United States
Department of
Agriculture

Forest Service

**Northeastern
Research Station**

General Technical
Report NE-324

Tree Chemistry Database (Version 1.0)

**Linda H. Pardo
Molly Robin-Abbott
Natasha Duarte
Eric K. Miller**

Abstract

The Tree Chemistry Database is a relational database of C, N, P, K, Ca, Mg, Mn, and Al concentrations in bole bark, bole wood, branches, twigs, and foliage. Compiled from data in 218 articles and publications, the database contains reported nutrient and biomass values for tree species in the Northeastern United States. Nutrient data can be sorted on parameters such as stand age, sample year, region, and glaciation. This report documents database development and provides instructions for use of the database, which is included on an accompanying CD-ROM.

The Authors

LINDA H. PARDO is an environmental engineer, MOLLY ROBIN-ABBOTT is a biological science technician, and NATASHA DUARTE is a soil scientist with the USDA Forest Service's Northeastern Research Station at Burlington, Vermont. ERIC K. MILLER is an environmental scientist with Ecosystems Research Group, Ltd., Norwich, Vermont.

Manuscript received in Publications 28 June 2004

Cover Photo

Fall foliage in Massachusetts is a brilliant example of tree chemistry at work.

Published by:

USDA FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073-3294

February 2005

For additional copies:

USDA Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740)368-0152

Visit our homepage at: **http://www.fs.fed.us/ne**

Introduction

The Tree Chemistry Database is designed to be a comprehensive and searchable relational database of C, N, P, K, Ca, Mg, Mn, and Al concentrations in above-ground tree-biomass compartments. The complete database contains all published nutrient values that could be located for tree species in the Northeastern United States. The database supports regional calculations of critical loads for N and S deposition to forest ecosystems. A key component of such calculations is estimating potential nutrient removal due to biomass removal. To estimate these values when direct measurements were unavailable, regional means of nutrient concentration and biomass (by compartment and species) were used. This compilation of nutrient concentrations for tree species in the Northeastern United States and eastern Canada can be used for estimates of nutrient content or nutrients removed during harvesting. The data also can be used to compare measured site data with regional means, or for modeling activities.

The data are entered into linked Microsoft Access[1] tables. This format increases efficiency and allows users to specify and extract tree chemistry values according to individual needs. An overview of the database design is shown in Figure 1.

Development of a complete database entails well-planned design, a thorough search for data sources, and intelligent data selection. The following sections describe the Tree Chemistry Database. The process of data extraction from and utilization of the database also is described, and extracted nutrient values for selected tree species are presented. The results are shown in Figures 2-9. Mean nutrient concentrations for 17 tree species are summarized in Table 1.

Tree Chemistry Database Design

As mentioned, all information included in the Tree Chemistry Database is entered into Microsoft Access tables. There are 10 tables in the database: Study Description, Nutrients, Site, Species, Land Use, Analytical Method, Plant Digest Method, Foliar Sample Location, State, and Publication (Fig. 1). The complete tables for Species, Land Use, Analytical Method, and Plant Digest Method are in the Appendix.

Entries in each table are identified by a unique ID number that allows the database tables to be linked in what Microsoft Access terms "one to many" relationships. For example, the ID number for sugar maple, 7, appears once in the "Species_#" column of the Species table. The same number appears several times in the "Species_#" column of the Nutrients table, thus linking multiple entries in the Nutrients table to one entry in the Species table.

Descriptions of the Tree Chemistry tables follow.

Study Description Table

The Study Description table contains reference information for each citation in the database. Each article, thesis, or book chapter has an individual entry. If the data from a

---

[1]The use of trade, firm, or corporation names in this report is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or Forest Service of any product or service to the exclusion of others that may be suitable.

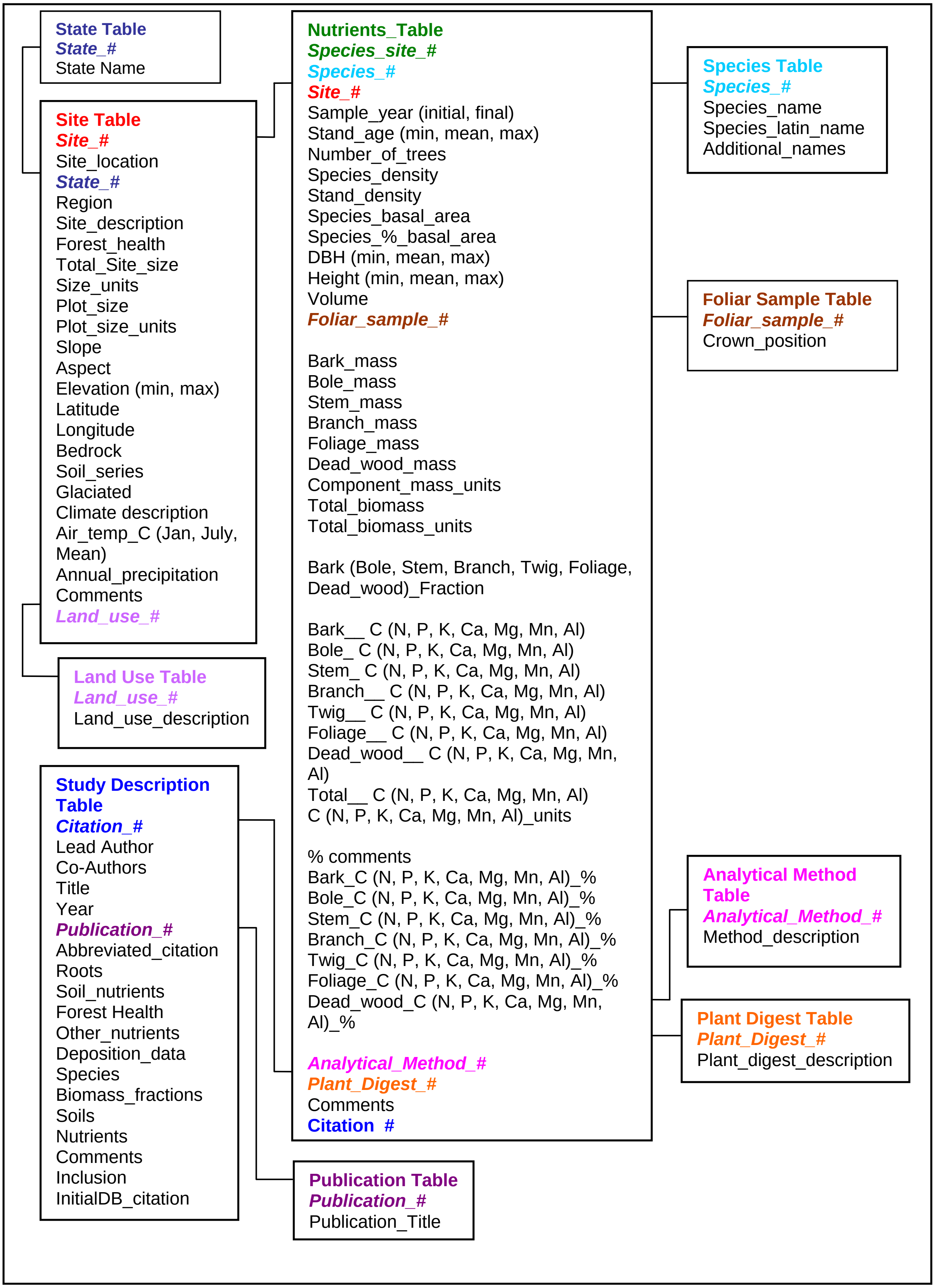


Figure 1.—Design of Tree Chemistry Database.

given citation were incompatible with database parameters, for example, they were for current needles only instead of for all age classes, the citation was entered into the Study Description table but not into the other tables.

The Study Description table includes Citation ID number, lead author, coauthors, year of publication, article title, abbreviated citation (e.g., publication name, volume, and page numbers); Publication ID number, lists of tree species, biomass compartments, and nutrients studied; comments on irregularities in the citation; Initial DB citation code (Y=in initial Excel[1] database, N=not in initial Excel database); and inclusion code (0=included, 1=excluded from the rest of the database). The table also includes sections coded to indicate whether root, soil, forest health, additional nutrient, and deposition data are reported in the citation (0=data not reported in the citation, 1=data reported in the citation). These sections are provided for informational purposes; specific data are not included in the database.

A citation may provide information for multiple Site and Nutrients table entries. The Study Description table has a "one to many" relationship with the Nutrients table and a "many to one" relationship with the Publication table (Fig. 1).

Nutrients Table

The Nutrients table provides information on stand growth characteristics, reported nutrient concentrations, and methods used for sampling. Each entry in the table is a unique combination of data on species, site, and stand age from one citation. As a result, multiple Nutrients table entries can be based on information in a single citation.

Entries in this table include Species and Site ID numbers; study year; stand age; number of trees sampled; foliar sample ID; DBH, height, species and stand density, basal area, and volume; total and compartment biomass; biomass fractions (percent distribution of above-ground biomass in biomass compartments); C, N, P, K, Ca, Mg, Mn, and Al nutrient concentrations in dead wood, stem (bole bark and wood combined), bark (bole bark), bole (bole wood), branches, twigs, and live foliage; nutrient-concentration units; C, N, P, K, Ca, Mg, Mn, and Al percent in dead wood, stem (bole bark and wood combined), bark (bole bark), bole (bole wood), branches, twigs, and live foliage; comments on percent calculations; comments on data entry irregularities; and Analytical Method, Plant Digest Method, and Citation ID numbers. Nutrient values for leaf litter are not included in the database.

There are separate categories for maximum, minimum, and average stand age, height, and DBH values. Entries were made into these categories if values were reported. The Nutrients table is linked to the Species, Site, Analytical Method, Plant Digest Method, Foliar Sample, and Study Description tables in "many to one" relationships (Fig. 1).

Site Table

The Site table contains information on site location and specific site characteristics. Each entry in the table is from a unique site or study area as described in a citation. Information from multiple sites can be reported in one citation. Site scale varies with the study protocol and can be as small as a plot of several hundred square meters or as large as a watershed. When authors combined data from multiple locations, the sites may span adjacent states.

The Site table provides the following information: description; location; State ID (state, province, or country); region; forest health code (0=healthy, 1=declining, 9999=data missing); site size and size units; plot size and units; slope, aspect, and elevation; latitude and longitude; bedrock type; soil series or soil description; glaciation code (0=not glaciated, 1=glaciated, 9999=data missing); climate description; average temperature and precipitation; comments on site data or data entry irregularities; and Land Use ID number. The Site table has a "one to many" relationship with the Nutrients table and a "many to one" relationship with the Land Use and State tables (Fig. 1).

Species Table

The Species table (Appendix Table 2) consists of a Species ID number (Species_#) for each species and its scientific, common, and alternate names. The Species table is linked to the Nutrients table through the Species ID number in a "one to many" relationship (Fig. 1).

Land Use Table

The Land Use table (Appendix Table 3) consists of a Land Use ID number and a description of land-use patterns. This table is linked to the Site table in a "one to many" relationship (Fig.1).

Analytical Method Table

Each entry in the Analytical Method table (Appendix Table 4) includes a unique set of procedures for determining the concentration of nutrient elements in prepared plant tissue. Similar analytical techniques were combined under a common name to simplify the database. Categorization was aided by information provided by Jane Hislop (USDA Forest Service) and Bickelhaupt (1979), among other sources. Micro, semi-micro, and Kjeldahl nitrogen determinations are *Kjeldahl N*. Technicon Autoanalyzer analysis is *colorimetric*, as are various phosphorus colorimetric assays. Flame Emission Spectroscopy, Flame Photometry, Spark Emission Spectroscopy, and Atomic Emission Spectroscopy are *AES* (Atomic Emission Spectroscopy). *AAS* is atomic absorption spectroscopy. *ICP-AES* is inductively coupled plasma atomic emission spectroscopy; *DCP-AES* is direct current plasma atomic emission spectroscopy. Spectroscopy, spectrometry, and spectrophotometry are considered interchangeable in this section. The Analytical Method table is related to the Nutrients table in a "one to many" relationship (Fig. 1).

Plant Digest Method Table

Each entry in the Plant Digest Method table (Appendix Table 5) includes chemical digestion procedures for extracting plant nutrients. This information is separate from the Analytical Method table to simplify the database. Many citations used the same plant digest technique or the same element analysis technique, but few used both the same plant digest and element analysis method. The Plant Digest Method table is linked to the Nutrients table in a "one to many" relationship (Fig.1).

Foliar Sample Table

The Foliar Sample table provides the foliar sample ID and the corresponding crown position description. It is linked to the Nutrients table in a "one to many" relationship (Fig. 1).

State Table

The State table contains an ID code and full name for each state, Canadian province, or non-North American country. It is linked to the Site table in a "one to many" relationship (Fig. 1).

Publication

The Publication table lists all publications from which various citations originated. This table is linked to the Study Description table in a "one to many" relationship (Fig. 1), and facilitates searches by publication title.

Data Sources

The Tree Chemistry Database contains all published nutrient values that could be located for above-ground biomass compartments of tree species in the Northeastern United States. Data are included both for trees sampled in the Northeast, and for Northeastern species sampled in other parts of the world. The database is as comprehensive as possible for the bole, bark, and branch chemistry of trees sampled in the Northeast. It does not include all published values for trees sampled in other regions, or for foliar data. Users interested in foliar data can access the NERC (Northeastern Ecosystem Research Cooperative) foliar chemistry database (http://www.folchem.sr.unh.edu/).

Sources for nutrient values were journal articles, books chapters and proceedings, USDA and Canadian Forest Service reports, and theses and dissertations. Reported sampling dates for included data ranged from 1931 to 1999; most samples are from after 1960.

Multiple search engines, including Scirus, Google, Altavista, and Agricola, and Web of Science[1], as well as a citation list from Rich Hallett (USDA Forest Service) were used to compile the database. In addition, the USDA and Canadian Forest Services' online literature databases were searched, as were publication lists at the Coweeta, Hubbard Brook, and Harvard Forest Long Term Ecological Research sites. Online library catalogues at universities in the North and Northeast were searched for relevant theses and dissertations. Search terms included *tree(s), nutrient(s), element(s), biomass, content(s), concentration, allocation*, and specific tree species, biomass compartments, and nutrient elements.

Data Selection Criteria

When possible, data were entered as the values and units reported in each citation; *9999* was entered when data for a database parameter were not included in a citation. To simplify data extraction, percentages for all reported nutrient concentrations were calculated and entered into the Tree Chemistry Database.

Much of the tree chemistry data could not be entered directly into the database. Data that did not conform to database parameters were transformed when possible; data that could not be transformed were excluded from database entry.

Examples of transformed data are the stand parameters height and DBH, which were converted from English to metric units when necessary. Nutrient values in non-database biomass compartments were transformed to biomass compartment values when possible. For example, branch nutrient data occasionally were presented separately for branch wood and branch bark. If the wood and bark values were reported as amounts (kg/ha), they were added to obtain a total branch value. If the branch nutrient data were reported as wood and bark concentrations and the mass for each compartment also was reported, a mass-weighted average concentration for the branch was calculated.

Data also were extracted from charts; data presented in bar graphs were measured and numerical values were calculated. All calculations are noted in the comments section of the Nutrients table.

If nutrient values were presented in an unusable form and could not be transformed, they were not entered into the database. Unusable values include current-year needle nutrient concentrations, which do not accurately represent total foliar nutrient values; nutrient values reported for several species combined; and data in line graphs that could not be measured accurately. At times, all data from a citation were excluded from the database. In such cases, the citation was entered into the Study Description table and marked as excluded.

Using the Database

The complete Tree Chemistry Database is included on the CD-ROM that accompanies this report. The three database versions provided, Microsoft Access 97, 2000, and 2002[1], contain identical information. Users should select the version appropriate to their software packages. The database and documentation also are available online (http://www.hubbardbrook.org/treechem/index.htm).

A basic understanding of Microsoft Access is required to use the database. For answers to specific questions, access the Microsoft Access help file or http://support.microsoft.com/.

In the Tree Chemistry Database, data for each record are stored in multiple tables. Dividing data between tables minimizes the repetition of common information. For example, one citation may provide information on multiple sites. Rather than repeat all of the citation information for every site, that citation is linked to each site with an ID number. To view a table in the open database, select *Tables* from the Objects menu at the left of the screen, then select the desired table.

Microsoft Access *Queries* recombine data from separate tables by "joins" on parameter fields shared between tables. In the Tree Chemistry Database, fields like *Citation ID* and *Site ID* are used to join tables. Queries can be used to retrieve specific information from the database without retrieving the entire record. This process is described in more detail elsewhere in this report. To modify an existing query, open the query, and then select *design* from the View menu.

The easiest way to extract data from the Tree Chemistry Database is through queries. Query results can be exported in multiple formats, including dBASE, Lotus, and Microsoft Excel[1], and analyzed or used directly. To export a query, highlight (but do not open) the desired query. From the File menu, select export. Be sure to choose the desired file type when exporting the file. The same procedure can be followed to export tables if users prefer to work with the data in a format other than Access.

Many parameters have been included in the database to help identify the appropriate subset of the data that is relevant to the user. For example, a user might choose only data from trees sampled in the Northeastern United States, or trees that are over a certain age. Factors that can be selected to limit the dataset include region (e.g., the Northeast or eastern Canada), forest health, land use (e.g., past cultivation or plantations), stand age, species, and DBH.

The Tree Chemistry Database contains several sample queries that can be used as references or modified according to user needs. The following are several sample queries of the Tree Chemistry Database: **Query 1**: Aspen bark and bole Ca, Mg (query of a single species); **Query 2**: Sugar maple, elevation>200 (single species, limited elevation); **Query 3**: Sugar maple, longitude>75 (single species, limited longitude); **Query 4**: Declining (all species with declining forest health); **Query 5**: Glaciated (all species on glaciated sites); **Query 6**: Land use (all species with similar land use); **Query 7**: Other nutrients reported in study citations (Study Description table query); **Query 8**: Nutrient values from the initial database (Study Description table and Nutrients table query); **Query 9**: Multiple species limited by age, forest health, and region.

Users may wish to review the queries in the order that they appear as the instructions are most detailed for the first queries.

Query 1: Aspen bark and bole Ca, Mg (query of a single species)
In this query, bark and bole biomass, Ca, and Mg data were extracted for a single species, quaking aspen. To replicate this query, follow these instructions: select *Queries* from the Object menu and then select *Create Query in Design View,* which appears at the top of the list. From the *Show table* box that appears, select the **Species** and **Nutrients** tables. From those tables, select the following parameter fields in the order you would like them to appear. From the **Nutrients** table, select *Species_#, Bark mass, Bole_mass, Component_mass_units, Bark_Ca, Bark_Mg, Bole_Ca, Bole_Mg, Ca_unit, Mg_unit, Bark_Ca_%, Bark_Mg_%, Bole_Ca_%, Bole_Mg_%, %_comments*, and *Comments*. From the **Species** table, select *Species_name*.

In the criteria row of the field **Nutrients** *Species_#,* enter 25, the species number for quaking aspen. This selects all quaking aspen entries in the **Nutrients** table.

After selecting the fields and setting the criteria, select *run* from the Query menu. Microsoft Access should return a spreadsheet similar to the following with the selected biomass and nutrient values for all quaking aspen in the database:

Species_name	Species_#	Bark_ mass	Bole_ mass	component_ mass_units	Bark_ Ca	Bark_ Mg	Bole_ Ca	Bole _Mg	Ca_unit	Mg_unit	Bark_ Ca_%	Bark_ Mg_%	Bole_ Ca_%	Bole_ Mg_%
quaking aspen	25	9999	9999	9999	16190	1386	1114	288	ug/g	ug/g	1.619	0.1386	0.111	0.0288
quaking aspen	25	9999	9999	9999	17347	861	1035	262	ug/g	ug/g	1.7347	0.0861	0.104	0.0262
quaking aspen	25	7.1	33.13	ton/ha	95.8	29.2	230.3	29.2	kg/ha	kg/ha	1.3493	0.4113	0.695	0.0881
quaking aspen	25	9999	9999	Mg/ha	9999	9999	9999	9999	kg/ha	kg/ha	1.52	0.076	0.12	0.02
quaking aspen	25	9999	9999	mg/cm2	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
quaking aspen	25	13.6	70.5	Mg/ha	134.8	11	64.3	10	kg/ha	kg/ha	0.9912	0.0809	0.091	0.0142
quaking aspen	25	9999	9999	9999	9999	9999	9999	9999	9999	9999	1.169	0.11	0.132	0.028
quaking aspen	25	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999

The comment columns have not been included in this sample spreadsheet.

This is the datasheet view of the query. To modify the query, select *design* from the View menu.

As seen in this subset of the spreadsheet, some of the entries have no Ca and Mg values for bole and bark. This is signified by 9999. The criteria entered indicated that all quaking aspen entries were desired regardless of their nutrient status. In the next query, entries that do not have any of the desired values will be eliminated.

Query 2: Sugar maple, elevation >200 (single species, limited elevation)

In this query, percent foliar N, P, K, Ca, Mg, and Al values for all sugar maple at reported elevations above 200 meters are extracted. To do this, select the **Nutrients**, **Species**, and **Site** tables. From the **Nutrients** table, select *Species_#, Foliage_N_%, Foliage_P_%, Foliage_K_%, Foliage_Ca_%, Foliage_Mg_%, Foliage_Mn_%, Foliage_Al_%, %_comments,* and *Comments*. From the **Species** table, select *Species_name*. From the **Site** table, select *Elevation_m_min*.

To return only **Nutrients** table entries with at least one of the specified nutrient values for sugar maples above 200 m, entries with missing values (9999) for all foliar nutrients must be eliminated. To do this, enter <>9999 (this selects for all numbers greater or less than 9999) in successive nutrient rows, as indicated:

Field:	Species_#	Species_name	Elevation_m_min	Foliage_N_%	Foliage_P_%	Foliage_K_%
Table:	Nutrients	Species	Site	Nutrients	Nutrients	Nutrients
Sort:						
Show:						
Criteria:	7		>200 And <>9999	<>9999		
Or:	7		>200 And <>9999		<>9999	
	7		>200 And <>9999			<>9999

The resulting spreadsheet from this query looks something like this:

Species_#	Species_name	Elevation_ m_min	Foliage_ N_%	Foliage_ P_%	Foliage_ K_%	Foliage_ Ca_%	Foliage_ Mg_%	Foliage_ Mn_%	Foliage_ Al_%
7	sugar maple	550	2.19	0.18	1.01	0.6	0.12	0.174	9999
7	sugar maple	630	2.19	0.18	1.01	0.6	0.12	0.174	9999
7	sugar maple	710	2.19	0.18	1.01	0.6	0.12	0.174	9999
7	sugar maple	260	1.7	0.22	0.68	0.58	0.06	9999	9999
7	sugar maple	410	1.67	0.11	0.75	0.44	0.06	9999	9999
7	sugar maple	400	2.02	0.18	0.59	0.68	0.1	9999	9999
7	sugar maple	220	1.75	0.18	0.74	0.58	0.09	9999	9999
7	sugar maple	240	1.55	0.21	0.48	0.51	0.13	9999	9999
7	sugar maple	335	1.55	9999	9999	9999	9999	9999	9999
7	sugar maple	259	1.38	9999	9999	9999	9999	9999	9999
7	sugar maple	270	9999	9999	9999	0.84	0.13	9999	9999
7	sugar maple	700	1.9	0.13	0.79	0.52	0.09	9999	9999
7	sugar maple	488	1.55	9999	9999	9999	9999	9999	9999
7	sugar maple	330	9999	9999	9999	0.53	0.09	9999	9999
7	sugar maple	500	1.965	0.135	0.65	0.97	0.29	0.08855	0.0026

The comment columns have not been included in this sample spreadsheet.

Although not all entries have percent values for every nutrient, they do have values for at least one of the seven nutrients. In the next query, only entries that contain values for all of the selected nutrients will be returned.

Query 3: Sugar maple, longitude >75 (single species, limited longitude)

This query selects N, P, and K percent values for sugar maple at longitudes greater than 75, as well as the state ID for each entry. Select the tables **Nutrients**, **Species**, and **Site**. From the **Nutrients** table select the parameter fields *Species_#, Foliage_N_%, Foliage_P_%,* and *Foliage_K_%*. From the **Species** table select *Species_name*. From the **Site** table, select *State_#* and *Longitude*.

Set the criteria so that only sugar maple entries with all desired nutrients will be returned:

Field:	Species_#	Species_name	State_#	Longitude	Foliage_N_%	Foliage_P_%	Foliage_K_%
Table:	Nutrients	Species	Site	Site	Nutrients	Nutrients	Nutrients
Sort:							
Show:							
Criteria:	7			>"75" And <>"9999"	<>9999	<>9999	<>9999

When the query is run, a table like this is returned:

Species_name	Species_.	State_#	Longitude	Foliage_N_%	Foliage_P_%	Foliage_K_%
sugar maple	7	WI	89.667 W	1.88	0.32	1.04
sugar maple	7	ON	76.317 W	1.8	0.22	0.47
sugar maple	7	MI	87.883 W	1.847	0.25	0.99
sugar maple	7	ON	77.533 W	1.009	0.195	0.767

The examples in the first three queries should give users an idea of how to perform a query to obtain desired information. The remaining query descriptions provide general information on selection and format.

Query 4: Declining (all species with declining forest health)

Query 4 selects all stands in the **Nutrients** table with declining forest health, and links the entries to their source citations. To do this, select the **Species**, **Site**, **Nutrients**, and **Study Description** tables. Select the following parameter fields from the tables: **Species** *Species_name*, **Site** *Forest_Health*, **Nutrients** *Citation_#,* and **Study Description** *Author, Title, Year*, and *Abbreviated_Citation*. To select declining stands, enter *1* in the criteria row of **Site** *Forest Health*. The forest health codes are given in the **Site** table description.

Query 5: Glaciated (all species on glaciated sites)

This query selects parameter fields from four tables: **Species**, **Site**, **Nutrients**, and **Study Description**. Select the fields **Species** *Species_name*, **Site** *Glaciated*, **Nutrients** *Citation_#,* and **Study Description** *Author, Title, Year*, and *Abbreviated_Citation*. To select for glaciated stands, enter *1* in the criteria row of **Site** Glaciated. Glaciation codes are given in the **Site** table description.

Query 6: Land use (all species with similar land use)

Select parameter fields from these tables: **Species** *Species_name*, **Site** *Land_Use_#,* **Land Use** *Land Use Description*, **Nutrients** *Citation_#,* and **Study Description** *Author, Title, Year*, and *Abbreviated_Citation*. To specify land use, enter *1 or 3 or 5 or 6 or 18 or 9* in the criteria row of **Site** *Land_use_#,* which selects for second-growth/regrowth, regrowth after burn, regrowth after past cultivation, regrowth after past pasture, plantation second growth, and regrowth after logging.

Query 7: Other nutrients reported in study citations

This query searches the **Study Description** table for citations with nutrients other than those found in the database. From the **Study Description** table, select the parameter fields *Citation_#, Author, Title, Year, Abbreviated_Citation, Other_Nutrients*, and *Nutrients*. Enter *1* into the criteria row of **Study Description** *Other_Nutrients* to select for citations with data for nutrients other than those entered into the database. This coding is explained in the **Study Description** table section. All nutrients reported in a citation are listed in the *Nutrients* field.

Query 8: Nutrient values from the initial database

Search for nutrient values from citations that were found in the initial Microsoft Excel version of the database. From the **Study Description**, **Species**, and **Nutrients** tables, select the parameter fields **Study Description** *Citation_#,* and *InitialDB_citation*, **Species** *Species_name*, and **Nutrients** *Species_#, Bark_N_%, Bark_K_%, Bark_Ca_%, Bark_Mg_%, Bole_N_%, Bole_K_%, Bole_Ca_%, Bole_Mg_%, Branch_N_%, Branch_K_%, Branch_Ca_%, Branch_Mg_%, Foliage_N%, Foliage_K_%, Foliage_Ca_%, Foliage_Mg_%, %_comments*, and *Comments*. To select only citations that were found in the initial Excel version of the database, enter *Y* in the criteria row of **Study Description**

InitialDB_citation. To select specific tree species, enter their species IDs: *25 or 66 or 8 or 61 or 60 or 18 or 2 or 3 or 41 or 6 or 14 or 22 or 1 or 7 or 9 or 4 or 55 or 5 or 21 or 10* into the criteria row of the **Nutrients** *Species_#* field.

In the final query, data is selected, extracted, and analyzed in Microsoft Excel.

Query 9: Multiple species limited by forest health, age, and region
This query was used to create Table 1. In this query, N, P, K, Ca, and Mg concentrations in the foliage, branch, bark and bole for multiple tree species are obtained. The results are limited so that only values from healthy trees more than 10 years old that were sampled in or near the Northeast are returned.

First select tables with parameter fields necessary for the calculations. These include **Nutrients**, **Site**, and **Species**. Next, select fields from the tables. From **Species**, select *Species_Name*. From the **Site** table, select *Forest_Health* and *Region*. From **Nutrients**, select *Species_#, Stand_age_average, Stand_age_min, Number_of_trees, %_comments, Bark_N_%, Bark_P_%, Bark_K_%, Bark_Ca_%, Bark_Mg_%, Bole_N_%, Bole_P_%, Bole_K_%, Bole_Ca_%, Bole_Mg_%, Branch_N_%, Branch_P_%, Branch_K_%, Branch_Ca_%, Branch_Mg_%, Foliage_N_%, Foliage_P_%, Foliage_K_%, Foliage_Ca_%, Foliage_Mg_%, Comments*, and *citation_#.*

In the criteria row of **Nutrients** *Species_#,* enter *25 or 66 or 8 or 61 or 60 or 18 or 2 or 3 or 41 or 6 or 14 or 22 or 1 or 7 or 9 or 4 or 55 or 5 or 21 or 10*, thus selecting all **Nutrients** table entries with those species numbers. In the criteria row of **Site** *Forest_Health*, enter <>1, which selects for all stands other than *1* (declining forest health) in the *Forest_Health* field. In the criteria row of **Site** *Region*, enter *eastern Canada or central Canada or northeast or mid Atlantic or north central* to limit the region accordingly. In **Nutrients** *Stand_age_average* and *Stand_age_min,* enter the criteria *>9*.

When all of the criteria have been entered, choose *run* to obtain results. The resulting query table should contain age and regionally limited nutrient values for the selected tree species.

At this point the data can be analyzed with a spreadsheet program. One option is to export the data to Microsoft Excel[1] to perform calculations. To create Table 1, the query results were exported to Excel such that all 9999 values were replaced with ".." so that calculations were not affected. Repeated nutrient values from citations 15 and 28 were eliminated from the calculations. The cause of these repeated nutrient values is discussed in the QA/QC section. A pivot table was then used to average values by tree species.

QA/QC

The Tree Chemistry Database is as uniform as possible; values for stand parameters, biomass, and nutrient concentrations were entered into fields that most accurately reflected the sampled compartments. However, the disparate nature of the source data meant that data were at times altered to conform to database parameters. These changes were documented in the comments column of the database. However, some inconsistencies may remain. This section contains information on potential sources of inaccuracy in the Tree Chemistry Database. These sources include sampling imprecision, nutrient value calculations and conversions, stand unit conversions, and assumptions about units.

Sampling

Samples were not taken uniformly, as definitions of biomass compartments–stem, bark, bole, branch, twig, and deadwood–differed between studies. Some authors provided clear descriptions of compartments studied while others did not. Most authors provided neither location of bole and bark samples on the stem, nor the volume included in bole measurements. Similarly, authors rarely distinguished between branches and twigs, and distinctions made were not consistent between studies. When reported data deviated from database categories, they were transformed when possible to match the most appropriate category. For example, wood values reported separately as light wood and dark wood were combined to obtain total bole nutrient values. Any transformations were noted in the comments column of the Nutrients table. If compartment samples deviated insignificantly from the database categories, the data were entered along with a comment in the comments column. Data that could not be placed in a database category (e.g., nutrient values for large branches and small branches reported separately and with insufficient data to combine them) were not entered into the database. This also was noted in the comments column.

Other sources of variability were foliar sample location and age. Foliar sample location varied between studies. Because it may be an important factor in foliar nutrient concentration variability, the sample location was indicated by a code number entered in the foliar sample location column of the Nutrients table. Conifer foliar samples were entered only if they were representative of all needle ages. Samples that included only current-year needles were not included in the database. Data on current-year only needles could have been entered into the database erroneously if sample age was not indicated by the authors.

Nutrient Value Calculations and Conversions

Other potential sources of inaccuracy in the database arise from the measurement and calculation of numeric nutrient values from line graphs, or from the calculation of nutrient percentages from biomass values. These calculations are noted in the comments and percent comments columns in the Nutrients table, respectively.

At times, multiple results were reported for the same species and location. These multiple values were reported across consecutive years, within one season, or for micro-sites (sites that did not differ at the resolution of the Tree Chemistry Database). In most cases, these multiple results were averaged to obtain one set of nutrient values for the species-site combinations. These calculations were noted in the comments column. Users of the database who would like a full set of values for these studies should refer to the original citation.

In two other citations, 15 and 28, the same nutrient concentration values were reported for stands with different biomass values. Each biomass-nutrient combination was entered into the database separately. Users should be aware that a query that includes data from the two citations may result in duplicate nutrient concentration values.

Stand Unit Conversions

As described earlier, stand parameters were occasionally converted to agree with predetermined database units. These conversions were documented in the comments column of the Nutrients table. It is possible that unconverted, and thus incorrect, stand values could have been entered into the database.

Unit Assumptions

Another potential source of unit error occurs with biomass. Some authors used the word "ton" without indicating the type, for example, metric, long, or short. The assumption was made that if all other units in the article were metric, the ton also was a metric ton. This assumption was not noted in the Nutrients table. Errors in this assumption could result in value errors if nutrient percent concentrations were calculated using biomass values.

Other sources of inaccuracy might be found in the database, including data entry or coding errors. However, the aforementioned are the most common sources of inaccuracy that should be considered when using the database.

Data Summary: Figures

The structure of the database allows the user to sort the data to restrict the subset extracted to the one that is most meaningful for the particular research question. It is important to consider how the dataset should be limited to best address the question. For example, the user might evaluate data collected only after a certain date, or above a certain elevation, or for a particular region. Caution must be used in interpreting data when the sample sizes are small. Also note that the number of stems measured may be much higher than the number of sites measured.

Figures 2-9 demonstrate a potential use of the database. In this case, nutrient values for selected species were extracted from the database with the following restrictions: trees were from non-declining stands, were at least 10 years old, and were sampled in the Northeast, mid-Atlantic, central or eastern Canada, or North Central regions. The resulting values were graphed in box plots to show the range of nutrient values in the selected tree species.

Figure 10 illustrates another way to use the database. Bole nutrient values were plotted against bark nutrient values for paper birch, aspen, balsam fir, and red pine to determine whether any patterns emerged.

Acknowledgments

This project was funded in part byt the Northeastern States Research Cooperative, a joint program of The Rubenstein School of Environment and Natural Resources at the University of Vermont and the Northeastern Research Station. We thank Rich Hallett for sharing tree nutrient chemistry citations. We also thank Julian Aherne, Mary Arthur, Scott Bailey, Nancy Burt, Ellen Denny, Steve Fay, Dave Funk, Christine Goodale, Jane Hislop, Steve Horsley, Bill Leak, Rock Ouimet, Paul Schaberg, and Shaun Watmough for their helpful comments and suggestions.

Published Literature Used in Compiling Tree Chemistry Database

Adamowicz, A.; Skelly, J.M.; McCormick, L.H. 1993. **Temporal changes in Norway spruce foliar nutrients and response to fertilization.** In: Huettl, R.F.; Mueller-Dombois, D., eds. Forest decline in the Atlantic and Pacific region. Berlin: Springer-Verlag: 144-161.

Adams, M.B.; Kochenderfer, J.N.; Angradi, T.R.; Edwards, P.J. 1995. **Nutrient budgets of two watersheds on the Fernow Experimental Forest.** Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 119-130.

Alban, D.H. 1988. **Nutrient accumulation in planted red and jack pine.** Res. Pap. NC-282. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.

Alban, D.H.; Pastor, J. 1993. **Decomposition of aspen, spruce, and pine boles on two sites in Minnesota.** Canadian Journal of Forest Research. 23: 1744-1749.

Alban, D.H.; Perala, D.A.; Schlaegel, B.E. 1978. **Biomass and nutrient distribution in aspen, pine and spruce stands on the same soil type in Minnesota.** Canadian Journal of Forest Research. 8: 290-299.

Alway, F.J.; Maki, T.E.; Methley W.J. 1934. **Composition of the leaves of some forest trees.** American Soil Survey Association Bulletin. 15: 81-84.

Arp, P.A.; Manasc, J. 1988. **Red spruce stands downwind from a coal burning power generator: tree ring analysis.** Canadian Journal of Forest Research. 18: 251-264.

Arthur, M.A.; Siccama, T.G.; Yanai, R.D. 1999. **Calcium and magnesium in wood of northern hardwood forest species: relations to site characteristics.** Canadian Journal of Forest Research. 29: 339-346.

Auchmoody, L.R.; Hammack, K.P. 1975. **Foliar nutrient variation in four species of upland oaks.** Res. Pap. NE-331. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Service Experiment Station.

Baer, N.W. 1985. **Nutrient content in eastern red cedar foliage: seasonal variation.** Tech. Bull. 86. Brookings, SD: South Dakota State University, Agricultural Experiment Station.

Baker, J.B.; Blackmon, B.G. 1977. **Biomass and nutrient accumulation in a cottonwood plantation—the first growing season.** Soil Science Society of America Journal. 41: 632-636.

Baker, J.B.; Randall, W.K. 1975. **Foliar nitrogen and potassium variation in cottonwood as affected by genetic and site factors.** In: Proceedings, ninth central states forest tree improvement conference, October 1974, Ames, Iowa. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 106-111.

Bandle, B.J.; Day, F.P., Jr. 1985. **Influence of species, season, and soil on foliar macronutrients in the Great Dismal Swamp.** Bulletin of the Torrey Botanical Club. 112(2): 146-157.

Bard, G.E. 1945. **The mineral nutrient content of the foliage of forest trees on three soil types of varying limestone content.** Soil Science Society Proceedings. 10: 419-422.

Bartos, D.L.; Johnston, R.S. 1978. **Biomass and nutrient content of quaking aspen at two sites in the western United States.** Forest Science. 24(2): 273-280.

Berger, T.W.; Eager, C.; Likens, G.E.; Stingeder, G. 2001. **Effects of calcium and aluminum chloride additions on foliar and throughfall chemistry in sugar maples.** Forest Ecology and Management. 149: 75-90.

Bernier, B.; Brazeau, M. 1988. **Foliar nutrient status in relation to sugar maple dieback and decline in the Quebec Appalachians.** Canadian Journal of Forest Research. 18: 754-761.

Bernier, B., Brazeau, M. 1988. **Magnesium deficiency symptoms associated with sugar maple dieback in a Lower Laurentians site in southeastern Quebec.** Canadian Journal of Forest Research. 18: 1265-1269.

Bickelhaupt, D.H. 1979. **Biomass and elemental contents of sugar maple as affected by branching characteristics.** Syracuse, NY: State University of New York, College of Environmental Science and Forestry. M.S. Thesis.

Blackmon, B.G. 1979. **Estimates of nutrient drain by dormant-season harvests of coppice American sycamore.** Res. Note SO-245. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Blackmon, B.G.; Baker, J.B.; Cooper, D.T. 1979. **Nutrient use by three geographic sources of eastern cottonwood.** Canadian Journal of Forest Research. 9: 532-534.

Blackmon, B.G.; White, E.H. 1972. **Nitrogen fertilization increases cottonwood growth on old-field soil.** Res. Note SO-143. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Bockheim, J.G.; Lee, S.W.; Leide, J.E. 1983. **Distribution and cycling of elements in a *Pinus resinosa* plantation ecosystem, Wisconsin.** Canadian Journal of Forest Research. 13: 609-619.

Bockheim, J.G.; Leide, J.E. 1991. **Foliar nutrient dynamics and nutrient-use efficiency of oak and pine on low fertility soil in Wisconsin.** Canadian Journal of Forest Research. 21: 925-934.

Bockheim, J.G.; Leide, J.E.; Tavella, D.S. 1986. **Distribution and cycling of macronutrients in a *Pinus resinosa* plantation fertilized with nitrogen and potassium.** Canadian Journal of Forest Research. 16: 778-785.

Boerner, R.E.J. 1985. **Foliar nutrient dynamics, growth, and nutrient use efficiency of *Hamamelis virginiana* in three forest microsites.** Canadian Journal of Botany. 63: 1476-1481.

Bondietti, E.A.; Momoshima, N.; Shortle, W.C.; Smith, K.T. 1990. **A historical perspective on divalent cation trends in red spruce stemwood and the hypothetical relationship to acidic deposition.** Canadian Journal of Forest Research. 20: 1850-1858.

Boyle, J.R.; Ek, A.R. 1972. **An evaluation of some effects of bole and branch pulpwood harvesting on site macronutrients.** Canadian Journal of Forest Research. 2: 407-412.

Briggs, R.D. 1985. **Estimating biomass and nutrient removals by whole-tree and tree-length harvesting of a northern hardwood stand.** Syracuse, NY: State University of New York, College of Environmental Science and Forestry. Ph.D. dissertation.

Briggs, R.D.; Czapowskyj, M.M.; White, E.H. 1984. **Effects of fertilization on the nutrient distribution of above-ground components of *Abies balsamea* (L.) Mill.** Plant and Soil. 80: 433-439.

Burton, A.J.; Pregitzer, K.S.; MacDonald, N.W. 1993. **Foliar nutrients in sugar maple forests along a regional pollution-climate gradient.** Soil Science Society of America Journal. 57: 1619-1628.

Carter, M.C.; White, E.H. 1971. **Dry weight and nutrient accumulation in young stands of cottonwood (*Populus deltoides* Bartr.).** Circ. 190. Auburn, AL: Auburn University, Agricultural Experiment Station.

Chatarpaul, L.; Burgess, D.; Methven, I.R. 1985. **Equations for estimating above-ground nutrient content of six eastern Canadian hardwoods.** Ottawa, ON: Canadian Forest Service, Petawawa National Forestry Institute.

Comerford, N.B. 1981. **Distributional gradients and variability of macroelement concentrations in the crowns of plantation grown *Pinus resinosa* (Ait.).** Plant and Soil. 63: 345-353.

Cote, B.; Camire, C. 1995. **Application of leaf, soil, and tree ring chemistry to determine the nutritional status of sugar maple on sites of different levels of decline.** Water, Air, and Soil Pollution. 83: 363-373.

Cote, B.; Hendershot, W.H.; O'Halloran, I. 1993. **Response of sugar maple to seven types of fertilization in southern Quebec: growth and nutrient status.** In: Huettl, R.F.; Mueller-Dombois, D., eds. Forest decline in the Atlantic and Pacific region. Berlin: Springer-Verlag: 162-174.

Cote, B.; O'Halloran, I.; Hendershot, W.H.; Spankie, H. 1995. **Possible interference of fertilization in the natural recovery of a declining sugar maple stand in southern Quebec.** Plant and Soil. 168-169: 471-480.

Cromack, K., Jr.; Monk, C.D. 1975. **Litter production, decomposition, and nutrient cycling in a mixed hardwood watershed and a white pine watershed.** In: Howell, F.G.; Gentry, J.B.; Smith, M.H., eds. Mineral cycling in Southeastern ecosystems: proceedings of a symposium; 1974 May 1-3; Augusta, GA. Oak Ridge, TN: U.S. Energy Research Development Administration: 609-624.

Czapowskyj, M.M. 1979. **Foliar nutrient concentrations in balsam fir as affected by soil drainage and methods of slash disposal.** Res. Note NE-278. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Czapowskyj, M.M.; Safford, L.O.; Briggs, R.D. 1980. **Foliar nutrient status of young red spruce and balsam fir in a fertilized stand.** Res. Pap. NE-467. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Day, F.P., Jr.; McGinty, D.T. 1975. **Mineral cycling strategies of two deciduous and two evergreen tree species on a southern Appalachian watershed.** In: Howell, F.G.; Gentry, J.B.; Smith, M.H., eds. Mineral cycling in Southeastern ecosystems: proceedings of a symposium; 1974 May 1-3; Augusta, GA. Oak Ridge, TN: U.S. Energy Research Development Administration: 736-743.

Day, F.P., Jr.; Monk, C.D. 1977. **Seasonal nutrient dynamics in the vegetation of a southern Appalachian watershed.** American Journal of Botany. 64(9): 1126-1139.

Demchik, M.; Sharpe, W.E. 2000. **The effect of soil nutrition, soil acidity, and drought on northern red oak (*Quercus rubra* L.) growth and nutrition on Pennsylvania sites with high and low red oak mortality.** Forest Ecology and Management. 136: 199-207.

De Visser, P.H.B. 1992. **The relation between chemical composition of oak tree rings, leaf, bark, and soil solution of a partly mixed stand.** Canadian Journal of Forest Research. 22: 1824-1831.

DeWalle, D.R.; Swistock, B.R.; Sayre, R.G.; Sharpe, W.E. 1991. **Spatial variations of sapwood chemistry with soil acidity in Appalachian Forests.** Journal of Environmental Quality. 20: 486-491.

Duchesne, L.; Ouimet, R.; Camire, C.; Houle, D. 2001. **Seasonal nutrient transfers by foliar resorption, leaching, and litter fall in a northern hardwood forest at Lake Clair Watershed, Quebec, Canada.** Canadian Journal of Forest Research. 31: 333-344.

Dyer, R.F. 1967. **Fresh and dry weight, nutrient elements and pulping characteristics of northern white cedar, *Thuja occidentalis*.** Tech. Bull. 27. Orono, ME: Maine Agricultural Experiment.

Elliot, K.J.; Boring, L.R.; Swank, W.T. 2002. **Aboveground biomass and nutrient accumulation 20 years after clear cutting a southern Appalachian**

watershed. Canadian Journal of Forest Research. 32: 667-683.

Ellis, R.C. 1975. **Sampling deciduous broadleaved trees for the determination of leaf weight and foliar elemental concentrations.** Canadian Journal of Forest Research. 5: 310-317.

Ellsworth, D.S.; Liu, X. 1994. **Photosynthesis and canopy nutrition of four sugar maple forests on acid soils in northern Vermont.** Canadian Journal of Forest Research. 24: 2118-2127.

Erdmann, G.G.; Crow, T.R.; Rauscher, H.M. 1988. **Foliar nutrient variation and sampling intensity for *Acer rubrum* trees.** Canadian Journal of Forest Research. 18: 134-139.

Evans, E.H. 1989. **Tree ring chemistry of eastern hemlock (*Tsuga canadensis* L. Carr): variation and controlling factors.** Philadelphia, PA: University of Pennsylvania. M.S. Thesis.

Fernandez, I.J.; Lawrence, G.B.; Richards, K.J. 1990. **Characteristics of foliar chemistry in a commercial spruce-fir stand of northern New England, USA.** Plant and Soil. 125: 288-292.

Fernandez, I.J.; Struchtemeyer, R.A. 1984. **Correlations between element concentrations in spruce foliage and forest soils.** Communications in Soil Science and Plant Analysis. 15(10): 1243-1255.

Fornes, R.H. 1969. **Studies in the growth and nutrition of *Picea abies* (L.) Karst.** Syracuse, NY: State University of New York, College of Forestry. M.S. thesis.

Fornes, R.H.; Berglund, J.V.; Leaf, A.L. 1970. **A comparison of the growth and nutrition of *Picea abies* (L.) Karst. and *Pinus resinosa* Ait. on a K-deficient site subjected to K fertilization.** Plant and Soil. 33: 345-360.

Foster, N.W.; Morrison, I.K. 1976. **Distribution and cycling of nutrients in a natural *Pinus banksiana* ecosystem.** Ecology. 57: 110-120.

Francis, J.K. 1984. **Yield and nutrient removal by whole-tree harvest of a young bottomland hardwood stand.** Res. Note SO-305. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Francis, J.K.; Baker, J.B. 1981. **Biomass and nutrient accumulation in a cottonwood plantation—the first four years.** Res. Note SO-278. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Freedman, B.; Duinker, P.N.; Barclay, H.; Morash, R.; Prager, U. 1982. **Forest biomass and nutrient studies in central Nova Scotia.** Inf. Rep. M-X-134. Fredericton, NB: Canadian Forestry Service, Maritimes Forest Research Center.

Freedman, B.; Duinker, P.N.; Morash, R. 1986. **Biomass and nutrients in Nova Scotian forests, and implications of intensive harvesting for future site productivity.** Forest Ecology and Management. 15: 103-127.

Freedman, B.; Morash, R.; Hanson, A.J. 1981. **Biomass and nutrient removals by conventional and whole-tree clear-cutting of a red spruce-balsam fir stand in central Nova Scotia.** Canadian Journal of Forest Research. 11: 249-257.

Frelich, L.E.; Bockheim, J.G.; Leide, J.E. 1989. **Historical trends in tree-growth and chemistry across an air-quality gradient in Wisconsin.** Canadian Journal of Forest Research. 19: 113-121.

Fyles, J.W.; Cote, B.; Courchesne, F.; Hendershot, W.H.; Savoie, S. 1994. **Effects of base cation fertilization on soil and foliage nutrient concentrations, and litterfall and throughfall nutrient fluxes in a sugar maple forest.** Canadian Journal of Forest Research. 24: 542-549.

Gordon, A.M.; Chourmouzis, C.; Gordon, A.G. 2000. **Nutrient inputs in litterfall and rainwater fluxes in 27-year old red, black, and white spruce plantations in Central Ontario, Canada.** Forest Ecology and Management. 138: 65-78.

Gordon, A.M.; McBride, R.A.; Fisken, A.J. 1989. **The effect of landfill leachate spraying on foliar nutrient concentrations and leaf transpiration in a northern hardwood forest, Canada.** Journal of Forestry. 62(1): 19-28.

Gosz, J.R.; Likens, G.E.; Bormann, F.H. 1972. **Nutrient content of litter fall on the Hubbard Brook Experimental Forest, New Hampshire**. Ecology. 53(5): 769-784.

Green, D.C.; Grigal, D.F. 1980. **Nutrient accumulations in jack pine stands on deep and shallow soils over bedrock.** Forest Science. 26(2): 325-333.

Hadley, J.L.; Amundson, R.G.; Laurence, J.A.; Kohut, R.J. 1993. **Red spruce bud mortality at Whiteface Mountain, New York.** Canadian Journal of Botany. 71: 827-833.

Hallett, R.A.; Hornbeck, J.W. 1997. **Foliar and soil nutrient relationships in red oak and white pine forests.** Canadian Journal of Forest Research. 27: 1233-1244.

Hansen, E.A.; Baker, J.B. 1979. **Biomass and nutrient removal in short rotation intensively cultured plantations.** In: Impact of intensive harvesting on forest nutrient cycling: proceedings of a symposium; 1979 August 13-16; Syracuse, NY. Syracuse, NY: State University of New York, College of Environmental Science and Forestry, School of Forestry: 130-151.

Heiberg, S.O.; White, D.P. 1950. **Potassium deficiency of reforested pine and spruce stands in northern New York.** Soil Science Society Proceedings. 15: 369-376.

Heisey, R.M. 1995. **Growth trends and nutritional status of sugar maple stands on the Appalachian plateau of Pennsylvania, U.S.A.** Water, Air, and Soil Pollution. 82: 675-693.

Hendershot, W.H. 1991. **Fertilization of sugar maple showing dieback symptoms in the Quebec Appalachians, Canada.** Fertilization Research. 27: 63-70.

Hendrickson, O.Q. 1988. **Biomass and nutrients in regenerating woody vegetation following whole tree and conventional harvest in a northern mixed forest.** Canadian Journal of Forest Research. 18: 1427-1436.

Hendrickson, O.Q.; Burgess, D.M.; Chatarpaul, L. 1987. **Biomass and nutrients in Great Lakes-St. Lawrence forest species: implications for whole tree and conventional harvest.** Canadian Journal of Forest Research. 17: 210-218.

Henry, D.G. 1973. **Foliar nutrient concentrations of some Minnesota forest species.** For. Res. Notes No. 241. St. Paul, MN: University of Minnesota, College of Forestry.

Holldampf, B.; Barker, A.V. 1993. **Mineral element composition of declining and healthy stands of red spruce in western Massachusetts.** Communications in Soil Science and Plant Analysis. 24(15/16): 1937-1944.

Hornbeck, J.W. 1977. **Nutrients: a major consideration in intensive forest management.** Gen. Tech. Rep. NE-29. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Hornbeck, J.W.; Kropelin, W. 1982. **Nutrient removal and leaching from a whole-tree harvest of northern hardwoods.** Journal of Environmental Quality. 11(2): 309-316.

Hornbeck, J.W.; Kropelin, W.K. 1983. **Estimating biomass and nutrient removal from a northern**

hardwood harvest. Journal of Forestry. 81(5): 287-288, 332.

Horsley, S.B.; Long, R.P.; Bailey, S.W.; Hallett, R.A.; Hall, T.J. 2000. **Factors associated with the decline disease of sugar maple on the Allegheny Plateau.** Canadian Journal of Forest Research. 30: 1365-1378.

Houle, D.; Duchesne, L.; Moore, J.-D.; Lafleche, M.R.; Ouimet, R. 2002. **Soil and tree-ring chemistry response to liming in a sugar maple stand.** Journal of Environmental Quality. 31: 1993-2000.

Hoyle, M.C. 1965. **Variation in foliage composition and diameter growth of yellow birch with season, soil, and tree size.** Soil Science Society Proceedings. 29: 475-480.

Hoyle, M.C. 1969. **Variation in content of microelements in yellow birch foliage due to season and soil drainage.** Soil Science Society of America Proceedings. 33(3): 458-459.

Hoyle, M.C.; Mader, D.L. 1964. **Relationships of foliar nutrients to growth of red pine in western Massachusetts.** Forest Science. 10(3): 337-347.

Huntington, T.G.; Peart, D.R.; Hornig, J.; Ryan, D.F.; Russo-Savage, S. 1990. **Relationships between soil chemistry, foliar chemistry, and condition of red spruce at Mount Moosilauke, New Hampshire.** Canadian Journal of Forest Research. 20: 1219-1227.

Hutchinson, T.C.; Watmough, S.A.; Sager, E.P.S.; Karagatzides, J.D. 1999. **The impact of simulated acid rain and fertilizer application on a mature sugar maple (*Acer saccharum* Marsh.) forest in central Ontario Canada.** Water, Air, and Soil Pollution. 109: 17-39.

Ingerslev, M.; Hallbacken, L. 1999. **Above ground biomass and nutrient distribution in a limed and fertilized Norway spruce (*Picea abies*) plantation. Part II. Accumulation of biomass and nutrients.** Forest Ecology and Management. 119: 21-38.

Jobidon, R. 2000. **Density-dependent effects of northern hardwood competition on selected environmental resources and young white spruce (*Picea glauca*) plantation growth, mineral nutrition, and stand structural development—a 5 year study.** Forest Ecology and Management. 130: 77-97.

Johnson, D.W.; Olson, R.J.; Mann, L.K.; Todd, D.E. 1990. **Changes in forest biomass and nutrient distribution in Walker Branch Watershed, Tennessee, from 1967 to 1987.** In: Gessel, S.P.; Lacate, D.S.; Weetman, G.F.; Powers, R.F., eds. Sustained productivity of forest soils: 7th North American forest soils conference; Vancouver, BC. Vancouver, BC: University of British Columbia: 122-136.

Johnson, D.W.; Todd, D.E. 1987. **Nutrient export by leaching and whole-tree harvesting in a loblolly pine and mixed oak forest.** Plant and Soil. 102: 99-109.

Johnson, D.W.; West, D.C.; Todd, D.E.; Mann, L.K. 1982. **Effects of sawlog vs. whole-tree harvesting on the nitrogen, phosphorus, potassium, and calcium budgets of an upland mixed oak forest.** Soil Science Society of America Journal. 46: 1304-1309.

Johnson, F.L.; Risser, P.G. 1974. **Biomass, annual net primary production, and dynamics of six mineral elements in a post oak-blackjack oak forest.** Ecology. 55(6): 1246-1258.

Johnson, J.E.; Bollig, J.J.; Rathfon, R.A. 1998. **Above-ground biomass and nutrient distribution of released and fertilized yellow-poplar trees.** Forest Ecology and Management. 105: 231-240.

Johnston, R.S.; Bartos, D.L. 1977. **Summary of nutrient and biomass data from two aspen sites in western United States.** Res. Note INT-227. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Jokela, E.J.; Shannon, C.A.; White, E.H. 1981. **Biomass and nutrient equations for mature *Betula papyrifera* Marsh.** Canadian Journal of Forest Research. 11: 298-304.

Jurgensen, M.F.; Leaf, A.L. 1965. **Soil moisture-fertility interactions related to growth and nutrient uptake of red pine.** Soil Science Society Proceedings. 29: 294-299.

Kaczmarek, D.J.; Rodkey, K.S.; Reber, R.T.; Pope, P.E.; Ponder, F.P., Jr. 1995. **Carbon and nitrogen pools in oak-hickory forests of varying productivity.** In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 79-93.

Kennedy, H.E., Jr. 1981. **Foliar nutrient concentrations and hardwood growth influenced by cultural treatments.** Plant and Soil. 63: 307-316.

Kennedy, H.E., Jr. 1985. **Cultural treatments influence hardwood growth and foliar nutrient concentration on a minor stream bottom site.** Res. Pap. SO-215. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Kennedy, H.E. Jr. 1993. **Effects of crown position and initial spacing on foliar nutrient composition of seven bottomland hardwoods.** Res. Note SO-371. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Kennedy, H.E. Jr.; Schlaegel, B.E. 1985. **Biomass and nutrient distribution in 3-year-old green ash and swamp chestnut oak grown in a minor stream bottom.** In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference; 1984 November 7-8; Atlanta, GA. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 507-513.

Kimmins, J.P.; Krumlik, G.J. 1976. **On the question of nutrient losses accompanying whole tree logging.** In: Oslo biomass studies: papers presented during the meeting of S4.01 in Oslo, Norway, June 22, 1976, XVIth International Congress of IUFRO. Orono, ME: College of Life Science and Agriculture, University of Maine at Orono: 41-54.

Kinerson, R.S.; Bartholomew, I. 1977. **Biomass estimation equations and nutrient composition of white pine, white birch, red maple, and red oak in New Hampshire.** Res. Rep. 62. Durham, NH: New Hampshire Agricultural Experiment Station.

Lafond, A. 1958. **Les deficiences en potassium et magnesium de quelques plantations de *Pinus strobus*, *Pinus resinosa*, et *Picea glauca* dans la Province de Quebec.** Contrib. No. 1. Montreal, PQ: L'Universite Laval, Fonds de Recherches Forestieres.

Lang, G.E.; Reiners, W.A.; Shellito, G.A. 1982. **Tissue chemistry of *Abies balsamea* and *Betula papyrifera* var. cordifolia from subalpine forests of Northeastern United States.** Canadian Journal of Forest Research. 12: 311-318.

Lea, R.; Tierson, W.C.; Bickelhaupt, D.H.; Leaf, A.L. 1979. **Stand treatment and sampling time of hardwood foliage.** Plant and Soil. 51: 515-533.

Lea, R.; Tierson, W.C.; Bickelhaupt, D.H.; Leaf, A.L. 1980. **Differential foliar responses of northern hardwoods to fertilization.** Plant and Soil. 54: 419-439.

Leyton, L.; Armson, K.A. 1955. **Mineral composition of the foliage in relation to the growth of Scots pine.** Forest Science. 1(3): 210-218.

Likens, G.E.; Bormann, F.H. 1970. **Chemical analyses of plant tissues from the Hubbard Brook ecosystem in New Hampshire.** Bull. 79. New Haven, CT: Yale University, School of Forestry.

Lin, Z.Q.; Schuepp, P.H.; Schemenauer, R.S.; Kennedy, G.G. 1995. **Trace metal contamination in and on**

balsam fir (*Abies balsamea* (L) Mill.) foliage in southern Quebec, Canada. Water, Air, and Soil Pollution. 81: 175-191.

Liu, G.; Cote, B.; Fyles, J. 1994. **Effects of base cation fertilization on the nutrient status, free amino acids and some carbon fractions of the leaves of sugar maple (*Acer saccharum* Marsh.).** Plant and Soil. 160: 79-86.

Long, R.P.; Davis, D.D. 1989. **Major and trace element concentrations in surface organic layers, mineral soil, and white oak xylem downwind from a coal fired power plant.** Canadian Journal of Forest Research. 19: 1603-1614.

Long, R.P.; Horsley, S.B.; Lilja, P.R. 1997. **Impact of forest liming on growth and crown vigor of sugar maple and associated hardwoods.** Canadian Journal of Forest Research. 27: 1560-1573.

Lowry, G.L. 1970. **Variations in nutrients of black spruce needles.** In: Youngberg, C.T.; Davey, C.B., eds. Tree growth and forest soils: proceedings of the third North American forest soils conference; 1968 August; Raleigh, NC. Corvallis, OR: Oregon State University Press: 235-259.

Lowry, G.L.; Avard, P.M. 1969. **Nutrient content of black spruce and jack pine needles. III. Seasonal variations and recommended sampling procedures.** Woodlands Pap. No. 10. Pointe Claire, PQ: Pulp and Paper Research Institute of Canada.

Lozano, F.C.; Hutnh, K.D. 1989. **Foliar diagnosis of sugar maple decline by DRIS.** Communications in Soil Science and Plant Analysis. 20 (17/18): 1895-1914.

MacLean, K.S.; Robertson, R.G. 1981. **Variation in the major element content of red spruce foliage with season, crown position, tree and tissue age.** Communications in Soil Science and Plant Analysis. 12(1): 39-49.

Mader, D.L.; Howarth, J.A. 1970. **Relationship between foliar nutrient levels and tree growth in red pine stands in Massachusetts.** In: Youngberg, C.T.; Davey, C.B., eds. Tree growth and forest soils: proceedings of the third North American forest soils conference; 1968 August; Raleigh, NC. Corvallis, OR: Oregon State University Press: 205-220.

Mader. D.L.; Thompson, B.W. 1969. **Foliar and soil nutrients in relation to sugar maple decline.** Soil Science Society of America Proceedings. 33: 794-800.

Madgwick, H.A.I. 1962. **Studies in the growth and nutrition of *Pinus resinosa* Ait.** Syracuse, NY: State University of New York, College of Forestry. Ph.D. dissertation.

Madgwick, H.A.I. 1970. **The nutrient contents of old-field *Pinus virginiana* stands.** In: Youngberg, C.T.; Davey, C.B., eds. Tree growth and forest soils: proceedings of the third North American forest soils conference; 1968 August; Raleigh, NC. Corvallis, OR: Oregon State University Press: 275-282.

Magill, A.H.; Downs, M.R.; Nadelhoffer, K.J.; Hallett, R.A.; Aber, J.D. 1996. **Forest ecosystem response to four years of chronic nitrate and sulfate additions at Bear Brooks Watershed, Maine, USA.** Forest Ecology and Management. 84: 29-37.

Majdi, H.; Rosengren-Brink, U. 1994. **Effects of ammonium sulfate application on the rhizosphere, fine-root, and needle chemistry in a *Picea abies* (L.) Karst stand.** Plant and Soil. 162: 71-80.

Majumdar, S.K.; Cline, S.W.; Zelnick, R.W. 1989. **Chemical analyses of soils and oak tree tissues from two forest habitats in Pennsylvania differing in their sensitivity to acid precipitation.** Environmental Technology Letters. 10: 1019-1026.

Maliondo, S.M.; Mahendrappa, M.K.; van Raalte, G.D. 1990. **Distribution of biomass and nutrients in some New Brunswick forest stands: possible implications of whole tree-harvesting.** Inf. Rep. M-X-170E/F. Fredericton, NB: Canadian Forestry Service, Maritimes Forest Research Center.

Malkonen, E. 1973. **Effect of complete tree utilization on the nutrient reserves of forest soils.** In: IUFRO biomass studies: papers presented during meetings of S4.01 in Nancy, France, June 25-29, 1973 and Vancouver, B.C., Canada, August 20-24, 1973. Orono, ME: University of Maine: 379-386.

Marks, P.L. 1974. **The role of pin cherry (*Prunus pensylvanica* L.) in the maintenance of stability in northern hardwood ecosystems.** Ecological Monographs. 44: 73-88.

Martin, C.W. 1995. **Development of a central hardwood stand following whole-tree clear cutting in Connecticut.** In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 37-46.

Martin, J.G.; Kloeppel, B.D.; Schaefer, T.L.; Kimbler, D.L.; McNulty, S.G. 1998. **Aboveground biomass and nitrogen allocation of ten deciduous southern Appalachian tree species.** Canadian Journal of Forest Research. 28: 1648-1659.

McClenahen, J.R.; Vimmerstedt, J.P.; Scherzer, A.J. 1989. **Elemental concentrations in tree rings by PIXE: statistical variability, mobility, effects of altered soil chemistry.** Canadian Journal of Forest Research. 19: 880-888.

McColl, J.G. 1980. **Seasonal nutrient variation in trembling aspen.** Plant and Soil. 54: 323-328.

McHargue, J.S.; Roy, W.R. 1932. **Mineral and nitrogen content of the leaves of some forest trees at different times in the growing season.** Botanical Gazette. 94: 381-393.

McVickar, J.S. 1949. **Composition of white oak leaves in Illinois as influenced by soil type and soil composition.** Soil Science. 68:317-328.

Messina, M.G.; Frederick, D.J.; Clark, A., III 1986. **Nutrient content and distribution in natural southern coastal plain hardwoods.** Biomass. 10: 59-79.

Messina, M.G.; Frederick, D.J.; Gardner, W.E.; Williford, M.; Clark, A.; Phillips, D.R. 1981. **Biomass and nutrient relationships in coastal plain hardwoods.** Gen. Tech. Rep. 34. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 242-247.

Mitchell, H.L. 1936. **Trends in the nitrogen, phosphorus, potassium, and calcium content of the leaves of some forest trees during the growing season.** Black Rock Forest Papers. 1(6): 30-44.

Mitchell, H.L.; Chandler, R.F., Jr. 1939. **The nitrogen nutrition and growth of certain deciduous trees of Northeastern United States.** Black Rock Forest Bulletin No. 11.

Mohamed, H.K.; Pathak, S.; Roy, D.N.; Hutchinson, T.C.; McLaughlin, D.L.; Kinch, J.C. 1997. **Relationship between sugar maple decline and corresponding chemical changes in the stem tissue**. Water, Air, and Soil Pollution. 96: 321-327.

Momoshima, N.; Bondietti, E.A. 1990. **Cation binding in wood: applications to understanding historical changes in divalent cation availability to red spruce.** Canadian Journal of Forest Research. 20: 1840-1849.

Moore, J.-M.; Camire, C.; Ouimet, R. 2000. **Effects of liming on the nutrition, vigor, and growth of sugar maple at the Lake Clair Watershed, Quebec, Canada.** Canadian Journal of Forest Research. 30: 725-732

Morrison, I.K. 1973. **Distribution of elements in aerial components of several natural jack pine stands in Northern Ontario.** Canadian Journal of Forest Research. 3: 170-179.

Morrison, I.K. 1974. **Within-tree variation in mineral content of leaves of young balsam fir.** Forest Science. 20(3): 276-278.

Morrison, I.K. 1985. **Effect of crown position on foliar concentrations of 11 elements in *Acer saccharum* and *Betula alleghaniensis* trees on a till soil.** Canadian Journal of Forest Research. 15: 179-183.

Morrison, I.K. 1990. **Organic matter and mineral distribution in an old-growth *Acer saccharum* forest near the northern limit of its range.** Canadian Journal of Forest Research. 20: 1332-1342.

Morrison, I.K. 2003. **Biomass growth and element uptake by young trembling aspen in relation to site treatments in northern Ontario, Canada.** Biomass and Bioenergy. 24: 351-363.

Morrison, I.K.; Foster, N.W. 1979. **Biomass and element removal by complete-tree harvesting of medium rotation forest stands.** In: Impact of intensive harvesting on forest nutrient cycling: proceedings of a symposium; 1979 August 13-16; Syracuse, NY. Syracuse, NY: State University of New York, College of Environmental Science and Forestry, School of Forestry: 111-129.

Mou, P.; Fahey, T.J.; Hughes, J.W. 1993. **Effects of soil disturbance on vegetation recovery and nutrient accumulation following whole-tree harvest of a northern hardwood ecosystem.** Journal of Applied Ecology. 30: 661-675.

Nihlgard, B. 1972. **Plant biomass, primary production and distribution of chemical elements in a beech and planted spruce forest in South Sweden.** Oikos. 23: 69-81.

Nowak, C.A. 1986. **The influence of four coniferous tree species on soil properties.** Syracuse, NY: State University of New York, College of Environmental Science and Forestry. M.S. Thesis.

Ohmann, L.F.; Grigal, D.F. 1979. **Early revegetation and nutrient dynamics following the 1971 Little Sioux Forest Fire in Northeastern Minnesota.** Forest Science Monograph. 21.

Ouimet, R.; Camire, C.; Furlan, V. 1995. **Endomycorrhizal status of sugar maple in relation to tree decline and foliar, fine-roots, and soil chemistry in the Beauce region, Quebec.** Canadian Journal of Botany. 73: 1168-1175.

Ouimet, R.; Fortin, J.-M. 1992. **Growth and foliar nutrient status of sugar maple: incidence of forest decline and reaction to fertilization.** Canadian Journal of Forest Research. 22: 699-706.

Ovington, J.D.; Madgwick, H.A.I. 1959. **Distribution of organic matter and plant nutrients in a plantation of Scots pine.** Forest Science. 5(4): 344-355.

Ovington, J.D.; Madgwick, H.A.I. 1959. **The growth and composition of natural stands of birch.** Plant and Soil. 10(4): 389-400.

Pare, D.; Bernier, B. 1989. **Changes in phosphorus nutrition of sugar maple along a topographic gradient in the Quebec Appalachians.** Canadian Journal of Forest Research. 19: 135-137.

Parrow, L.C. 1976. **Allegheny hardwoods—biomass and nutrient response to fertilization.** Syracuse, NY: State University of New York, College of Environmental Science and Forestry. M.S. Thesis.

Pastor, J.; Bockheim, J.G. 1984. **Distribution and cycling of nutrients in an aspen-mixed-hardwood-spodosol ecosystem in northern Wisconsin.** Ecology. 65(2): 339-353.

Perala, D.A.; Alban, D.H. 1982. **Biomass, nutrient distribution and litterfall in *Populus*, *Pinus*, and *Picea* stands on two different soils in Minnesota.** Plant and Soil. 64: 177-192.

Pletscher, D.H. 1982. **White-tailed deer and nutrient cycling in the Hubbard Brook Experimental Forest,**

New Hampshire. New Haven, CT: Yale University. Ph.D. dissertation.

Ponder, F.P., Jr.; Mikkelson, N.M. 1995. **Characteristics of a long-term forest soil productivity research site in Missouri.** In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 272-281.

Pregitzer, K.S.; Burton, A.J.; Mroz, G.D.; Liechty, H.O.; MacDonald, N.W. 1992. **Foliar sulfur and nitrogen along an 800 km pollution gradient.** Canadian Journal of Forest Research. 22: 1761-1769.

Raitio, H. 1993. **Calcium and magnesium deficiency in young pines and the stand structure on the affected habitats.** In: Huettl, R.F.; Mueller-Dombois, D., eds. Forest decline in the Atlantic and Pacific region. Berlin: Springer-Verlag: 132-143.

Richardson, A.D.; Denny, E.G.; Forbush, J.A.; Siccama, T.G.; Hunter, K.S. 2001. **Differential aluminum and calcium concentrations in the tissues of ten *Cornus* species.** Journal of the Torrey Botanical Society. 128(2): 120-127.

Ricklefs, R.E.; Matthew, K.K. 1982. **Chemical characteristics of the foliage of some deciduous trees in southeastern Ontario.** Canadian Journal of Botany. 60: 2037-2045.

Rieske, L.K.; Housman, H.H.; Arthur, M.A. 2002. **Effects of prescribed fire on canopy foliar chemistry and suitability for an insect herbivore.** Forest Ecology and Management. 160: 177-187.

Rolfe, G.L.; Akhtar, M.A.; Arnold, L.E. 1978. **Nutrient distribution and flux in a mature oak-hickory forest.** Forest Science. 24(1): 122-130.

Roy, G.; Sauvesty, A.; Pagé, F.; van Hulst, R.; Ansseau, C. 2002. **A comparison of soil fertility and leaf nutrient status of sugar maples (*Acer saccharum*) in relation to microrelief in two maple forests in Quebec.** Canadian Journal of Soil Science. 82(1): 23-31.

Ruark, G.A.; Bockheim, J.G. 1988. **Biomass, net primary production, and nutrient distribution for an age sequence of *Populus tremuloides* ecosystems.** Canadian Journal of Forest Research. 18: 435-443.

Rutkowski, D.R.; Stottlemyer, R. 1993. **Composition, biomass, and nutrient distribution in mature northern hardwood and boreal forest stands, Michigan.** American Midland Naturalist, 130: 13-30.

Safford, L.O.; Filip, S.M. 1974. **Biomass and nutrient content of 4-year-old fertilized and unfertilized northern hardwood stands.** Canadian Journal of Forest Research. 4: 549-554.

Safford, L.O.; Young, H.E. 1968. **Nutrient content of the current foliage of red spruce growing on three soils in Maine.** Research in the Life Sciences. April: 27-31.

Salonius, P.O.; Beaton, K.P.; van Raalte, G.D.; Mahendrappa, M.K.; Glen, W.M. 1988. **Mortality in semi-mature white spruce on Prince Edward Island: age-related foliar nutrient studies.** Inf. Rep. M-X-172. Fredericton, NB: Canadian Forestry Service, Maritimes Forest Research Center.

Schmitt, M.D.C.; Czapowskyj, M.M.; Safford, L.O.; Leaf, A.L. 1981. **Biomass and elemental uptake in fertilized and unfertilized *Betula papyrifera* Marsh. and *Populus grandidentata* Michx.** Plant and Soil. 60: 111-121.

Schomaker, C.E. 1973. **Variations in foliar nutrient concentrations in red spruce.** Tech. Bull. 63. Orono, ME: University of Maine, Life Sciences and Agricultural Experiment Station.

Shepard, J.P.; Mitchell, M.J. 1990. **Nutrient cycling in a red pine plantation thirty-nine years after**

potassium fertilization. Soil Science Society of America Journal. 54: 1433-1440.

Smith, C.T., Jr. 1984. **Nutrient removals and soil leaching from a whole-tree harvest of a red spruce (*Picea rubens* Sarg.)-balsam fir (*Abies balsamea* (L.) Mill.) stand in north central Maine.** Orono, ME: University of Maine. Ph.D. dissertation.

Smith, C.T., Jr.; McCormack, M.L., Jr.; Hornbeck, J.W.; Martin, C.W. 1986. **Nutrient and biomass removals from a red spruce-balsam fir whole tree harvest.** Canadian Journal of Forest Research. 16: 381-388.

Son, Y.; Gower, S.T. 1991. **Aboveground nitrogen and phosphorus use by five plantation-grown trees with different leaf longevities.** Biogeochemistry. 14: 167-191.

Son, Y.; Gower, S.T. 1992. **Nitrogen and phosphorus distribution for five plantation species in southwestern Wisconsin.** Forest Ecology and Management. 53: 175-193.

Sprugel, D.G. 1984. **Density, biomass, productivity, and nutrient-cycling changes during stand development in wave-regenerated balsam fir forests.** Ecological Monographs. 54(2): 165-186.

Stone, D.M.; Christenson, D.R. 1975. **Effects of thinning and fertilization on foliar nutrient concentrations of sugar maple.** Canadian Journal of Forest Research. 5: 410-413.

Titus, B.D.; Roberts, B.A.; Deering, K.W. 1998. **Nutrient removals with harvesting and by deep percolation from white birch (*Betula papyrifera* [Marsh.] sites in central Newfoundland.** Canadian Journal of Soil Science. 78: 127-137.

Tritton, L.M.; Martin, C.W.; Hornbeck J.W.; Pierce, R.S. 1987. **Biomass and nutrient removals from commercial thinning and whole-tree clearcutting of central hardwoods.** Environmental Management. 11(5): 659-666.

Van Gurp, K.P. 1984. **Biomass and Elemental Content of *Picea abies* (L.) Karst growing in unthinned stands in Central New York.** Syracuse, NY: State University of New York, College of Environmental Science and Forestry. M.S. thesis.

Van Miegroet, H.; Johnson, D.W.; Todd, D.E. 1993. **Foliar response of red spruce saplings to fertilization with Ca and Mg in the Great Smoky Mountains National Park.** Canadian Journal of Forest Research. 23: 89-95.

Walker, L.C. 1956. **Foliage symptoms as indicators of potassium-deficient soils.** Forest Science. 2(2): 113-120.

Wang, J.R.; Letchford, T.; Comeau, P.; Kimmins, J.P. 2000. **Above- and below-ground biomass and nutrient distribution of a paper birch and subalpine fir mixed-species stand in the Sub-Boreal Spruce zone of British Columbia.** Forest Ecology and Management. 130: 17-26.

Wang, J.R.; Zhong, A.L.; Comeau, P.; Tsze, M.; Kimmins, J.P. 1995. **Aboveground biomass and nutrient accumulation in an age sequence of aspen (*Populus tremuloides*) stands in the Boreal White and Black Spruce Zone, British Columbia.** Forest Ecology and Management. 78: 127-138.

Wang, J.R.; Zhong, A.L.; Simard, S.W.; Kimmins, J.P. 1996. **Aboveground biomass and nutrient accumulation in an age sequence of paper birch (*Betula papyrifera*) in the Interior Cedar Hemlock zone, British Columbia.** Forest Ecology and Management. 83: 27-38.

Watmough, S.A. 2002. **A dendrochemical survey of sugar maple (*Acer saccharum* Marsh) in South-Central Ontario, Canada.** Water, Air, and Soil Pollution. 136: 165-187.

Watmough, S.; Brydges, T.; Hutchinson, T. 1999. **The tree-ring chemistry of declining sugar maple in central Ontario, Canada.** Ambio. 28(7): 613-618.

Watmough, S.A.; Hutchinson, T.C.; Evans, R.D. 1998. **The quantitative analysis of sugar maple tree rings by laser ablation in conjunction with ICP-MS.** Journal of Environmental Quality. 27: 1087-1094.

Watmough, S.A.; Hutchinson, T.C.; Sager, E.P.S. 1998. **Changes in tree ring chemistry in sugar maple (*Acer saccharum*) along an urban-rural gradient in southern Ontario.** Environmental Pollution. 101: 381-390.

Weaver, G.T. 1975. **The quantity and distribution of four nutrient elements in high-elevation forest ecosystems, Balsam Mountains, North Carolina.** In: Howell, F.G.; Gentry, J.B.; Smith, M.H., eds. Mineral cycling in Southeastern ecosystems: proceedings of a symposium; 1974 May 1-3; Augusta, GA. Oak Ridge, TN: U.S. Energy Research Development Administration: 715-728.

Weetman, G.F.; Webber, B. 1972. **The influence of wood harvesting on the nutrient status of two spruce stands.** Canadian Journal of Forest Research. 2: 351-369.

White, D.P. 1954. **Variation in the nitrogen, phosphorus, and potassium contents of pine needles with season, crown position, and sample treatment.** Soil Science Society Proceedings. 18: 326-330.

White, E.H. 1964. **Uptake and distribution of nutrient elements in red pine plantations.** Syracuse, NY: State University of New York, College of Environmental Science and Forestry. M.S. thesis.

White, E.H. 1974. **Whole-tree harvesting depletes soil nutrients.** Canadian Journal of Forest Research. 4: 530-535.

White, E.H.; Carter, M.C. 1970. **Relationships between foliage nutrient levels and growth of young natural stands of *Populus deltoides* Bartr.** In: Youngberg, C.T.; Davey, C.B., eds. Tree growth and forest soils: proceedings of the third North American forest soils conference; 1968 August; Raleigh, NC. Corvallis, OR: Oregon State University Press: 283-294.

White, E.H.; Leaf, A.L. 1965. **Soil and tree potassium contents related to tree growth: II. Tissue K as determined by total tree analysis techniques.** Soil Science. 99(2): 109-114.

White, G.; Fernandez, I.; Wiersma, G. 1999. **Impacts of ammonium sulfate treatment on the foliar chemistry of forest trees at the Bear Brook watershed in Maine.** Environmental Monitoring and Assessment. 55: 235-250.

Whittaker, R.H.; Likens, G.E.; Bormann, F.H.; Eaton, J.S.; Siccama, T.G. 1979. **The Hubbard Brook ecosystem study: forest nutrient cycling and element behavior.** Ecology. 60(1): 203-220.

Wilmot, T.R.; Ellsworth, D.S.; Tyree, M.T. 1995. **Relationships among crown condition, growth, and stand condition in seven northern Vermont sugarbushes.** Canadian Journal of Forest Research. 25: 386-397.

Wilmot, T.R.; Ellsworth, D.S.; Tyree, M.T. 1996. **Base cation fertilization and liming effects on nutrition and growth of Vermont sugar maple stands.** Forest Ecology and Management. 84: 123-134.

Wittwer, R.F.; Leaf, A.L.; Bickelhaupt, D.H. 1975. **Biomass and chemical composition of fertilized and/or irrigated *Pinus resinosa* Ait. plantations.** Plant and Soil. 42: 629-651.

Wood, B.W.; Wittwer, R.F.; Carpenter, S.B. 1977. **Nutrient element accumulation and distribution in an intensively cultured American sycamore plantation.** Plant and Soil. 48: 417-433.

Woodwell, G.M. 1974. **Variation in the nutrient content of leaves of *Quercus alba*, *Quercus coccinea*, and *Pinus rigida* in the Brookhaven forest from bud-break to abscission.** American Journal of Botany. 61(7): 749-753.

Woodwell, G.M.; Whittaker, R.H.; Houghton, R.A. 1975. **Nutrient concentrations in plants in the Brookhaven oak-pine forest.** Ecology. 56: 318-332.

Xydias, G.K. 1964. **Dry matter and nutrient-element relations in *Pinus resinosa* Ait. plantations.** Syracuse, NY: State University of New York, College of Forestry. M.S. thesis.

Yanai, R.D. 1998. **The effect of whole-tree harvest on phosphorus cycling in a northern hardwood forest.** Forest Ecology and Management. 104: 281-295.

Yorks, T.E. 2001. **Effects of forest harvest, deer herbivory, and tree mortality on nutrient cycling in the Catskill mountains of New York.** Syracuse, NY: State University of New York, College of Environmental Science and Forestry. Ph.D. dissertation.

Young, H.E. 1971. **Preliminary estimates of bark percentages and chemical elements in complete trees of eight species in Maine.** Forest Products Journal. 21(5): 56-59.

Young, H.E.; Carpenter, P.M. 1967. **Weight, nutrient element and productivity studies of seedlings and saplings of eight tree species in natural ecosystems**. Tech. Bull. 28. Orono, ME: University of Maine, Agricultural Experiment Station.

Young, H.E.; Dyer, R.F.; Dube, G.F. 1967. **Nutrient distribution in the crown of pole sized red spruce and white pine**. Maine Farm Research: 30-34.

Young, H.E.; Guinn, V.P. 1966. **Chemical elements in complete mature trees of seven species in Maine.** TAPPI. 49: 190-197.

Zoettl, H.W.; Huettl, R.F. 1986. **Nutrient supply and forest decline in southwest-Germany**. Water, Air, and Soil Pollution. 31: 449-462.

Table 1.—Nutrient values in multiple species limited by age, forest health, and region

Species	N Avg.	Stdev	No. of stands [a]	No. of stems [b]	P Avg.	Stdev	No. of stands [a]	No. of stems [b]	K Avg.	Stdev	No. of stands [a]	No. of stems [b]	Ca Avg.	Stdev	No. of stands [a]	No. of stems [b]	Mg Avg.	Stdev	No. of stands [a]	No. of stems [b]
BARK																				
American beech	**0.750**		1	18	**0.040**		1	18	**0.220**		1	18	**3.086**	0.786	2	19	**0.050**		1	18
Balsam fir	**0.462**	0.173	17	73	**0.053**	0.015	11	67	**0.257**	0.108	17	73	**0.739**	0.180	17	73	**0.064**	0.014	17	73
Eastern hemlock	**0.267**	0.024	3	6	**0.051**	0.017	3	6	**0.123**	0.017	3	6	**0.756**	0.182	3	6	**0.036**	0.014	3	6
Norway spruce	**0.514**	0.091	3	60	**0.071**	0.018	3	60	**0.296**	0.133	2	45	**1.232**	0.175	2	45	**0.091**	0.031	2	45
Paper birch	**0.409**	0.100	15	123	**0.030**	0.007	15	123	**0.117**	0.034	15	123	**0.807**	0.250	15	123	**0.043**	0.006	15	123
Quaking aspen	**0.436**	0.195	16	62	**0.055**	0.022	16	62	**0.288**	0.026	16	62	**1.213**	0.274	16	62	**0.089**	0.017	16	62
Red maple	**0.454**	0.049	5	12	**0.049**	0.011	5	12	**0.198**	0.029	5	12	**1.299**	0.234	6	13	**0.046**	0.005	5	12
Red oak	**0.384**	0.067	3	20	**0.023**	0.006	3	20	**0.144**	0.030	2	5	**2.841**	0.717	2	5	**0.037**	0.010	2	5
Red pine	**0.310**	0.038	26	173	**0.044**	0.008	26	173	**0.088**	0.027	25	158	**0.765**	0.391	25	158	**0.046**	0.013	25	158
Red spruce	**0.241**	0.101	4	18	**0.037**	0.005	4	18	**0.155**	0.023	4	18	**0.663**	0.282	4	18	**0.047**	0.008	4	18
Sugar maple	**0.499**	0.068	6	62	**0.038**	0.007	7	118	**0.318**	0.103	7	118	**2.433**	0.754	8	119	**0.060**	0.017	7	118
White ash													**2.206**		1	1				
Atl. white-cedar	**0.280**		1	1	**0.020**		1	1	**0.080**		1	1	**2.450**		1	1	**0.070**		1	1
White oak	**0.415**		1	5	**0.047**		1	5	**0.182**		1	5	**4.112**	2.266	2	6	**0.054**		1	5
White pine	**0.354**	0.093	5	37	**0.046**	0.010	5	37	**0.147**	0.025	4	22	**0.422**	0.060	4	22	**0.061**	0.003	4	22
White spruce	**0.356**	0.038	8	46	**0.054**	0.012	8	46	**0.242**	0.033	8	46	**1.295**	0.276	8	46	**0.067**	0.010	8	46
Yellow birch	**0.545**	0.086	4	23	**0.030**	0.000	4	23	**0.132**	0.011	4	23	**1.090**	0.130	4	23	**0.048**	0.007	4	23
BOLE																				
American beech	**0.110**		1	18	**0.010**		1	18	**0.070**		1	18	**0.083**	0.033	2	19	**0.020**		1	18
Balsam fir	**0.092**	0.041	16	72	**0.007**	0.006	9	65	**0.092**	0.036	16	72	**0.082**	0.024	16	72	**0.020**	0.003	16	72
Eastern hemlock	**0.077**	0.018	2	5	**0.016**	0.006	2	5	**0.069**	0.036	3	6	**0.077**	0.022	3	6	**0.014**	0.005	3	6
Norway spruce	**0.069**	0.005	3	60	**0.006**	0.002	3	60	**0.023**	0.001	2	45	**0.136**	0.040	2	45	**0.011**	0.002	2	45
Paper birch	**0.096**	0.018	14	122	**0.009**	0.004	14	122	**0.050**	0.016	14	122	**0.074**	0.020	14	122	**0.018**	0.004	14	122
Quaking aspen	**0.102**	0.045	15	61	**0.009**	0.003	15	61	**0.093**	0.029	15	61	**0.117**	0.027	15	61	**0.021**	0.007	15	61
Red maple	**0.089**	0.010	4	11	**0.008**	0.004	4	11	**0.080**	0.033	4	11	**0.118**	0.036	5	12	**0.021**	0.009	4	11
Red oak	**0.126**	0.017	3	20	**0.005**	0.005	3	20	**0.104**	0.034	2	5	**0.054**	0.019	2	5	**0.004**	0.005	2	5
Red pine	**0.082**	0.011	26	173	**0.008**	0.002	26	173	**0.024**	0.009	25	158	**0.109**	0.035	25	158	**0.019**	0.012	25	158
Red spruce	**0.070**	0.023	3	17	**0.005**	0.004	3	17	**0.023**	0.006	3	17	**0.075**	0.013	3	17	**0.009**	0.002	3	17
Sugar maple	**0.098**	0.017	6	62	**0.009**	0.001	9	90	**0.068**	0.029	35	167	**0.123**	0.056	36	168	**0.019**	0.006	35	167
White ash													**0.123**		1	1				
Atl. white-cedar																				
White oak	**0.166**		1	5	**0.014**		1	5	**0.100**		1	5	**0.109**	0.026	2	6	**0.015**		1	5
White pine	**0.078**	0.002	4	36	**0.006**	0.003	6	65	**0.032**	0.007	6	51	**0.052**	0.043	6	51	**0.010**	0.004	6	51
White spruce	**0.065**	0.010	8	46	**0.006**	0.003	8	46	**0.034**	0.012	8	46	**0.094**	0.019	8	46	**0.010**	0.003	8	46
Yellow birch	**0.105**	0.027	4	23	**0.010**	0.000	4	23	**0.048**	0.022	4	23	**0.076**	0.029	5	24	**0.016**	0.007	4	23

									BRANCH											
American beech	**0.300**		1	18	**0.030**		1	18	**0.120**		1	18	**0.470**		1	18	**0.030**		1	18
Balsam fir	**0.410**	0.135	14	57	**0.077**	0.036	7	50	**0.261**	0.087	14	57	**0.380**	0.082	14	57	**0.051**	0.011	14	57
Eastern hemlock	**0.278**	0.137	3	9	**0.048**	0.003	2	8	**0.109**	0.057	3	9	**0.454**	0.115	3	9	**0.036**	0.014	3	9
Norway spruce	**0.471**	0.067	3	60	**0.065**	0.008	3	60	**0.187**	0.055	2	45	**0.473**	0.040	2	45	**0.050**	0.006	2	45
Paper birch	**0.363**	0.107	14	119	**0.045**	0.020	14	119	**0.148**	0.055	14	119	**0.389**	0.137	14	119	**0.045**	0.014	14	119
Quaking aspen	**0.509**	0.167	15	57	**0.081**	0.041	15	57	**0.340**	0.100	15	57	**0.943**	0.349	15	57	**0.099**	0.029	15	57
Red maple	**0.304**	0.080	5	14	**0.045**	0.022	5	14	**0.189**	0.055	5	14	**0.432**	0.157	5	14	**0.037**	0.009	5	14
Red oak	**0.375**	0.075	4	28	**0.063**	0.013	4	28	**0.252**	0.037	3	13	**0.902**	0.261	3	13	**0.066**	0.009	3	13
Red pine	**0.327**	0.061	26	228	**0.039**	0.007	26	228	**0.096**	0.035	25	213	**0.551**	0.248	25	213	**0.050**	0.023	25	213
Red spruce	**0.258**	0.132	3	6	**0.056**	0.034	4	21	**0.158**	0.128	4	21	**0.347**	0.106	4	21	**0.042**	0.011	4	21
Sugar maple	**0.325**	0.095	6	62	**0.043**	0.018	6	62	**0.224**	0.075	6	62	**0.698**	0.276	6	62	**0.042**	0.007	6	62
White ash																				
Atl. white-cedar	**0.240**	0.000	2	40	**0.025**	0.000	2	40	**0.047**	0.000	2	40	**1.140**	0.000	2	40	**0.045**	0.000	2	40
White oak	**0.280**		1	5	**0.070**		1	5	**0.243**		1	5	**0.570**		1	5	**0.066**		1	5
White pine	**0.396**	0.158	5	55	**0.056**	0.028	5	55	**0.192**	0.130	4	40	**0.302**	0.077	4	40	**0.055**	0.008	4	40
White spruce	**0.375**	0.104	7	38	**0.054**	0.019	7	38	**0.250**	0.112	7	38	**0.585**	0.157	7	38	**0.051**	0.015	7	38
Yellow birch	**0.480**	0.057	3	19	**0.055**	0.035	3	19	**0.126**	0.037	3	19	**0.406**	0.020	3	19	**0.043**	0.018	3	19
									FOLIAGE											
American beech	**2.138**	0.191	11	116	**0.149**	0.032	9	88	**0.935**	0.279	9	88	**0.737**	0.365	9	88	**0.167**	0.037	6	73
Balsam fir	**1.332**	0.342	17	71	**0.140**	0.020	10	57	**0.414**	0.106	17	71	**0.762**	0.402	17	71	**0.079**	0.021	17	71
Eastern hemlock	**1.263**	0.255	5	19	**0.197**	0.046	6	20	**0.749**	0.272	6	20	**0.669**	0.107	6	20	**0.125**	0.021	4	10
Norway spruce	**1.322**	0.436	3	60	**0.197**	0.081	3	60	**0.354**	0.130	2	45	**0.877**	0.313	2	45	**0.064**	0.003	2	45
Paper birch	**1.992**	0.450	19	153	**0.189**	0.049	18	145	**0.887**	0.252	19	153	**0.718**	0.233	19	153	**0.225**	0.080	19	153
Quaking aspen	**2.219**	0.489	21	106	**0.213**	0.061	18	79	**0.916**	0.417	19	87	**1.060**	0.455	19	87	**0.209**	0.057	19	87
Red maple	**1.618**	0.271	19	129	**0.195**	0.053	15	96	**0.731**	0.164	16	89	**0.730**	0.322	16	104	**0.162**	0.030	13	93
Red oak	**2.073**	0.437	23	163	**0.179**	0.041	14	88	**0.982**	0.271	18	98	**0.709**	0.249	18	98	**0.163**	0.029	14	82
Red pine	**1.149**	0.130	38	587	**0.128**	0.016	37	579	**0.367**	0.100	37	572	**0.417**	0.160	37	572	**0.086**	0.034	37	572
Red spruce	**1.010**	0.124	10	58	**0.186**	0.053	10	58	**0.583**	0.261	10	58	**0.434**	0.163	10	58	**0.113**	0.051	10	58
Sugar maple	**1.970**	0.372	60	861	**0.148**	0.057	54	789	**0.822**	0.174	55	809	**1.040**	0.402	63	1005	**0.163**	0.056	59	989
White ash	**1.955**	0.258	11	122	**0.216**	0.070	6	72	**1.288**	0.358	6	72	**1.407**	0.530	6	72	**0.307**	0.072	3	57
Atl. White-cedar	**0.830**	0.000	2	40	**0.089**	0.000	2	40	**0.210**	0.000	2	40	**1.470**	0.000	2	40	**0.107**	0.000	2	40
White oak	**2.098**	0.684	12	54	**0.205**	0.115	9	30	**1.015**	0.362	9	30	**0.796**	0.434	9	30	**0.128**	0.039	6	19
White pine	**1.317**	0.247	13	90	**0.164**	0.025	7	57	**0.455**	0.166	13	76	**0.286**	0.149	12	75	**0.118**	0.029	12	75
White spruce	**1.053**	0.182	9	47	**0.142**	0.028	8	39	**0.525**	0.110	9	47	**1.053**	0.511	9	47	**0.092**	0.016	9	47
Yellow birch	**2.331**	0.378	11	73	**0.179**	0.034	11	73	**1.014**	0.277	11	73	**0.986**	0.397	11	73	**0.248**	0.039	9	63

a – Number of stems used to calculate the mean. b – Number of trees in each mean; unreported tree numbers credited as 1.

Data are from healthy trees at least ten years old that were sampled in the Northeastern United States.

Appendix

Table 2.—Species table

Species	Species name	Species latin name	Additional names
2	balsam fir	*Abies balsamea* (L.) Mill.	
49	subalpine fir	*Abies lasiocarpa*	
50	boxelder	*Acer negundo* L.	
23	striped maple	*Acer pensylvanicum* L.	
112	Norway maple	*Acer plantanoides*	
6	red maple	*Acer rubrum* L.	
111	silver maple	*Acer saccharinum*	soft maple
7	sugar maple	*Acer saccharum* Marsh.	
104	maple	*Acer sp.*	
28	mountain maple	*Acer spicatum* Lam.	moose maple
93	buckeye	*Aesculus glabra*	
52	speckled alder	*Alnus rugosa*	tag alder
87	downy serviceberry	*Amelanchier arborea*	
10	yellow birch	*Betula alleghaniensis* Britt.	*Betula lutea*
13	sweet birch	*Betula lenta L.*	black birch
9	paper birch	*Betula papyrifera* Marsh.	White birch
114	European white birch	*Betula pendula* Roth.	*Betula verrucosa*
11	silver birch	*Betula populifolia* Marsh.	gray birch
103	birch	*Betula sp.*	
34	European hornbeam	*Carpinus betulus* L.	
53	American hornbeam	*Carpinus caroliniana*	Blue beech
57	bitternut hickory	*Carya cordiformus* (Wang.) K. Koch	
82	pignut hickory	*Carya glabra* (Mill.) Sweet	
105	sweet pecan	*Carya illinoiensis*	
58	shagbark hickory	*Carya ovata* (Mill.) K. Koch	
73	hickory	*Carya spp.*	
83	chestnut	*Castanea dentata* (Marsh.) Borkh.	American chestnut
94	catalpa	*Catalpa speciosa*	
95	hackberry	*Celtis occidentalis*	
90	Atlantic white-cedar	*Chamaecyparis thyoides*	
102	Kentucky yellowwood	*Cladrastis kentukea*	*Cladrastis lutea*
54	alternateleaf dogwood	*Cornus alternifolia* L. f	
76	flowering dogwood	*Cornus florida*	
121	Japanese dogwood	*Cornus kousa*	
123	Cornelian cherry	*Cornus mas*	
122	roundleaf dogwood	*Cornus rugosa*	
120	red-osier dogwood	*Cornus sericea*	
86	dogwood	*Cornus sp.*	
116	beaked hazelnut	*Corylus cornuta*	
99	persimmon	*Diospyros virginiana*	

Continued

Table 2.—Continued

Species	Species name	Species latin name	Additional names
8	American beech	*Fagus grandifolia* Ehrh.	
75	European beech	*Fagus sylvatica*	
18	white ash	*Fraxinus americana* L.	
60	black ash	*Fraxinus nigra* Marsh.	
61	red ash	*Fraxinus pennsylvanica* Marsh.	green ash
84	Witch-hazel	*Hamamelis virginiana* L.	
96	American holly	*Ilex opaca*	
59	butternut	*Juglans cinerea* L.	
101	black walnut	*Juglans nigra*	
91	common juniper	*Juniperus communis*	
45	eastern redcedar	*Juniperus virginiana* L.	
79	European larch	*Larix decidua* Mill.	
109	tamarack	*Larix laricina* (Du Roi) K. Koch	larch
89	sweetgum	*Liquidambar styraciflua*	
15	yellow-poplar	*Liriodendron tulipifera* L.	tulip poplar, tuliptree
92	sweet crabapple	*Malus coronaria*	*Prunus coronaria*
63	apple	*Malus sp.*	
97	red mulberry	*Morus rubra*	
80	blackgum	*Nyssa sylvatica*	
19	eastern hophornbeam	*Ostrya virginiana* (Mill.) K. Koch	ironwood
110	sourwood	*Oxydendrum arboreum*	
41	Norway spruce	*Picea abies* (L.) Karst.	
21	white spruce	*Picea glauca* (Moench) Voss	
43	black spruce	*Picea mariana* (Mill.) B.S.P.	
1	red spruce	*Picea rubens* Sarg.	
42	jack pine	*Pinus banksiana* Lamb.	
119	shortleaf pine	*Pinus echinata*	
22	red pine	*Pinus resinosa* Ait.	
44	pitch pine	*Pinus rigida* Mill.	
5	Eastern white pine	*Pinus strobus* L.	
47	Scotch pine	*Pinus sylvestris* L.	Scots pine
113	Virginia pine	*Pinus virginiana*	
100	sycamore	*Platanus occidentalis*	
64	balsam poplar	*Populus balsamifera* L.	
65	eastern cottonwood	*Populus deltoides* Bartr.	
66	bigtooth aspen	*Populus grandidentata* Michx.	Largetooth aspen
25	quaking aspen	*Populus tremuloides* Michx.	trembling aspen, poplar
24	pin cherry	*Prunus pensylvanica* L.	fire cherry
16	black cherry	*Prunus serotina* Ehrh.	
62	chokecherry	*Prunus virginiana* L.	
55	white oak	*Quercus alba*	

Continued

Table 2.—Continued

Species	Species name	Species latin name	Additional names
78	scarlet oak	*Quercus coccinea*	
81	bear oak	*Quercus ilicifolia*	
118	laurel oak	*Quercus laurifolia* Michx.	
56	bur oak	*Quercus macrocarpa* Michx.	
108	swamp chestnut oak	*Quercus michauxii* Nutt.	
106	water oak	*Quercus nigra* (L.)	
107	cherrybark oak	*Quercus pagoda* Raf.	
98	pin oak	*Quercus palustris*	
71	chestnut oak	*Quercus prinus*	
33	English oak	*Quercus robur* L.	
14	northern red oak	*Quercus rubra* L.	
72	oak	*Quercus sp.*	
74	post oak	*Quercus stellata* Wang.	
26	black oak	*Quercus velutina* Lam.	
77	great laurel	*Rhododendron maximum*	
51	staghorn sumac	*Rhus typhina* L.	
85	black locust	*Robinia pseudoacacia* L.	
67	black willow	*Salix nigra* Marsh.	
88	sassafras	*Sassafras albidnum*	
12	mountain ash	*Sorbus americana*	Pyrus americana
117	bald cypress	*Taxodium distichum* (L.) Rich.	
4	white cedar	*Thuja occidentalis* L.	northern white cedar
20	basswood	*Tilia americana* L.	
3	eastern hemlock	*Tsuga canadensis* (L.) Carr.	
68	white elm	*Ulmus americana* L.	American elm
69	slippery elm	*Ulmus rubra Muhl.*	*Ulmus fulva* Michx
70	rock elm	*Ulmus thomasii*	
115	withe-rod	*Viburnum cassinoides*	
9999	missing		

Table 3.—Land use table

Land use #	Land use description
1	second growth/regrowth
2	old growth
3	previously burned
4	previously selectively cut
5	past cultivation
6	past pasture
7	national park
8	plantation
9	previously logged
10	research forest
11	national forest
18	plantation, second growth
20	maple syrup production
25	old growth, past cultivation
28	mixed old growth and plantation
30	arboretum
38	previously burned plantation
39	previously burned, logged
40	paper company land
56	past cultivation, pasture
58	past cultivation, plantation
98	previously logged plantation
369	previously burned, grazed, and logged
458	fertilized, past cultivation, plantation
9999	missing

Table 4.—Analytical method table

Method #	Method description[a]
1	N Kjeldahl; (P), K, Ca, Mg, (Mn), (Al) ICP-AES
2	N, P colorimetric; K, Ca AES; Mg AAS; Al, Mn ICP-AES
3	N Kjeldahl; P, K, Ca, Mg, (Mn), (Al) "spectrographic" analysis
4	N Kjeldahl; P, Ca, Mg, K, (Mn), (Al) AES
5	N Kjeldahl; P colorimetric; (K), Ca, Mg, (Mn), (Al) AAS
6	P colorimetric; K, Ca, Mg, (Mn) AAS
7	N, (P) colorimetric; K, Ca, Mg, (Al) AAS
8	C, N, Infrared Absorption Spectrophotometry; P, K, Ca, Mg, Mn ICP-AES
9	N Kjeldahl
10	C wet combustion; N Kjeldahl; P colorimetric; K, Ca, Mg, Mn AAS
11	N Kjeldahl; P colorimetric; K AES; Ca, Mg, (Mn), (Al) AAS
12	N Kjeldahl; P colorimetric; K AES; Mg titan yellow; Ca versenate (EDTA) technique
13	N, P colorimetric; K AES; Ca, Mg AAS
14	N, (P) colorimetric; K, Ca, Mg, (Mn), Al DCP
15	leaves and twigs - N Kjeldahl; P, K, Ca, Mg Spark AES; bark and wood - K, Ca, Mg AAS
16	N Kjeldahl; K, Ca, Mg AAS
17	(N), (P), K, Ca, Mg, Mn, (Al) ICP-AES
18	N, (P) colorimetric
19	leaves - N, P colorimetric; K, Ca, Mg AAS; wood - K, Ca, Mg, Al ICP-AES
20	N Kjeldahl; P AES, (K, Ca, Mg, Mn, Al "spectrographic")
21	N Kjeldahl; P colorimetric; (K, Ca AES, Mg, (Mn) AAS)
22	K, Ca, Mg, Mn, (Al) - Neutron activation analysis
23	N CHN analyzer; P, K, Ca, Mg ICP-AES
24	N colorimetric; P, K, Ca, Mg ICP-AES
25	N, P colorimetric; Ca precipitation and titration
26	N Kjeltic titration; P flow injection; K AES; Ca, Mg, Mn, Al AAS
27	N Kjeltic titration; P flow injection; K AES; Ca, Mg, Al AAS; P, Ca, Mg, Mn by ICP-AES
28	N Kjeldahl; P colorimetric (vandate); K, Ca, Mg AES
29	N AOAC method; P colorimetric; K, Ca precipitated and titrated; Mg pyrophospate method
30	K AES
31	N Kjeldahl; P colorimetric (vandate); K, CA, Mg "spectrophotometrically"
32	N colorimetric: Ca AAS
33	N Wescan 360 ammonia analyzer; Ca ICP-AES
34	N Kjeldahl, K AES
35	N Kjeldahl; P, K colorimetric; Ca precipitated as oxalate
36	N Combustion elemental analyzer
37	N CHN analyzer; P colorimetric, K, Ca, Mg AAS
38	N nitrogen analyzer; P colorimetric; K AES; Ca, Mg AAS
39	N, P colorimetric; K AAS; Ca, Mg ICP-AES
40	N microdiffusion, P colorimetric, K AES, Ca, Mg AAS
41	K, Ca, Mg ICP-MS
42	P, K, Ca, Mg, Mn, Al PIXE spectroscopy
9999	not specified

[a]Elements in parenthesis were not necessarily analyzed in all studies using the specified method.

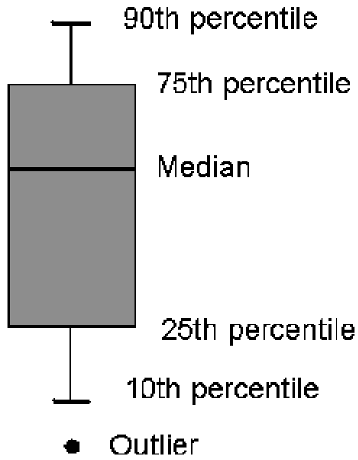
Table 5.—Plant digest method table

Plant digest #	Plant digest technique[a]
1	H_2S0_4 for N
2	HNO_3 and $HClO_4$ for all but N
3	H_2SO_4, HNO_3 and $HClO_4$ for P; HCl for K, Ca, Mg
4	HCl for all but Kjeldahl N
5	HNO_3 for all but N, (C)
6	$HClO_4$ for P, K; $NaCO_3$ fusion for Ca
7	$HClO_4$ for P; HNO_3 and $HClO_4$ for K, Ca, Mg, Mn
8	H_2SO_4 and H_2O_2 for N, (P); HCl for (K), Ca, (Mg)
9	H_2SO_4, HNO_3 and $HClO_4$ for P, K, Ca, Mg
10	H_2SO_4 and H_2O_2
11	H_2SO_4 for N, P
12	wood - HCl; leaves - H_2SO_4, H_2O_2, and $LiSO_4$
13	H_2SO_4, H_20_2, and $LiSO_4$
14	H_2SO_4 and H_2SeO_3
15	H_2SO_4
16	H_2SO_4 and H_2O_2 for N, P; HF, HCL and HNO_3 for K, Ca, Mg
17	$Mg(NO_3)_2$ for P; H_2SO_4, HNO_3, and $HClO_4$ for K, Ca, Mg
18	H_2SO_4 for N and P; HNO_3-$HClO_4$ for K, Ca, Mg, Mn, Al
19	H_2SO_4 and H_2O_2 for N, P
20	HNO_3 and $HClO_4$
21	wood and bark - $HN0_3$; leaves and twigs not specified
22	HNO_3 and $HClO_4$ for K, Ca, Mg, Mn
23	$C_2H_4O_2$ for K; HNO_3 and $HClO_4$ for K, Ca, Mg, Mn
24	Li-HCl for all but N
25	Li-HCl
26	HNO_3 and HCl for all but N
27	HNO_3 and H_20_2 for all but N
28	$HClO_4$ for P, K
29	$HClO_4$ for all but N
9999	not specified

[a]Elements in parenthesis were not necessarily analyzed in all studies using the specified method

Figures 2-9—Box plots of Bark, Bole, Branches, Foliage

The box plots in Figures 2-9 indicate the range of values for each species. For small sample sizes, the entire range is not included:



In the legends, the numbers in parentheses indicate the number of stands and the number of stems included in each sample. The tree codes indicate the following tree species in the Northeastern United States:

Species code	Scientific name	Common name
FAGR	*Fagus grandifolia*	American beech
ACSA	*Acer saccharum*	Sugar maple
ACRU	*Acer rubrum*	Red maple
BEAL	*Betula alleghaniensis*	Yellow birch
BEPA	*Betula payrifera*	Paper birch
POTR	*Populus tremuloides*	Quaking aspen
FRAM	*Fraxinus americana*	White ash
QURU	*Quercus rubra*	Red oak
QUAL	*Quercus alba*	White oak
ABBA	*Abies balsamea*	Balsam fir
PIST	*Pinus strobus*	White pine
PIRE	*Pinus resinosa*	Red pine
PIAB	*Picea abies*	Norway spruce
PIGL	*Picea glauca*	White spruce
PIRU	*Picea rubens*	Red spruce
THOC	*Thuja occidentalis*	White cedar
TSCA	*Tsuga canadensis*	Eastern hemlock

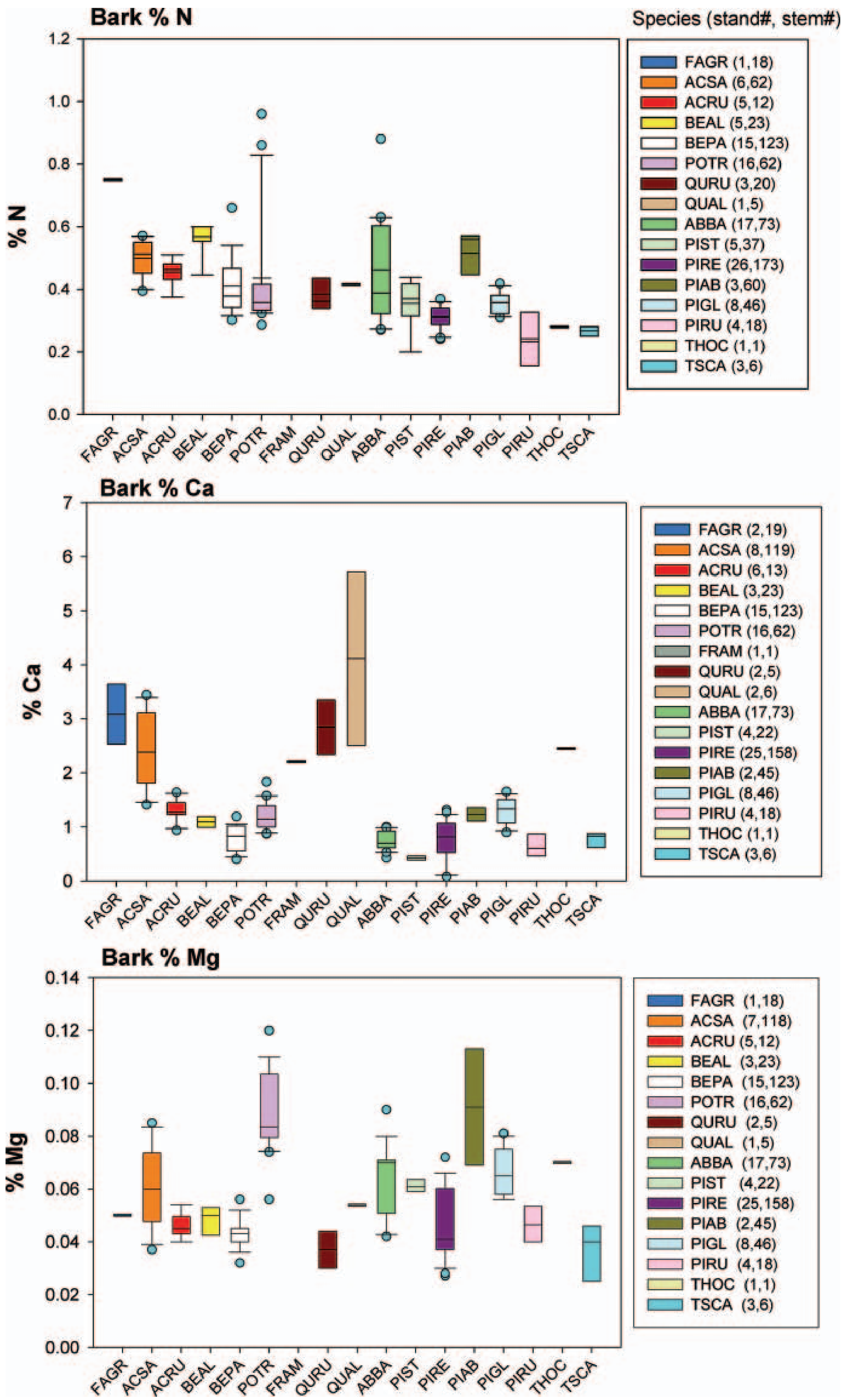


Figure 2.—Bark % N, % Ca, and % Mg

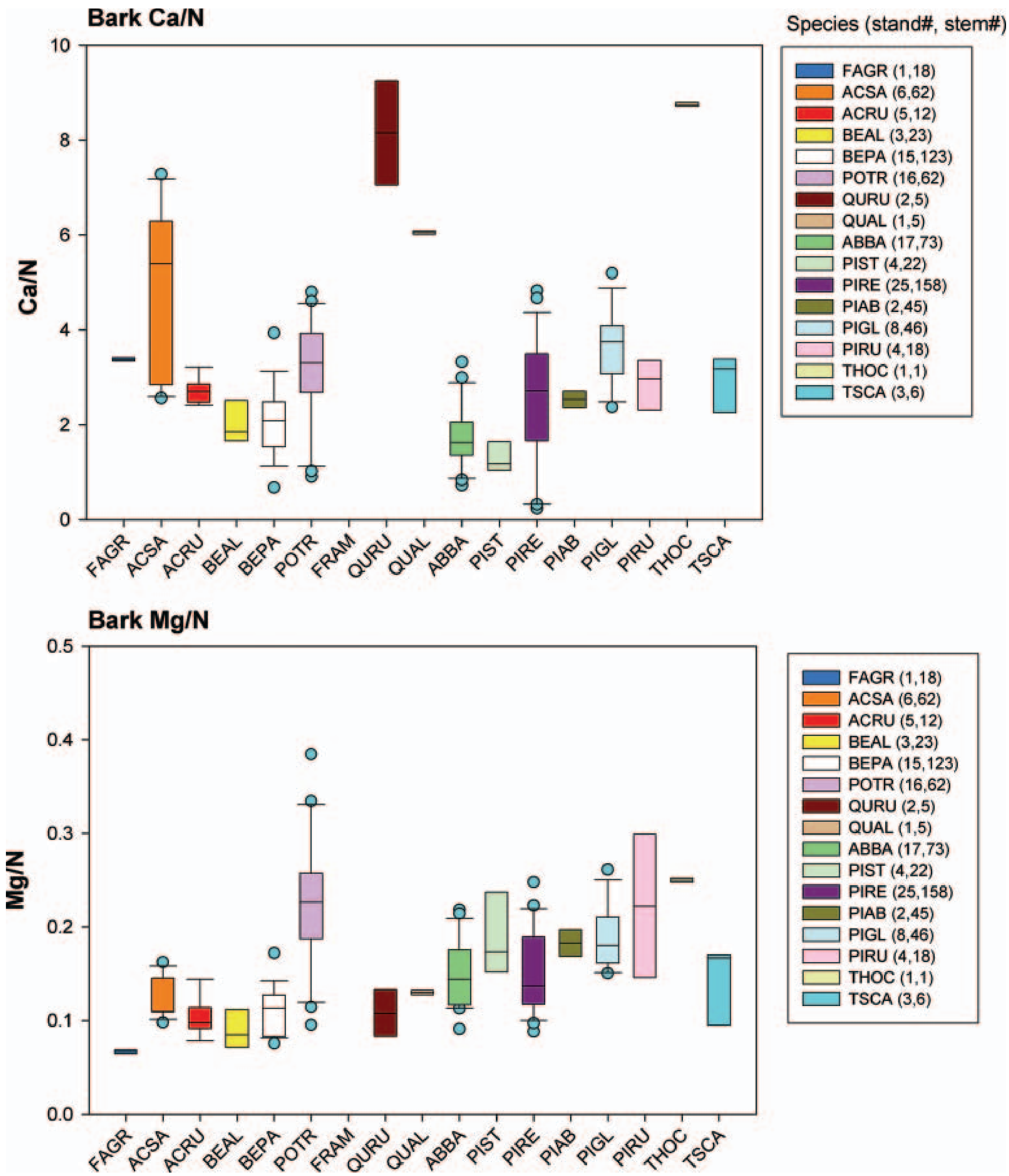


Figure 3.—Bark Ca/N and Mg/N

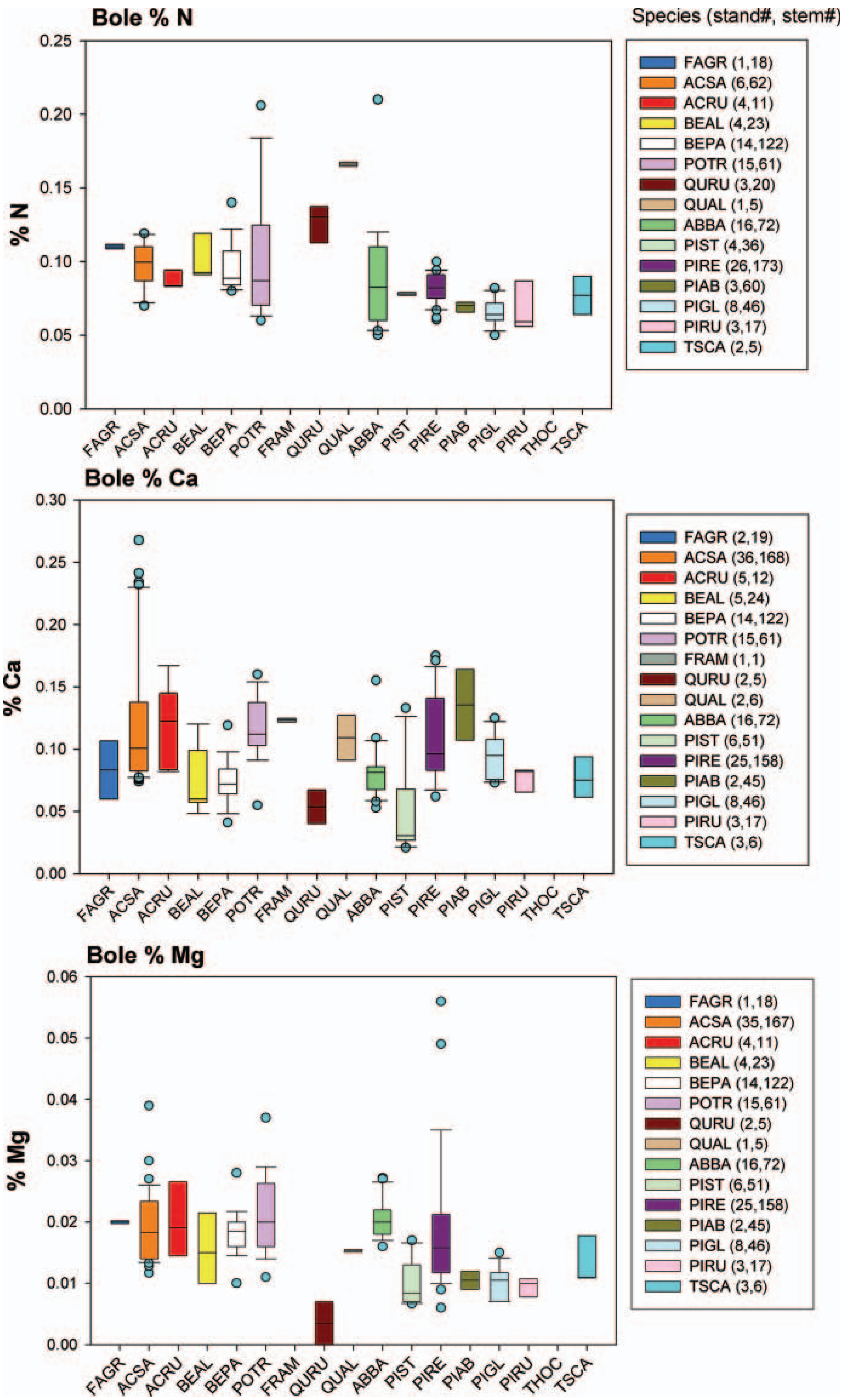


Figure 4.—Bole % N, % Ca, and % Mg

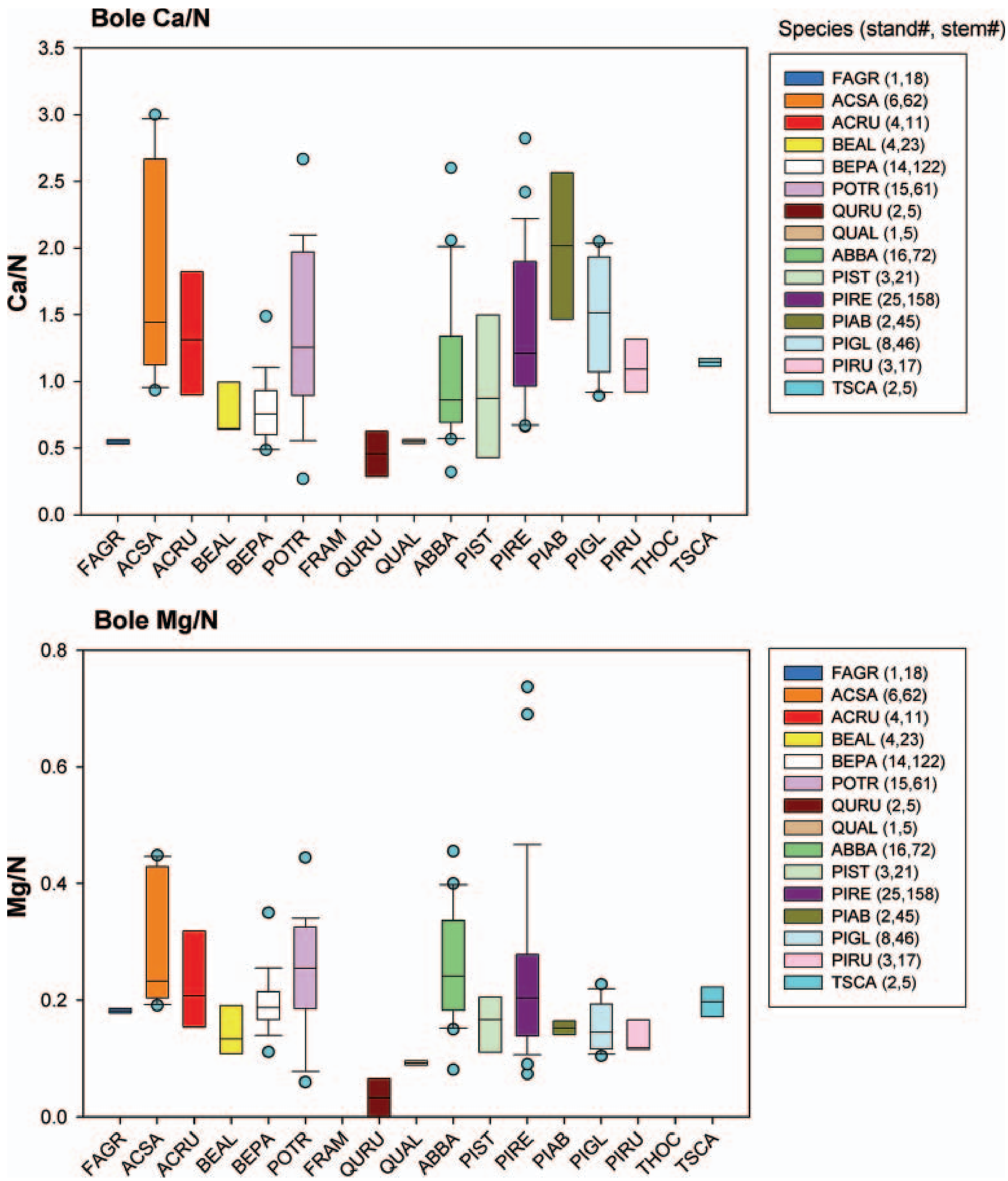


Figure 5.—Bole Ca/N and Mg/N

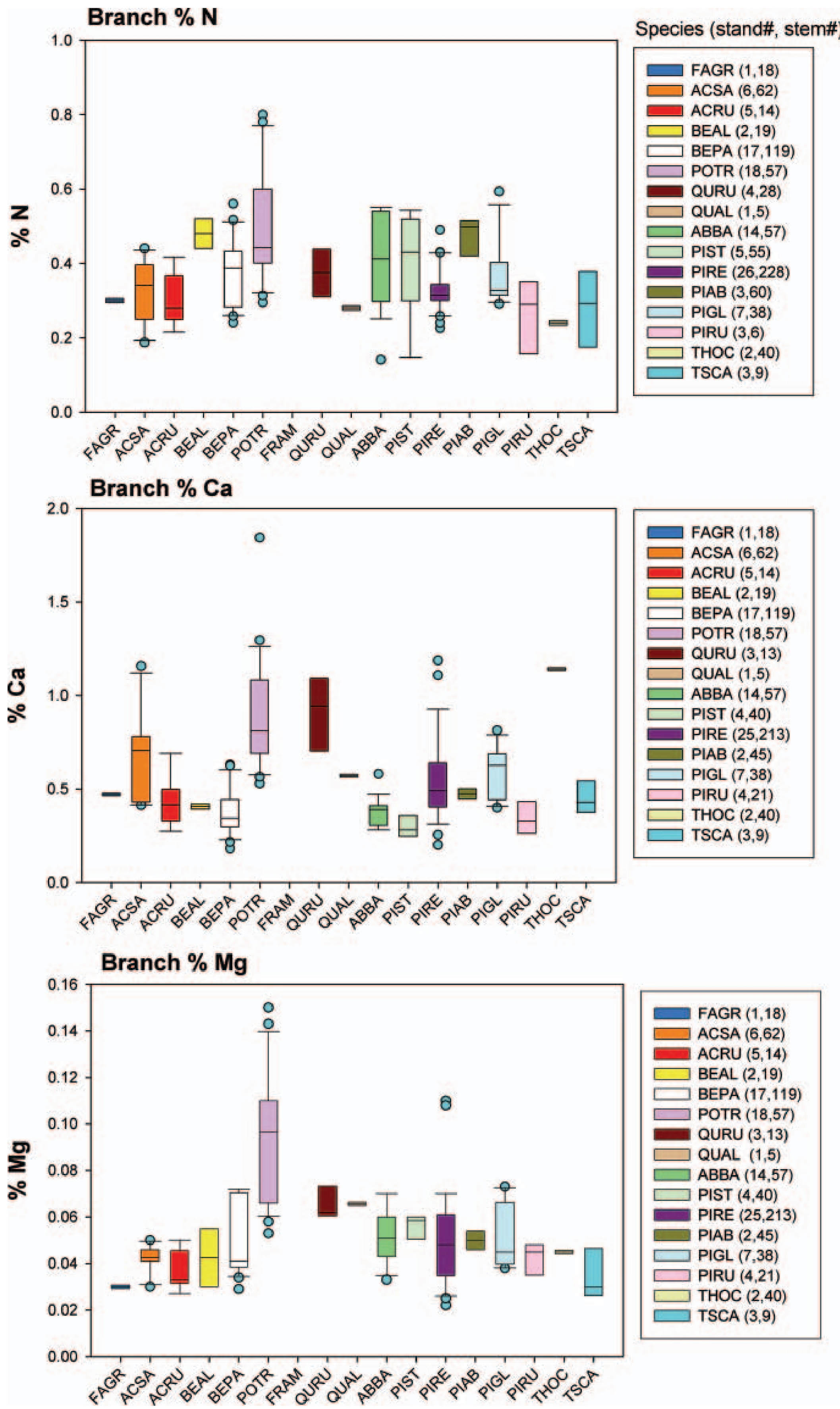


Figure 6.—Branch % N, % Ca, and % Mg

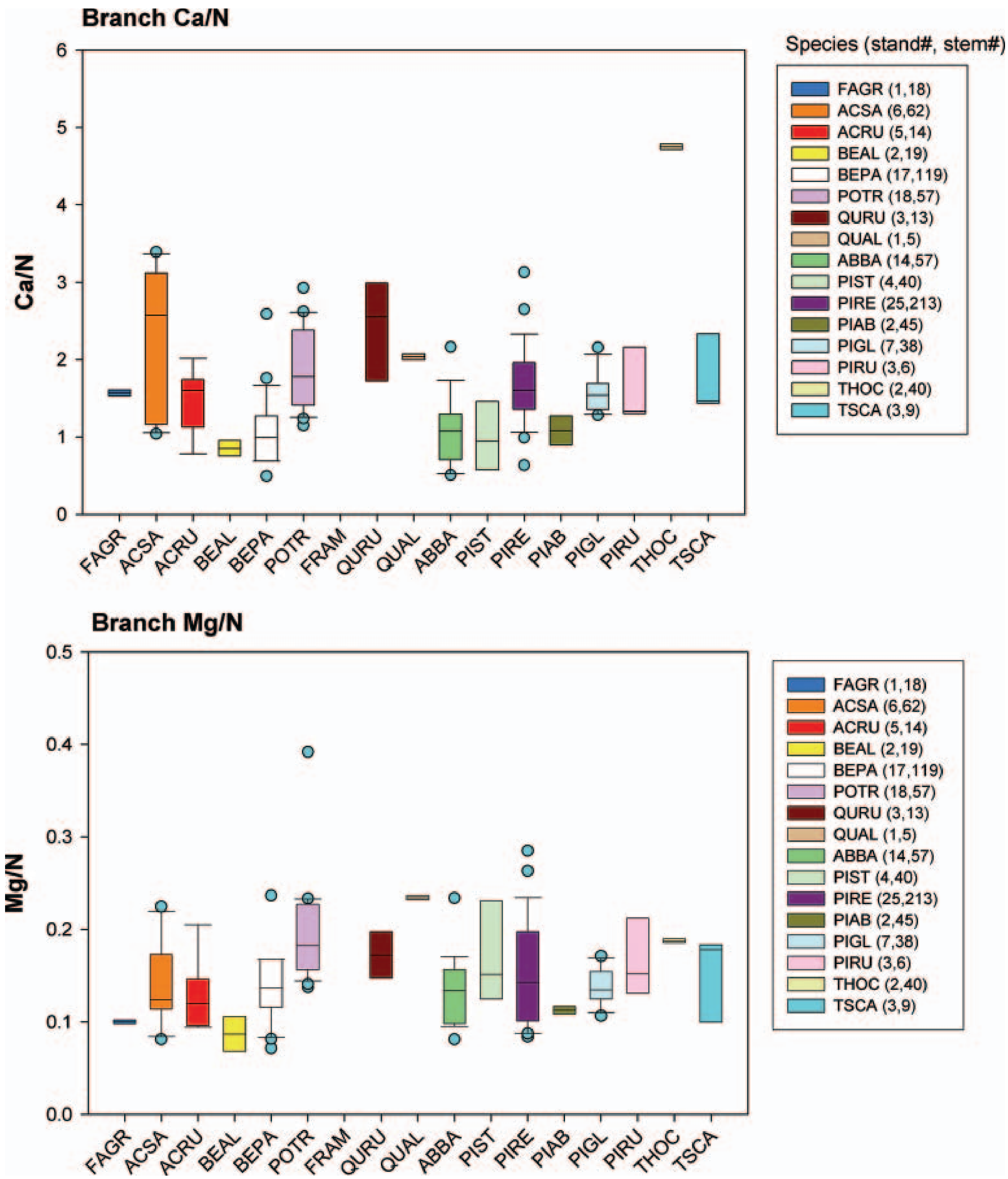


Figure 7.—Branch Ca/N and Mg/N

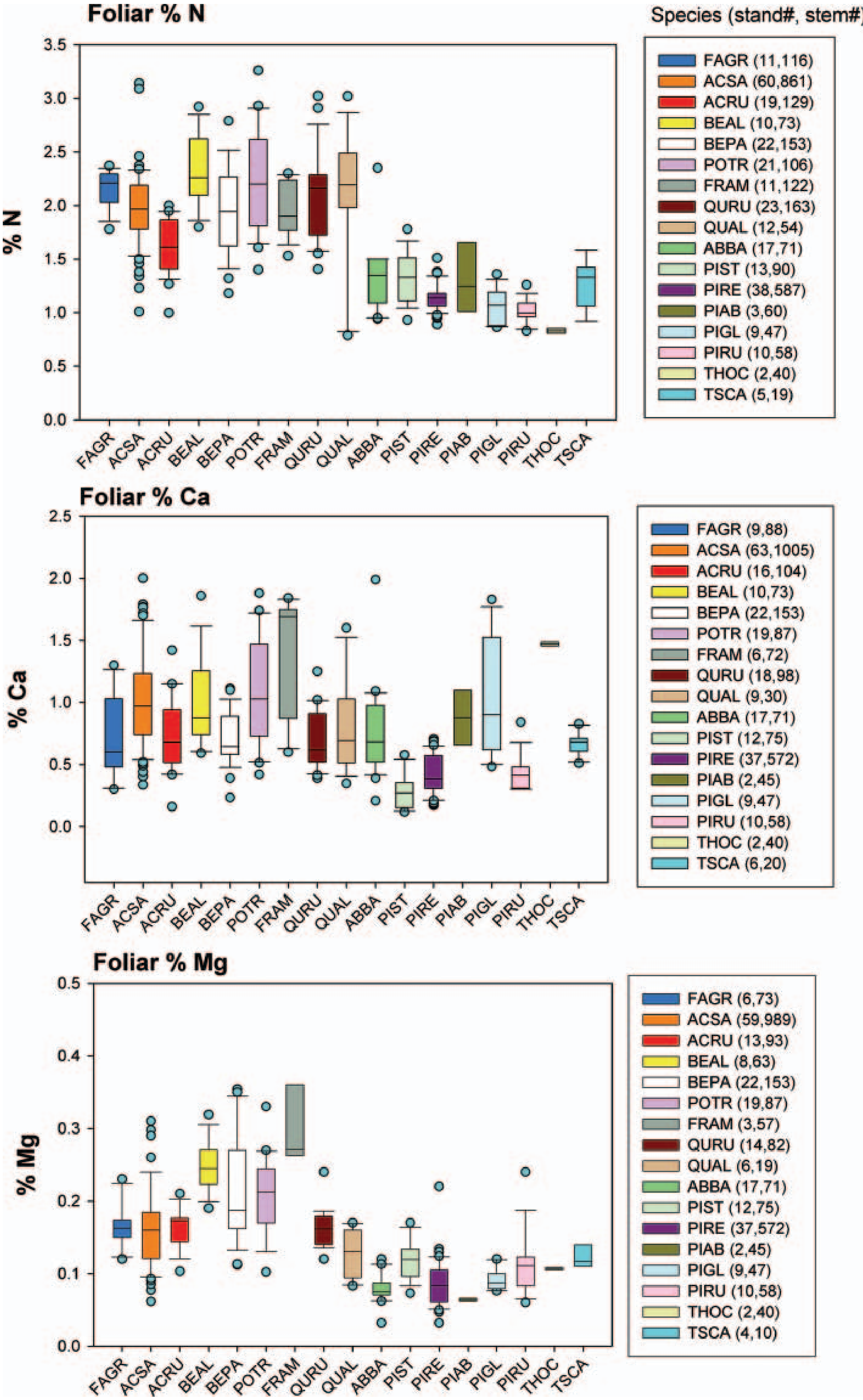


Figure 8.—Foliar % N, % Ca, and % Mg

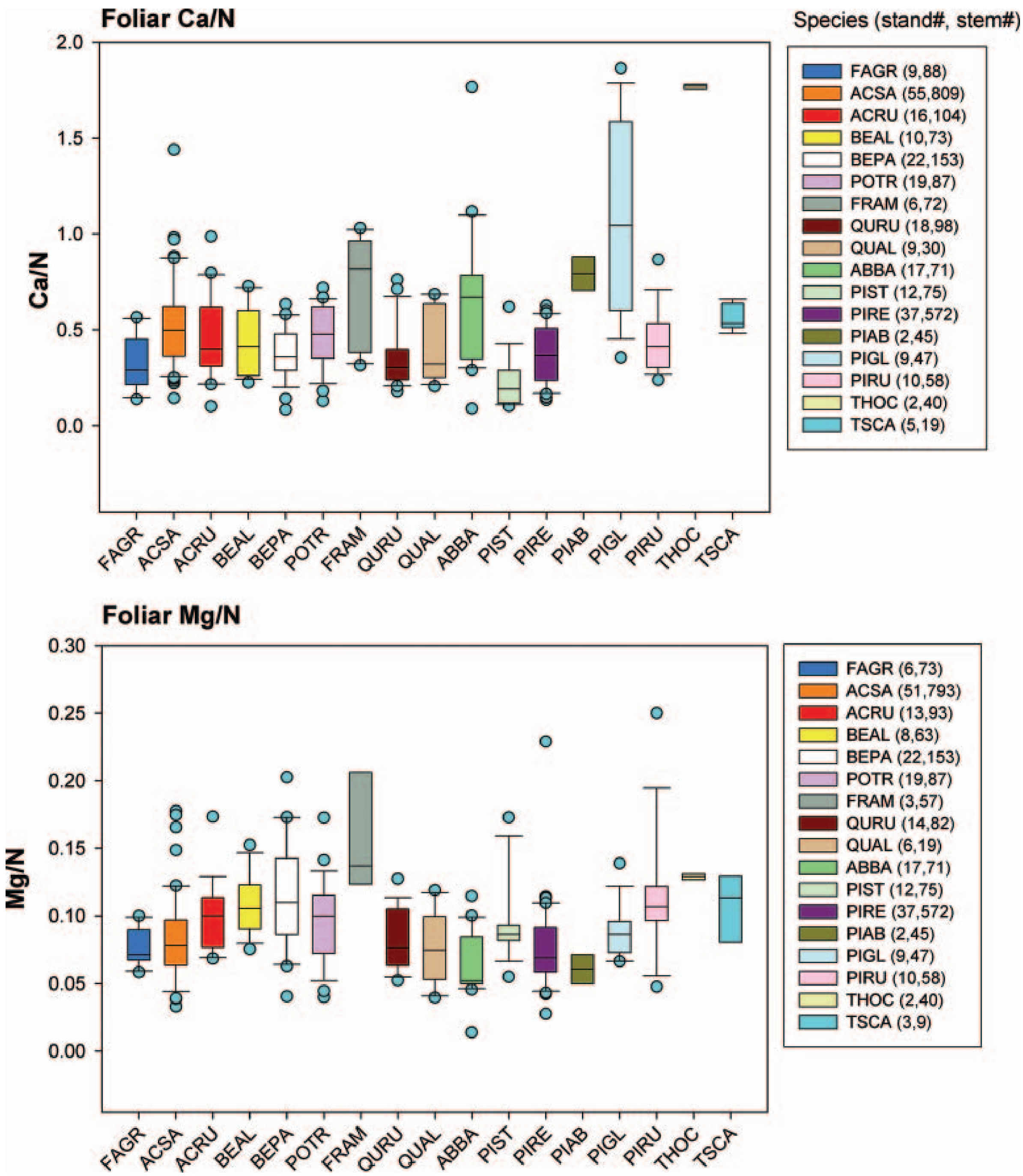


Figure 9.—Foliar Ca/N and Mg/N

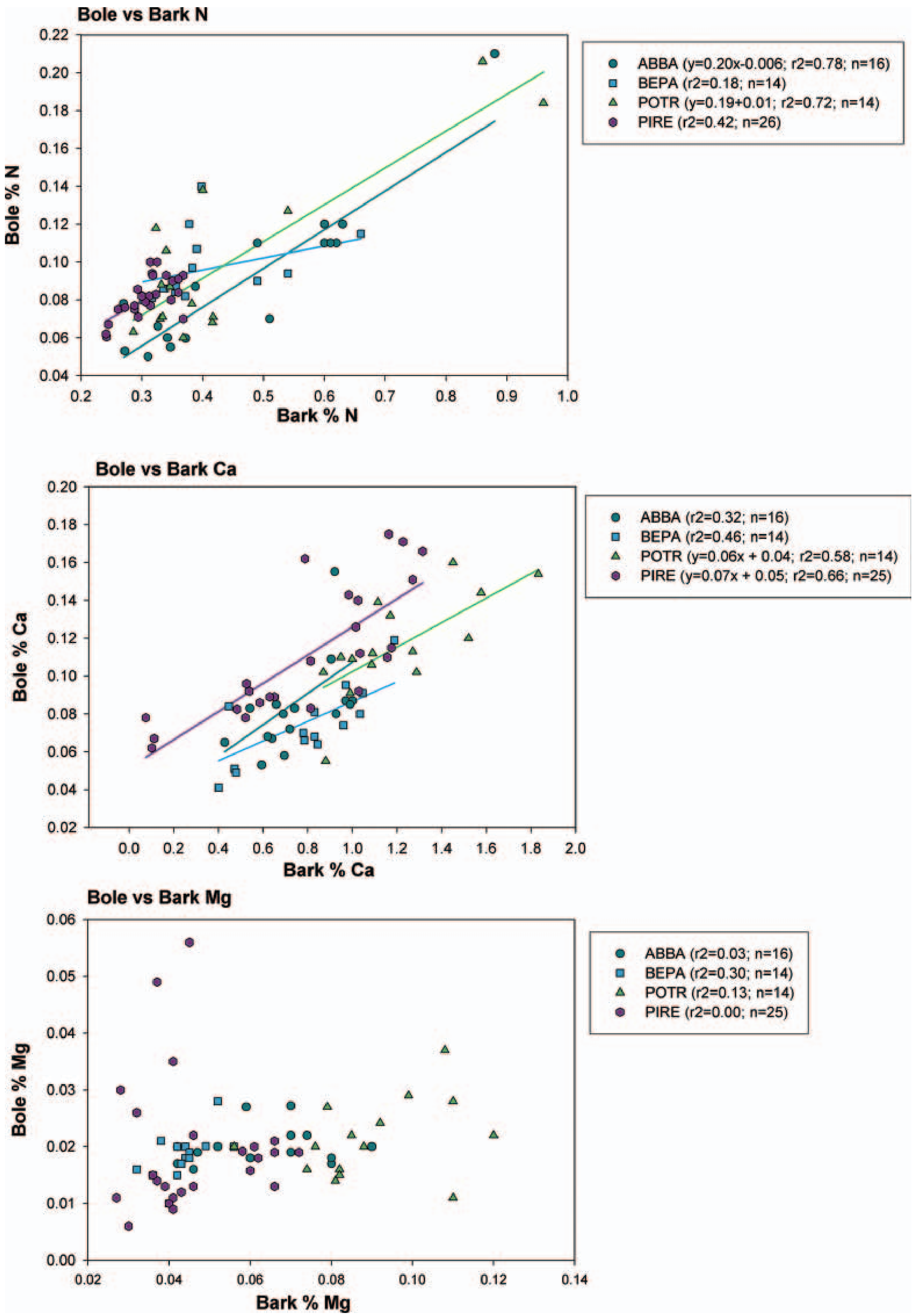


Figure 10.—Bole versus Bark N, Ca, and Mg

This CD-ROM includes an electronic version of the publication in Adobe pdf format. Also included is a folder containing the database files in Microsoft Access® 97, 2000 and 2002 formats.

Pardo, Linda H.; Robin-Abbott, Molly; Duarte, Natasha; Miller, Eric K. 2005. **Tree chemistry database (version 1.0).** Gen. Tech. Rep. NE-324. Newtown Square PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 45 p.

The Tree Chemistry Database is a relational database of C, N, P, K, Ca, Mg, Mn, and Al concentrations in bole bark, bole wood, branches, twigs, and foliage. Compiled from data in 218 articles and publications, the database contains reported nutrient and biomass values for tree species in the Northeastern United States. Nutrient data can be sorted on parameters such as stand age, sample year, region, and glaciation. This report documents database development and provides instructions for use of the database, which is included on an accompanying CD-ROM.

Keywords: Tree species; nutrient elements; biomass; Northeastern United States

Printed on Recycled Paper

Headquarters of the Northeastern Research Station is in Newtown Square, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Parsons, West Virginia

Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

Warren, Pennsylvania

"Caring for the Land and Serving People Through Research"