugar maple, YB for yellow birch, PC for pin cherry, RM for red maple, and WB for white birch

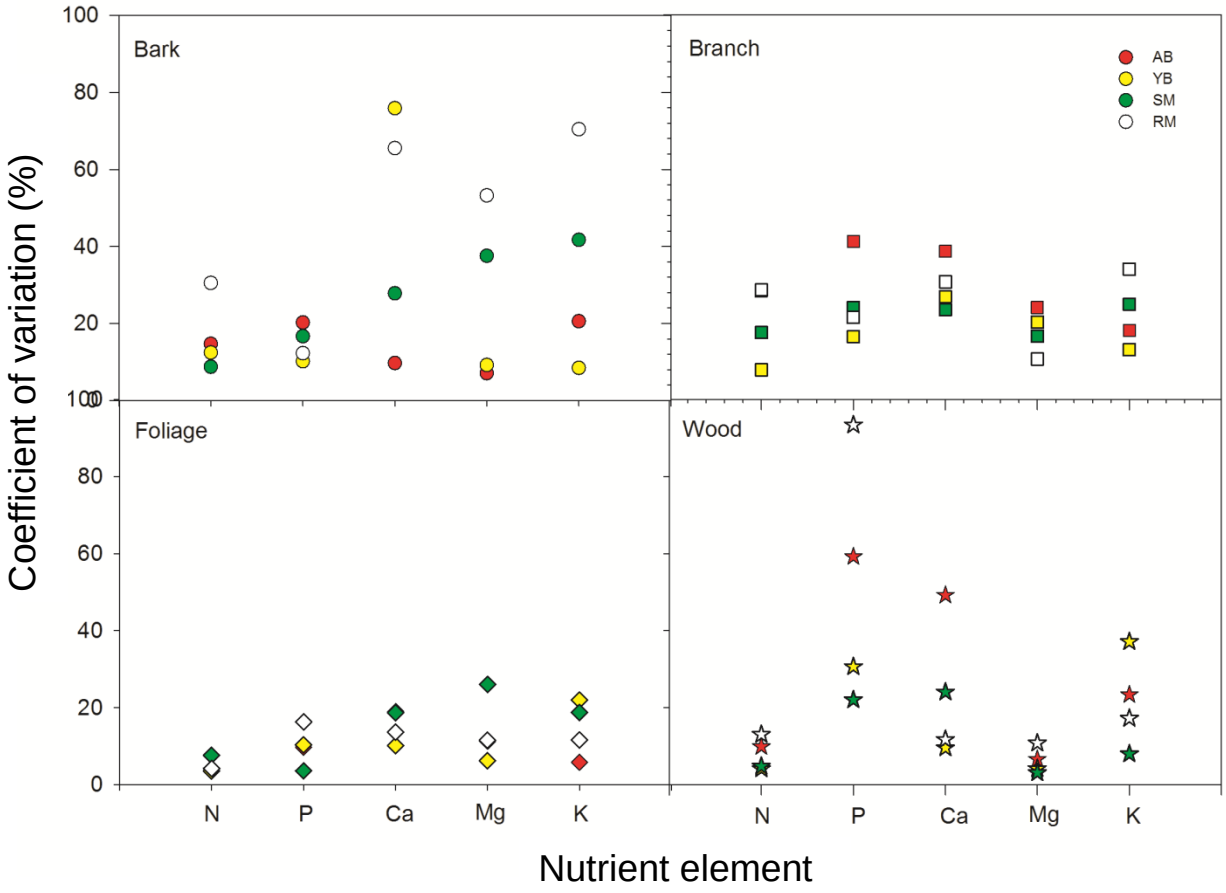

Figure 5. Inter-annual CV of nutrient concentrations using data from HWF in 1985, 1986 and 1987.

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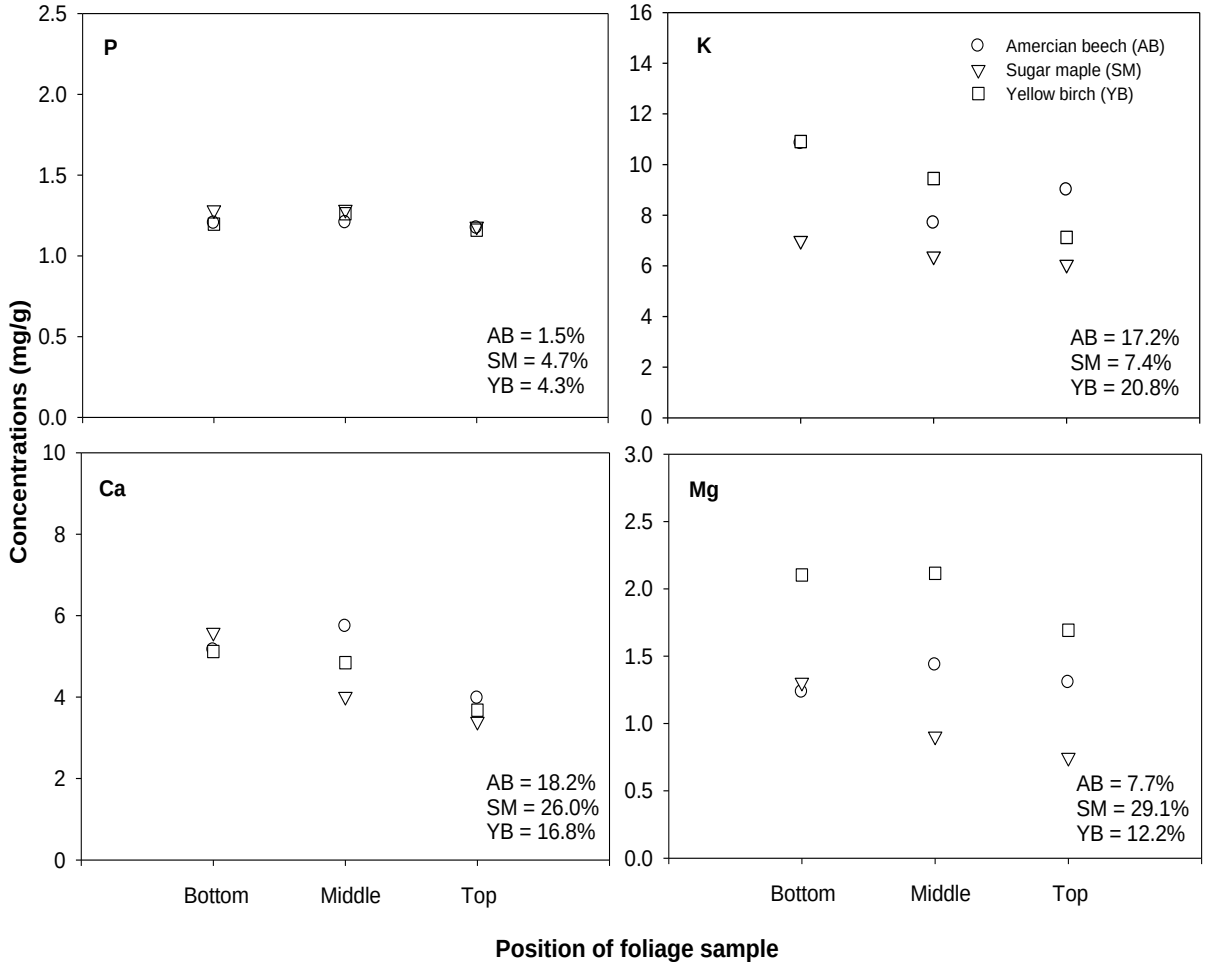
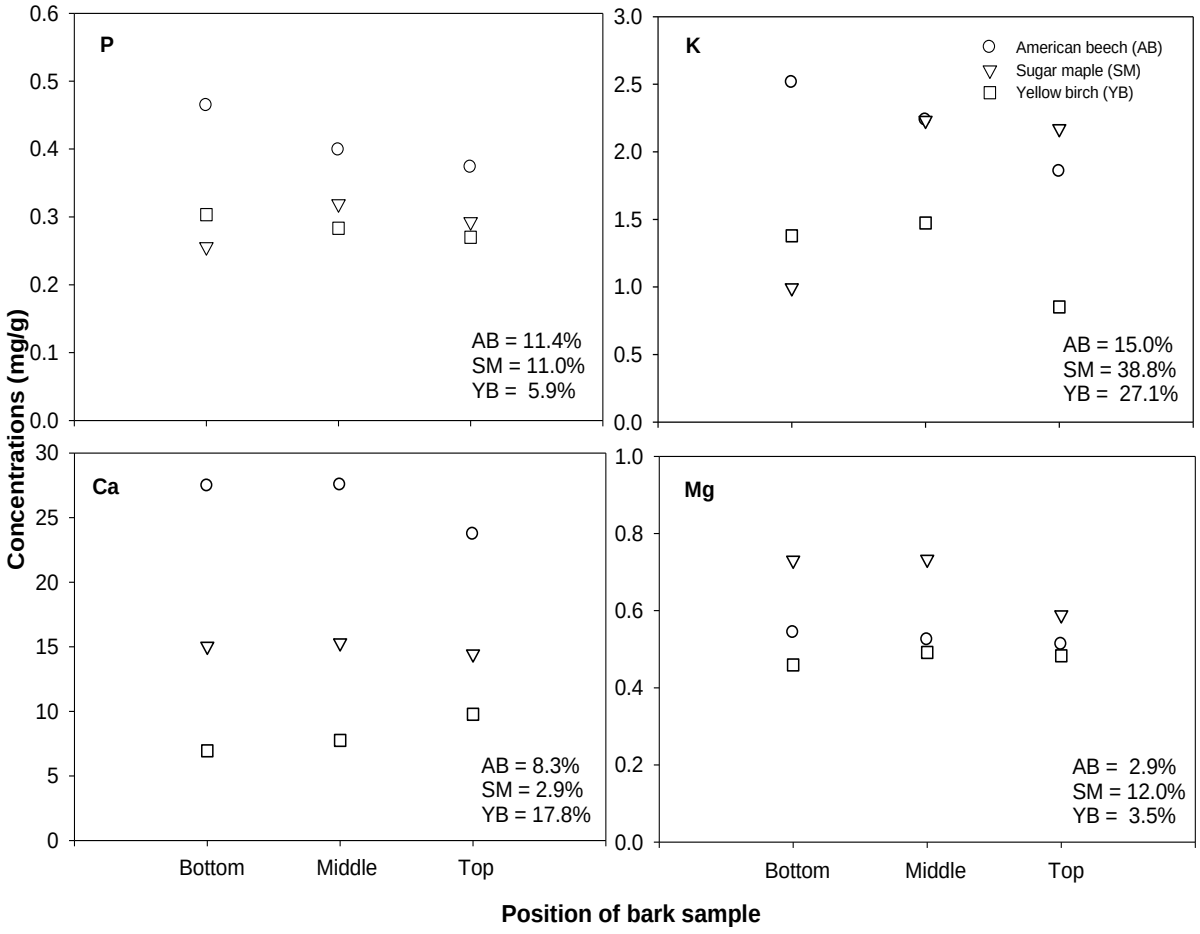
Appendices

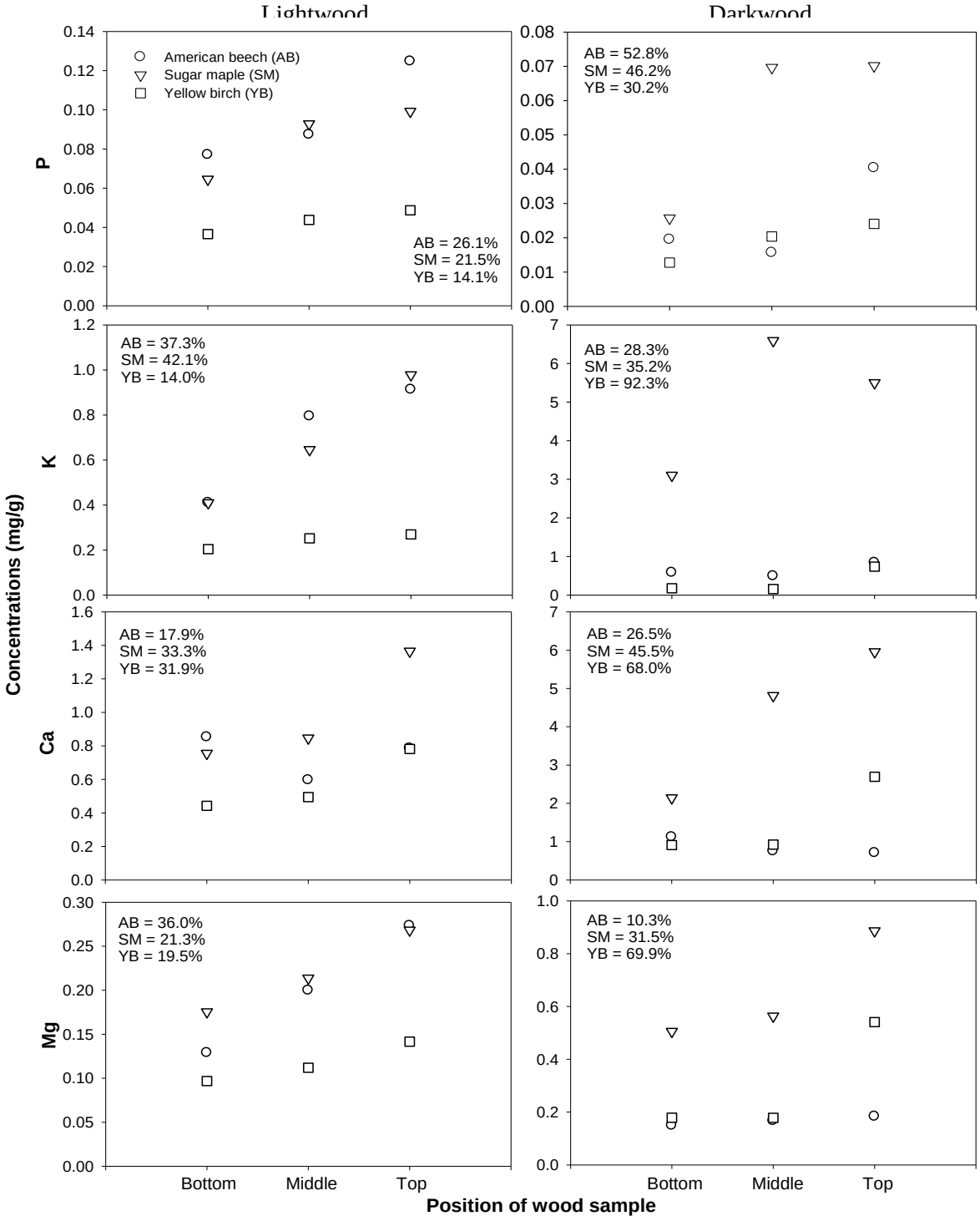
Spatial variation of nutrient concentrations in foliage within the tree. CV was calculated for nutrient concentrations among different sampling positions for each species.



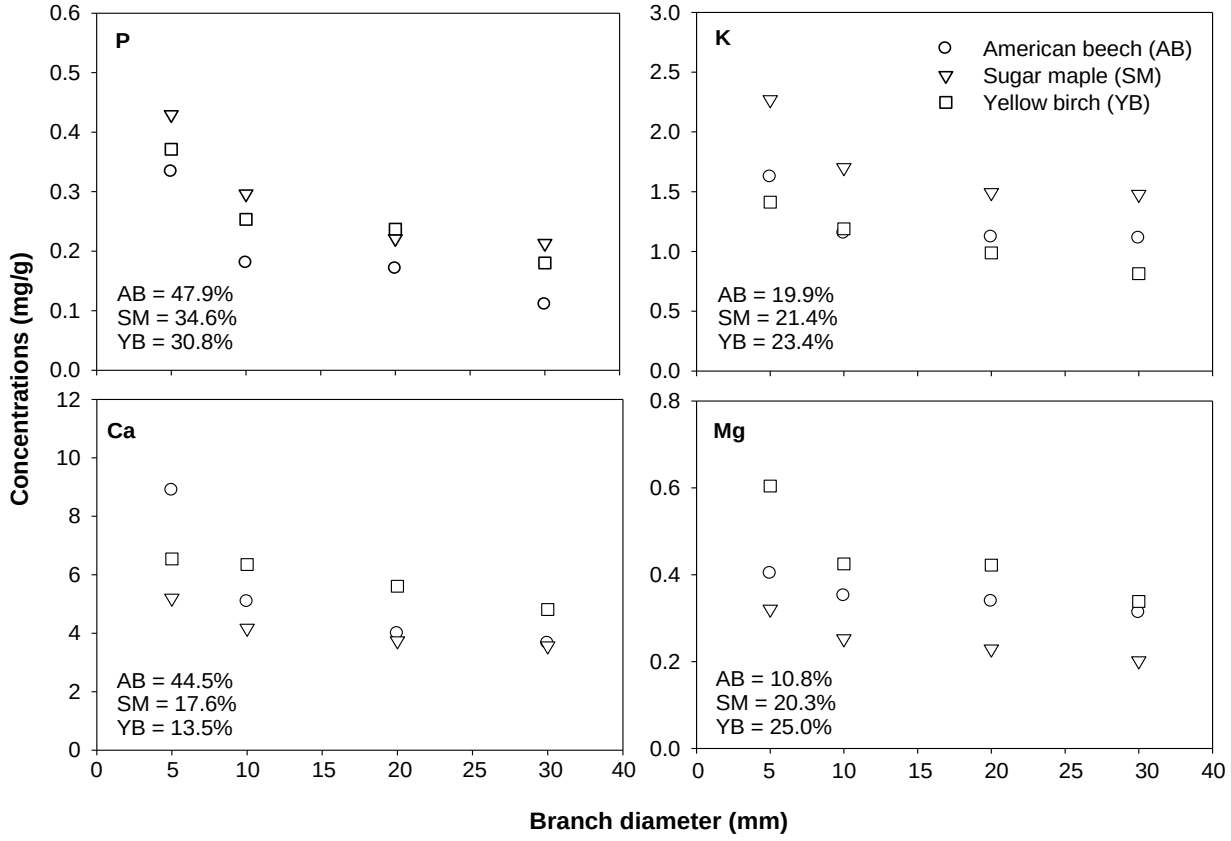
Spatial variation of nutrient concentrations in bark within the tree.



Spatial variation of nutrient concentrations in wood within the tree.



Spatial variation of nutrient concentrations in branches within the tree.



Vita

YANG YANG

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EDUCATIONAL BACKGROUND

State University of New York 2015
College of Environmental Science and Forestry, Syracuse, NY
M.S. in Forest and Natural Resources Management

Minzu University of China, Beijing, China 2012
B.S. in Environmental Science

RESEARCH EXPERIENCE

SUNY College of Environmental Science and Forestry Spring and Summer 2014
Research Project Collaborator

- Collaborated with PIs to design the experiments of measuring mercury in wood, helped write the proposal and received $5,700 as a seed grant at ESF.
- Collected tree disc samples in the Hubbard Brook Experimental Forest, prepared wood samples using different drying temperature, analyzed total mercury concentrations using the Milestone Analyzer.

United States Department of Agriculture Forest Service Summer 2013
Research Intern in Northern Research Station

- Wrote proposals to Research Approval Committee in Hubbard Brook Experimental Forest and received the approval of collecting tree samples in watershed 7.
- Collected samples and analyzed nutrient concentrations in different tree components by tissue positions using CN-analyzer and ICP-MS.

SUNY College of Environmental Science and Forestry 2012-14
Research Assistant (Ruth Yanai's lab)

- Assisted with monitoring soil respiration, taking minirhizotron images and doing tree inventory in the Bartlett Experiment Forest.
- Modeled streamflow datasets using composite, regression and linear interpolation methods, calculated the loads and related bias for four solutes.
- Performed uncertainty analysis of litterfall mass and nutrient concentrations using bootstrapping.
- Collected tree samples in Huntington Wildlife Forest, analyzed nutrient concentrations in tree samples using CN-analyzer and ICP-MS.
- Trained technicians in the field and laboratory, and provided analysis assistance.

Minzu University of China, Beijing, China 2009-10
Project Leader

- Organized and managed a research team, wrote proposals and received $4,700 from Program of 985 Project Foundation of MUC (MUC985-09) and Undergraduate Research Training Program of MUC (URTP201011071).
- Performed nitrogen fertilization in urban greenings and remote forests, collected soil samples, analyzed physical and chemical properties.
- Performed data management and analysis, wrote and presented a report.

Minzu University of China, Beijing, China Spring 2012
Field and Lab Technician (Jinchao Feng's lab)

- Measured plant respiration rate using IRGA along with soil moisture.
- Assisted with soil sampling and data management.

- Prepared reagents and pre-set instruments for Environmental Monitoring laboratory sections.

Chinese Research Academy of Environmental Science (CRAES), Beijing, China Spring 2011
Research Intern in Environmental Ecological Research Institute
- Ground soil samples, performed acid digestion and ICP analysis.
- Assisted with data management, analysis and report writing.

TEACHING EXPERINECE

Syracuse City School District Spring 2015
Instructor, Natural science and chemistry
- Developed syllabus, lectured, and designed experiments for Fifth grade at Dr. King Elementary School and Van Duyn Elementary School.
- Coordinated the production and distribution of print and web-based information materials.
- Generated evaluations and reports for elementary mentoring program.

SUNY College of Environmental Science and Forestry Fall 2012–14
Teaching Assistant, General Chemistry II and Introduction of Chemistry
- Taught two laboratory sections, graded lab reports and exams, held weekly office hours.

VOLUNTEER EXPERIENCE

Guilin Environmental Center (NGO), Guangxi, China December 2013
Project Coordinator
- Organized volunteers and interns, improved the team capacity.
- Developed the research aspects of survey plan for Lijiang River.
- Evaluated projects and wrote summary reports.

American Chemical Society Syracuse Section, Syracuse, NY October 2012
Project Assistant
- Presented demonstrations of experiments focusing on nanotechnology to the public.
- Conducted activities about chemical experiments for children.

UCT International Culture Development, New York (NGO) Summer 2011
International Coordinator
- Assisted with organizing Chinese culture exhibition in the United Nations in New York.
- Coordinated with UN Chinese Book Club to organize media press conference and banquet.

60th National Day Celebration Committee of the Municipal government, Beijing, China 2010
Project Assistant
- Trained 15 volunteers and performed dancing in Tiananmen Square at the National Celebration Day.
- Provided tour description and direction to foreign visitors.

PUBLICATIONS

Yang, Y., R.D. Yanai., M. Montesdeoca., and C.T. Driscoll. 2015. Measuring Mercury in Wood: Important but Challenge. Canadian Journal of Forest Research. (*Under review*)

Germain, R.H., R.D. Yanai, A.K. Mishler, **Y. Yang** and BB Park. 2014. Landscape and Individual Tree Predictors of Dark Heart Size in Sugar Maple. Journal of Forestry.113: 20-29.

PRESENTATIONS

Yang, Y., R.D. Yanai., M. Montesdeoca., and C.T. Driscoll. Measuring Mercury in Wood: Important but Challenge. SUNY/CUNY Graduate Research Poster Session. Albany, NY. February 11, 2015.

Yang, Y., R.D. Yanai., M. Montesdeoca., and C.T. Driscoll. Measuring Mercury in Wood: Important but Challenge. New York Society of American Foresters Meeting, Syracuse, NY. January 22, 2015.

Yang, Y. Detecting differences of tissue chemistry in four northern hardwoods tree species. Presentation in defense of Masters Thesis, SUNY-ESF, Syracuse, NY. November 14, 2014.

Yang, Y., R.D. Yanai., M. Montesdeoca., and C.T. Driscoll. Measuring Mercury in Wood: Important but Challenge. American Geophysical Union Fall Meeting, San Francisco, CA. December 18, 2014.

Yang, Y., R.D. Yanai, and R.D. Briggs. Detecting differences of tissue chemistry in four northern hardwoods tree species. Ecological Society of America Annual Meeting, Sacramento, CA. August 14, 2014

Yang, Y., C.R, See, and R.D. Yanai. Sampling intensity and uncertainty in litterfall mass and nutrient flux in northern hardwoods. Ecological Society of America Annual Meeting Later Poster Session, Sacramento, CA. August 15, 2014

Yang, Y., R.D. Yanai, and R.D. Briggs. Detecting differences of tissue chemistry in four northern hardwoods tree species. SUNY-ESF Spotlight on Graduate Student Research, Syracuse, NY.

Yang, Y. Source of variability in tissue chemistry in northern hardwood species. New York Society of American Foresters Meeting, Syracuse, NY. January 23, 2014

Aulenbach, B.T., D.A. Burns., J.B. Shanley., R.D. Yanai., KiKiang. Bae., A.D. Wild., **Y. Yang**., and Y. Dong. Uncertainty of streamwater solute fluxes in five contrasting headwater catchments including model uncertainty and natural variability. American Geophysical Union Fall Meeting, San Francisco, CA. December 10, 2013

Yang, Y. Detecting change over time in tree tissue chemistry. Rochester Academy of Science Fall Paper Session, Rochester, NY. November 9, 2013

Yang, Y, and R.D. Yanai. Detecting change over time in tree tissue chemistry Hubbard Brook 50th Cooperator's Meeting, Hubbard Brook Experimental Forest, NH. July 10, 2013

Yang, Y, and Jinchao FENG. Effects of simulated nitrogen deposition on soil microbial quantities in Fragrant Mountain in Beijing Undergraduate Research and Training Program Report Session, Minzu University of China, BJ, China. December 25, 2010

FELLOWSHIPS, GRANTS, AWARDS, AND CERTIFICATE

C. Eugene Farnsworth Fellowship	Dept Forest and Natural Resources Management, SUNY-ESF (2015)
Graduate Student Travel Grant	Dept Forest and Natural Resources Management, SUNY-ESF (2014)
Certificate of Level-1 Game of Logging Chainsaw Training	Bill Lindloff's ProCUTS (2013)
Sussman Foundation Fellowship	Edna Bailey Sussman Foundation (2013)
Second-class scholarship	Minzu University of China, China (2012)
Second prize of 2nd Chemical Experiment Competition	Minzu University of China, China (2010)
Second prize of 1st Biological Experiment Competition	Minzu University of China, China (2010)
Second-class scholarship	Minzu University of China, China (2010)
First-class scholarship	Minzu University of China, China (2009)
Undergraduate Research Training Grant	Minzu University of China, China (2009)

SKILLS

Statistics and Spatial: R, SAS, SPSS, Microsoft offices and ArcGIS
Field: Soil respiration (Licor 8100) and Minirhizotrons
Laboratory: ICP-MS, Kjeltec Auto Analyzer and Total Mercury Analyzer

SOCIETY MEMBERSHIPS

- Ecological Society of America
- American Geophysical Union