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FOREST HEALTH MONITORING PLOT DESIGN AND LOGISTICS STUDY

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EXECUTIVE SUMMARY

BACKGROUND

The Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP-Forests) has joined the U.S. Department of Agriculture Forest Service and other government agencies in an effort to monitor and assess the condition of the nation's forested ecosystems in relation to natural and manmade stresses A long-term and multi-tiered strategy for monitoring and assessment includes elements for detecting, evaluating, and explaining changes in forest condition. To improve the efficiency of monitoring, part of the strategy is to test and optimize field measurement procedures.

A preliminary set of measurements was chosen for testing in the detection phase of monitoring based on workshops, a review of the literature, expert opinion, and reports from studies done elsewhere. The interagency Forest Health Monitoring (FHM) program is now conducting research to expand that set and to verify the capabilities of measurements to accurately represent and respond to changes in forest condition over time. Research is needed to optimize the deployment of selected measurements, because any per-unit cost reductions will be multiplied many times in a nationwide program.

Thus, the FHM program conducted a field test of plot design and logistics for previously-selected measurements in 1990. Not all of the possible measurements were tested, and not all of the questions that have been asked about the selected measurements were asked in this study. The objectives of the field test were:

- to evaluate plot design and subsampling procedures,
- to quantify time and resource requirements,
- to assess the relative efficiency of competing methods in some cases, and
- to supply information to improve the national FHM program.

The purpose of this report is to summarize the results that were obtained Recommendations are made to guide further planning of the monitoring program.

Section 1 provides an overview of the rationale, objectives, and approach to the field study. Section 2 describes the site and stand characteristics of the forests that were sampled. Sections 3 and 4 are the main focus of the report, they summarize the results obtained for plot design and logistics. Recommendations are based on the detailed results obtained for different groups of measurements as reported in Sections 5 through 9. These measurements include the following.

- Visual Symptoms - selected mensurational variables such as tree size and the percentage of live crown, and tree crown dieback, transparency, discoloration, defoliation, and density.
- Soil Productivity - soil chemical and physical properties.
- Foliar Nutrients/Chemical Contaminants - chemical analyses of foliage from sample trees
- Vegetation Structure - vertical vegetation structure.
- Growth Efficiency - canopy transmittance of photosynthetically active radiation.

The starting point for measurements and plot design was based on several interagency committee reports, the FHM measurement strategy, and the current plans for monitoring. From this starting point, a suite of measures of forest site and stand "condition," broadly defined, were selected for testing. The potential efficacy of these measures has been established through peer review. The question of their efficiency is important because many are likely to be included in the collection of measurements deployed in the field The type of information needed about these measurements includes, for example, how many sites should be measured, how frequently should measurements be made, how should measurements be physically arranged in the field, how much do different methods cost, and what infrastructures are required to make the measurements.

The field test was conducted in the New England and the Southeast regions of the United States In New England, 20 field plots were located in northern hardwoods forest types. In Virginia, 20 field plots were located in loblolly pine-hardwoods forest types. The plot locations were selected systematically (Virginia) or randomly (New England) from candidate locations defined by the EMAP sampling grid and by the U.S. Forest Service forest inventory system. At each selected location, a plot consisting of four subplots was established. Within subplots, further subsampling rules were devised according to the particular objectives for each set of measurements. This sampling design established a multistage sample framework to address the objective of sources of variance It also established a realistic setting for the test of logistics.

In New England, the field plots were located on a wide variety of site conditions, but all were contained in the maple-beech-birch forest-type group. In Virginia, the coastal plain sites were less variable, but both the loblolly-shortleaf pine and the oak-pine forest-type groups were sampled. The field plots are representative of uniform, fully stocked, mature stands on typical soil types in these forest types and regions. Stand density (basal area) ranged from 19 to 48 m^2/ha in New England and from 13 to 47 m^2/ha in Virginia. Stem density was between 500 and 1300 trees/ha in New England and between 400 and 1550 trees/ha in Virginia. Species composition was different for the two regions, but the range and average number of overstory species were similar between regions The New England stands had structures approaching uneven-aged, and the Virginia stand structures were suggestive of multistoried stands.

PLOT DESIGN

Standard statistical procedures were used to estimate the optimum number of sample units for different measurements and stages of sampling under two sets of cost assumptions These results should be considered guidelines rather than rules for sampling. In most cases, the sample designs developed for the 1990 and 1991 field tests are adequate for a regional monitoring program, but generalizations to untested species and regions may be tenuous. The optimum solutions were not particularly sensitive to cost reductions in the final stage of sampling In comparison to locating field plots and establishing subplots, the costs of the final stages are less important than the information gained, suggesting that the measurement effort not be unduly constrained by logistical considerations once personnel are on the plot. Spatial correlation was not an important factor to consider when calculating optimum sample sizes for measurements that were made on systematic grids within plots.

The recommended sample allocations suggest that the current design of four subplots per field plot location is more than adequate for most of the measurements that were tested. The estimates of sample allocation suggest that two trees per each of three or four subplots should be sufficient for visual symptoms measurements for any single species. If separate statistics are desired for each species, then the total number of trees measured at each location depends on the number of species present. Analyses of typical mensuration variables suggested that two subplots were sufficient for characterizing average tree sizes and total stand basal area, but the subplots may be too small because not enough trees were present on them to adequately portray stand structure.

The soils data suggested that two to three soil pits will be sufficient These pits should be systematically arranged so as to represent the entire field plot location. The foliage chemistry data were quite variable and only two species were tested. The suggested allocation is for five to six branches from each of one to two trees taken from each of two to three subplots, or a total of between 15 and 30 branch samples per species per plot location If interest centers on the subset of macronutrients, then only one-third as many branches are required. The larger sample sizes would be required mainly to characterize the heavy metals in foliage.

A conservative estimate of the number of vegetation structure measurements required in the forest types tested is six subplots and four measurement stations per subplot. The results for photosynthetically active radiation (PAR) suggest between two and six subplots, more on cloudy days and fewer on clear days, and two measurement stations per subplot. Both the vegetation structure and PAR measurements need to be tested under a wider variety of forest canopy types before firm recommendations can be given, because the results obtained were highly conditioned upon the subplots being "rotated" into similar canopy conditions

LOGISTICS

The elements of logistics that were examined included: staffing and personnel, procurement and inventory control, training, reconnaissance, sampling, communications, and safety. It was feasible for a five-person crew to make the measurements on a plot in a ten-hour day. Six specific recommendations are made to improve the efficiency of field activities:

- Specify the criteria for eliminating sampling sites prior to reconnaissance.
- Provide reconnaissance prior to field sampling to reduce the time it takes a field crew to locate a sampling site.
- Review all equipment and consumable items with measurement coordinators to determine exactly what is required.
- Determine staff requirements early and ensure that contracts are established before field sampling activities commence.
- Provide an assistant to the field crews to stock equipment and consumables and to receive, maintain, transport, and track samples.
- Provide a better communications network. The regional project leader or an identified assistant should be responsible for all communication with the field crew leader. The logistics personnel should have early and close communication with other groups (design, indicators, QA, information management) to develop efficient field implementation.

VISUAL SYMPTOMS

Measures of visual symptoms and mensuration are important elements of forest monitoring in most countries, but care must be taken to obtain comparable measurements for different species and locations. This study sampled trees according to the protocols that were used for implementation of FHM in New England in 1990, and despite the comparatively small sample sizes in this study, the results were generally similar to those reported by the FHM program based on New England monitoring effort. There was no comparable sample for Virginia, however. The variance analysis of crown density yielded results similar to those obtained in a field test in Great Britain. Most of the variability of crown density can be attributed to tree-to-tree variability, and most of the remainder to stand-to-stand variability. The quantitative analysis of these sources of variance allow FHM to derive optimum numbers of trees to sample within each stand Additional analyses are needed to determine which of the competing measurement methods are most efficient or accurate. Additional analyses of root and tree increment core samples are also needed.

SOILS

Measurements of soil physical and chemical properties are fundamental to forest monitoring The study focused on logistical concerns and on quantifying the measurement variability that may be expected when soil measurements become a routine part of monitoring. Two different statistical techniques were applied to a set of laboratory chemical parameters that were measured on soil samples collected from eight intensively-sampled field plots in each region. The results suggest that the present systematic sampling design of three soil holes per field plot is sufficient. The variance among pits within clusters was the same as the variance among pits among clusters, indicating that a sampling design with individual pits as the subsampling unit provides a better allocation of resources

FOLIAR CHEMISTRY

Sugar maple (in New England) and loblolly pine (in Virginia) foliage samples were obtained from the upper crowns of dominant and co-dominant trees on 10 plots in each region. A suite of chemical analyses were performed which included macro- and micronutrients, total C, N, and S, and selected trace elements. Between-plot, between-subplot, between-tree, and between-branch variances were calculated. Between-branch variances could not be estimated for sugar maple because the samples were collected incorrectly. The sample optimization suggested five to six branches from each of one to two trees on two to three subplots for most elements, but fewer branches were required to characterize just the macronutrients. Most of the relatively large branch-to-branch variability observed for the trace elements may be attributed to concentrations at or below the analytical detection limit

VEGETATION STRUCTURE

Physical alteration of habitats is a threat to biotic diversity. For this reason, the structural features of land use, land cover types, and animal habitats are candidate indicators of biotic integrity. The primary objective of this study was to compare an ocular method to a pole method for measuring the amount, arrangement, and composition of forest vegetation. These methods differ in their conceptual and procedural approaches to estimate foliage occupancy and distribution. The results indicated that ocular estimates of total foliage occupancy are significantly (3 to 13%, $p<0.01$) larger than pole estimates. The advantages of the ocular method include speed and a capability for generating a complete stand profile (the pole method was limited to the lowest 30 ft of the profile). The advantages of the pole method include lower measurement error, more flexibility for data manipulation, and better variance estimates. Both methods were successfully implemented, but additional analyses of associations among measurements and of existing data bases are required before a definitive judgement can be made about which method is preferable for FHM program needs.

PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

Ground-based measures of canopy density and processes are considered to be more of a research topic than a candidate for full implementation at this time In the uniform-canopy stands that were sampled, it was possible to estimate the plot median percentage of transmitted PAR with a relative standard error of between 0.1 and 2.7% using a portable integrating radiometer in less than one hour. Under ideal sky conditions, the number of measurements should be chosen to characterize the spatial variation over the whole plot rather than to achieve a target level of precision, because relatively few measurements are needed to estimate plot-level statistics with a high precision under uniform canopies. Cloudy sky conditions reduced the sampling efficiency but they did not invalidate the sampling design. To alleviate problems associated with cloudy skies, fewer samples per subplot but more subplots, or the simultaneous measurement of both ambient and under-canopy radiation, should be investigated.

SUMMARY

The field test of plot design and logistics provided information to help plan the detection phase of forest monitoring for selected measurements. In general, the plot design and sampling recommendations are within the realm of practical possibilities. Most measurements will require further testing in other forest types and regions before definitive national recommendations can be made. Some measurements will require a critical evaluation to determine if it is practically possible to implement them everywhere. It is anticipated that the indicator development research currently underway in other FHM projects will suggest additional procedures for which plot design and logistical questions may be tested in the future.

SPECIES NOMENCLATURE

Common name	Latin name	Common name	Latin name
American basswood	*Tilia americana* L.	post oak	*Quercus stellata* Wangenh
American beech	*Fagus grandifolia* Ehrh.	quaking aspen	*Populus tremuloides* Michx.
American holly	*Ilex opaca* Ait.	red maple	*Acer rubrum* L.
American mountain-ash	*Sorbus americana* Marsh	red pine	*Pinus resinosa* Ait
balsam fir	*Abies balsamea* (L.) Mill.	red spruce	*Picea rubens* Sarg.
bigtooth aspen	*Populus grandidentata* Michx.	rock elm	*Ulmus thomasii* Sarg
black cherry	*Prunus serotina* Ehrh.	sassafras	*Sassafras albidum* (Nutt.) Nees
black oak	*Quercus velutina* Lam.	scarlet oak	*Quercus coccinea* Muenchh.
black walnut	*Juglans nigra* L.		
blackjack oak	*Quercus marilandica* Muenchh	Scots pine	*Pinus sylvestris* L.
		sessile oak	*Quercus petraea* (Mattuschka) Lieblein
bluebeech	*Carpinus caroliniana* Walt.		
cherry	*Prunus spp*	shortleaf pine	*Pinus echinata* Mill
common choke cherry	*Prunus virginiana* L.	Sitka spruce	*Picea sitchensis* (Bong.) Carr.
eastern white pine	*Pinus strobus* L.		
eastern hemlock	*Tsuga canadensis* (L.) Carr.	sourwood	*Oxydendrum arboreum* (L.) DC.
eastern hophornbeam	*Ostrya virginiana* (Mill.) K. Koch	southern red oak	*Quercus falcata* Michx.
		striped maple	*Acer pennsylvanicum* L.
eastern redcedar	*Juniperus virginiana* L.	sugar maple	*Acer saccharum* Marsh
elm	*Ulmus spp.*	sweet birch	*Betula lenta* L.
English oak	*Quercus robur* L.	sweetbay	*Magnolia virginiana* L.
European beech	*Fagus sylvatica* L.	sweetgum	*Liquidambar styraciflua* L.
flowering dogwood	*Cornus florida* L.	upland blackgum	*Nyssa sylvatica* Marsh
green ash	*Fraxinus pennsylvanica* Marsh.	Virginia pine	*Pinus virginiana* Mill
		water oak	*Quercus nigra* L.
hickory	*Carya spp.*	white ash	*Fraxinus americana* L.
loblolly pine	*Pinus taeda* L.	white oak	*Quercus alba* L.
lowland blackgum	*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.	white pine	*Pinus strobus* L.
		white spruce	*Picea glauca* (Moench) Voss
northern red oak	*Quercus rubra* L.		
northern white-cedar	*Thuja occidentalis* L.	willow oak	*Quercus phellos* L.
Norway spruce	*Picea abies* (L.) Karst.	yellow birch	*Betula alleghaniensis* Britton
paper birch	*Betula papyrifera* Marsh		
persimmon	*Diospyros virginiana* L.	yellow-poplar	*Liriodendron tulipifera* L.
pond pine	*Pinus serotina* Michx.		

CONVERTING FACTORS FOR COMMON UNITS OF MEASUREMENT

Metric unit	English equivalent
<u>Length</u>	
1 centimeter (cm)	0 39370 inches (in)
1 meter (m)	3.28083 feet (ft)
1 kilometer (km)	0.62137 miles (mi)
<u>Area</u>	
1 square centimeter (cm^2)	0.15500 in^2 0 001076 ft^2
1 square meter (m^2)	10.76387 ft^2
1 hectare (ha)	2 471044 acres (ac) 0.0038610 mi^2
1 square kilometer (km^2)	247.104 ac 0.38610 mi^2
1 m^2/ha	4.3560 ft^2/ac

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1 PLOT DESIGN AND LOGISTICS

"These reprehensible beings [statisticians] are commonly accused of (1) demanding too many trees per treatment and (2) being ready to base results on samples that are not large enough."

– S.C. Pearce (1953)

The U.S. Environmental Protection Agency's (EPA's) Environmental Monitoring and Assessment Program (EMAP-Forests) has joined the U.S. Department of Agriculture (USDA) Forest Service and other government agencies in an effort to monitor and assess the condition of the nation's forested ecosystems in relation to natural and manmade stresses. A long-term and multi-tiered strategy for monitoring and assessment (Palmer et al., 1991) includes elements for detecting, evaluating, and explaining changes in forest condition.

To implement the many aspects of monitoring, the interagency Forest Health Monitoring (FHM) program draws upon organizations with skills in forest inventory, pest and health management, ecological research, and environmental regulation Within EPA, the FHM effort is linked to the monitoring of other resource classes (e.g., agricultural and arid lands) and draws expertise from groups that coordinate statistical design, measurement selection, information management, and other technical areas (Palmer et al , 1991).

Because the FHM program is large and complex, it cannot be fully implemented everywhere at once, and therefore the strategy for implementation is conservative. The detection phase of forest monitoring began in 1990 with a survey of 206 field plots in New England (Brooks et al., 1991a) and has been expanded to the Mid-Atlantic and Southeast regions of the United States in 1991. Because budgets are limited, the strategy includes pilot tests, regional demonstrations, and critical evaluations of procedures prior to implementation. Selected procedures for the detection phase of monitoring were evaluated in a regional test in 1990, and the testing was continued in the Southeast and Western United States in 1991.

The purpose of this report is to summarize the 1990 field test. The test was designed to answer specific questions about field plot design and logistics for selected measurements (Palmer et al., 1990) Not all of the possible measurements were tested, and not all of the possible questions were asked about the measurements that were tested. The purpose of this document is to summarize what was learned about plot design and logistics from that field test. The goal is to provide a timely analysis to help guide the expansion of the monitoring program in 1991

The purpose of this introductory section is to provide an overview of the scope and purpose of the field study. The contents of each section will be reviewed, the rationale for the plot design and logistics objectives will be given, and the approach to the study will be described A quality assurance report (Burkman and Mickler, 1990) and a field methods manual (Dwire et al , 1990) provide additional information about the study.

1.1 CONTENT AND ORGANIZATION

This report is organized into nine sections. Section 2 describes the site and stand characteristics at the field plot locations. Section 3 summarizes the statistical issues and lessons learned about field plot design and required sample sizes Section 4 reviews logistical issues and makes recommendations for implementing these measurements. The lessons and recommendations are based on the test results for different groups of measurements that are reported in Sections 5 through 9.

1.2 RATIONALE AND OBJECTIVES

Measurement selection and plot design was based on interagency committee reports (Forest Damage Survey Workshop, Chapel Hill, NC, November 1987; Forest Health Task Force meeting, Harper's Ferry WV, July 1988; and Joint EPA/USDA Forest Service FHM National Coordination Meeting, Research Triangle Park, NC, January 1990), the EMAP measurement strategy (Hunsaker and Carpenter, 1990), and the current monitoring plans (Brooks et al., 1991b)

One important question for any measurement is its biological accuracy, or its capability to represent forest "condition." But there is a practical difficulty of testing this, because accuracy assessment requires that "good" sites be distinguished, *a priori*, from "bad" sites. That implies there is at least one metric that is guaranteed to accurately classify condition (or else the sites would be indistinguishable). Any correlated metric will also appear accurate; any uncorrelated metric will appear inaccurate. The difficulty is that, of a suite of measurements chosen to characterize several dimensions of "condition", some will incorrectly appear to be inaccurate only because they measure "good" vs. "bad" on a different scale.

For example, choosing "good" and "bad" sites in terms of past growth virtually guarantees that growth will appear to be an accurate metric of condition. It also makes it more likely that a correlated measure such as crown density will appear accurate. But any uncorrelated measure of, for example, wildlife abundance would appear to be "inaccurate", *without even receiving a fair test!* This difficulty can be overcome, but it was decided that a fair test of accuracy of all the proposed measurements was beyond the scope of this study.

Instead, another set of questions was asked about selected measurements. It is reasonable to assume that some measurements have a high probability of being included in forest assessments, based on expert opinions, the experiences of monitoring programs in other countries, and the need to simply characterize the monitoring sites. A small increase in the efficiency of these measurements would translate to substantial cost reductions in a fully-implemented national effort.

Preference was therefore given to selected measures of forest site and stand "condition", broadly defined, that can potentially be applied in any type of forest. The type of information needed about these measurements is rather utilitarian, for example, how many sites should be measured, how frequently should measurements be made, how should measurements be physically arranged in the field, how much do different methods cost, and what infrastructures are required to make the measurements.

A study of the components of variance of forest condition measurements was conducted in a way that logistical questions could also be addressed in a realistic setting. The objectives were:

- to evaluate plot design and subsampling procedure sensitivity to spatial heterogeneity at the scale of monitoring,
- to quantify the time and fiscal requirements of making these measurements,
- to assess the relative efficiency of competing measurement methods in some cases, and
- to apply the results in planning the further implementation of the national FHM program

A secondary objective was to start to set up an infrastructure for monitoring and assessments This infrastructure is needed, for example, for information management, quality assurance, logistics, and data analysis Another secondary objective was to generate a set of data that could be used in future simulation studies to explore alternate designs for monitoring and reporting.

1.3 APPROACH TO THE STUDY

In October 1989, EMAP-Forests was directed to conduct a field study to augment the current Forest Service monitoring plans in New England. The FHM program determined in March 1990 that EMAP-Forests would conduct a pilot test of selected measurements in two forest types: one in the Northeast and the other in the Southeast regions of the United States The test would be conducted as a separate but related effort of the ongoing implementation in New England

An interagency work group was set up to plan and conduct the pilot test (Palmer et al , 1990). Individuals were assigned lead roles for specific sets of measurements, for quality assurance, and for logistics. Both agencies participated in the review of study plans, sampling designs, and field methods. Staff from both agencies arranged the resources to physically conduct the study. The study was set up in the months of April and May 1990

Methods were refined and field crews were trained and tested in typical field settings at the Pocahontas State Forest, VA, during two weeks in early summer. A debriefing workshop was conducted after the field work was completed

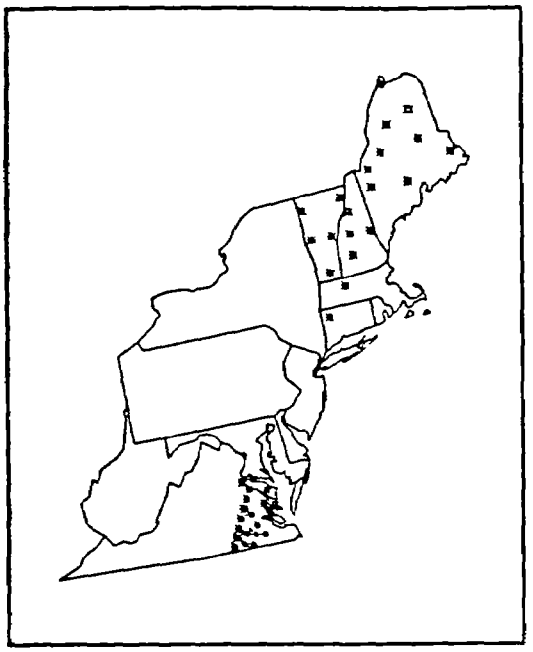

Figure 1-1. FIELD STUDY PLOT LOCATIONS IN NEW ENGLAND AND VIRGINIA

The study was conducted at 40 field plot locations: 20 in the northern hardwoods forest types in New England and 20 in the loblolly pine-hardwoods forest types in eastern Virginia (Fig 1-1) In Virginia, the plot locations were selected systematically from the phase 1 (aerial photograph) sample used for multiphase forest inventory by the U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA) projects (U.S. Forest Service, 1985a) In New England, the plot locations were selected randomly from the stage 2 (ground plot) FIA forest inventory sample. To maximize geographic representation within the selected forest types and to provide realistic tests of logistics, at most one location was selected within one of the EMAP 40-km^2 sampling units (Overton et al., 1990).

At each selected location, a plot consisting of four subplots was established. The four-subplot design was convenient because it established a multistage sample framework at each location (needed to address the objective of sources of variance), and because it was similar to the design that was planned for monitoring in New England. Within subplots, further subsampling rules were devised according to the objectives for each set of measurements

These initial studies used the USFS Northeast station's protocols for "rotating" subplots. With rotation, all subplots are certain to be located in the same forest type at each location. Rotation provided the opportunity to obtain compatible data within plots and simplified the analysis of resource allocation.

Table 1-1 summarizes the data that were available for this report. Note that not all measurements were planned for every location, so the table is sparse for some measurements For example, "intensive" soil sampling and foliar chemical measurements were planned for 8 to 10 of the 20 total locations per region. Foliage data for some locations were not available because the laboratory analyses had not been completed in time.

The following brief descriptions of the designs for the measurements set the stage for the more detailed descriptions in later sections.

- "Visual symptoms" includes forest inventory measurements and several measures of tree crown condition that were made on trees in the four 0 0169-ha circular subplots (Fig 1-2)
- "Sample trees" includes measurements of roots, branches, tree increment cores, insects, and diseases that were made on 4 to 6 dominant or co-dominant trees in the 0.0843-ha annular subplots (Fig. 1-2). This sample was limited to sugar maple and red maple in New England and loblolly pine in Virginia These data are not reported in this document.
- "Foliage" includes chemical analyses of samples obtained from the sugar maple and loblolly pine sample trees described above.
- "Soil" includes physical and chemical measurements made at nine "pits" at each plot (Fig 1-3). At the less-intensively sampled plots, fewer measurements were made and they are not reported here.
- "Vegetation structure" refers to the physiognomic class and height of vegetation at each of 16 sample stations overlaid upon two of the four subplots (Fig. 1-4).
- "PAR" refers to measurements of light irradiance at 16 sample stations overlaid upon each of the four subplots (Fig 1-4).

Table 1-1 SUMMARY OF MEASUREMENTS AVAILABLE FOR EACH STUDY PLOT LOCATION

Plot no	Visual symptoms	Sample trees[a]	Soil	Foliage	Vegetation structure	PAR
New England						
16	X	X			X	X
117	X	X			X	
122	X	X	X	X	X	X
155	X	X			X	X
159	X	X	X	X	X	
160	X	X			X	X
166	X	X			X	
173[b]	X	X			X	X
174	X	X	X	X	X	X
181	X	X			X	X
267	X	X	X	X	X	X
270	X	X	X		X	X
289	X	X			X	X
321	X	X	X	X	X	X
347	X	X			X	X
420	X	X			X	X
508	X	X	X		X	X
692	X	X			X	X
902			X		X	X
3270	X	X			X	X
Virginia						
1839	X	X			X	X
1841	X	X			X	X
1843	X	X	X	X	X	X
1954	X	X		X	X	X
1955	X	X	X	X	X	X
1957	X	X			X	X
1958	X	X	X		X	X
1959	X	X	X	X	X	X
2072	X	X	X	X	X	X
2074	X	X			X	X
2075	X	X	X		X	
2185	X	X			X	X
2186	X	X			X	X
2187	X	X		X	X	X
2188	X	X			X	X
2189	X	X	X	X	X	X
2190	X	X	X		X	X
2191	X	X			X	X
2192	X	X			X	X
2303	X	X			X	X

[a] Laboratory diagnoses of sample tree leaf and twig symptoms are reported by Nash et al (1990) for New England species Laboratory diagnoses of loblolly pine symptoms have not been reported

[b] Data from the 0 0014-ha subplots are missing for plot number 173

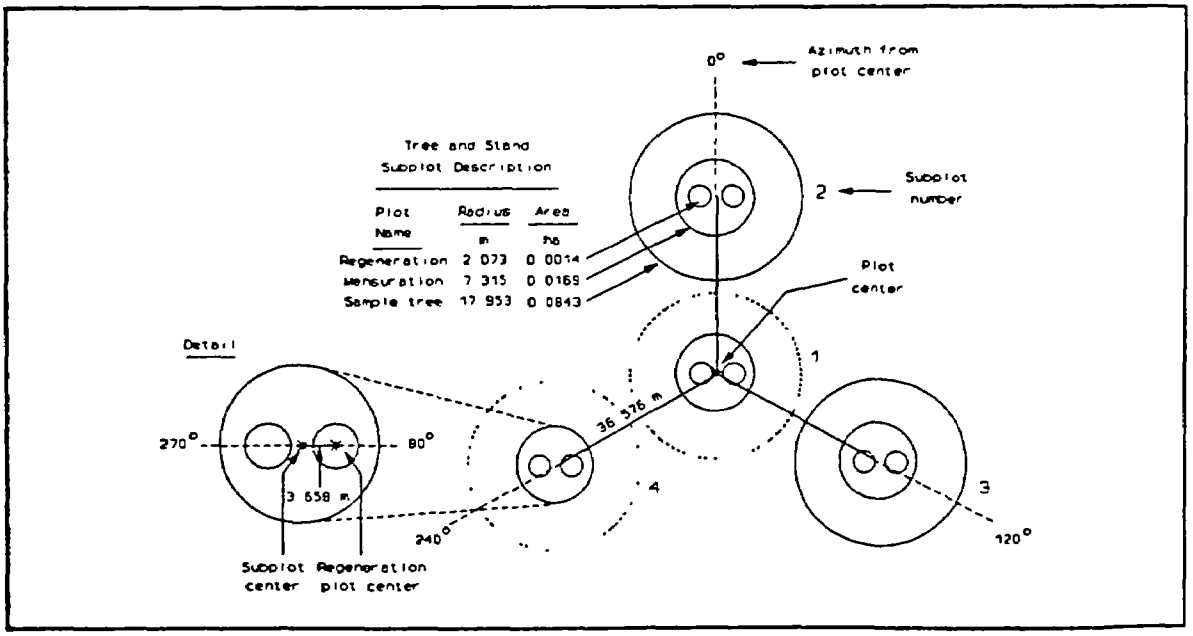

Figure 1-2. SAMPLING DESIGN FOR TREE AND FOLIAR MEASUREMENTS TREES < 7 62 cm dbh WERE MEASURED ON REGENERATION PLOTS, AND TREES ≥ 7 62 cm dbh WERE MEASURED ON THE MENSURATION PLOTS SAMPLES OF ROOTS, TREE INCREMENT CORES, AND FOLIAGE WERE OBTAINED FROM TREES ON THE SAMPLE TREE PLOTS

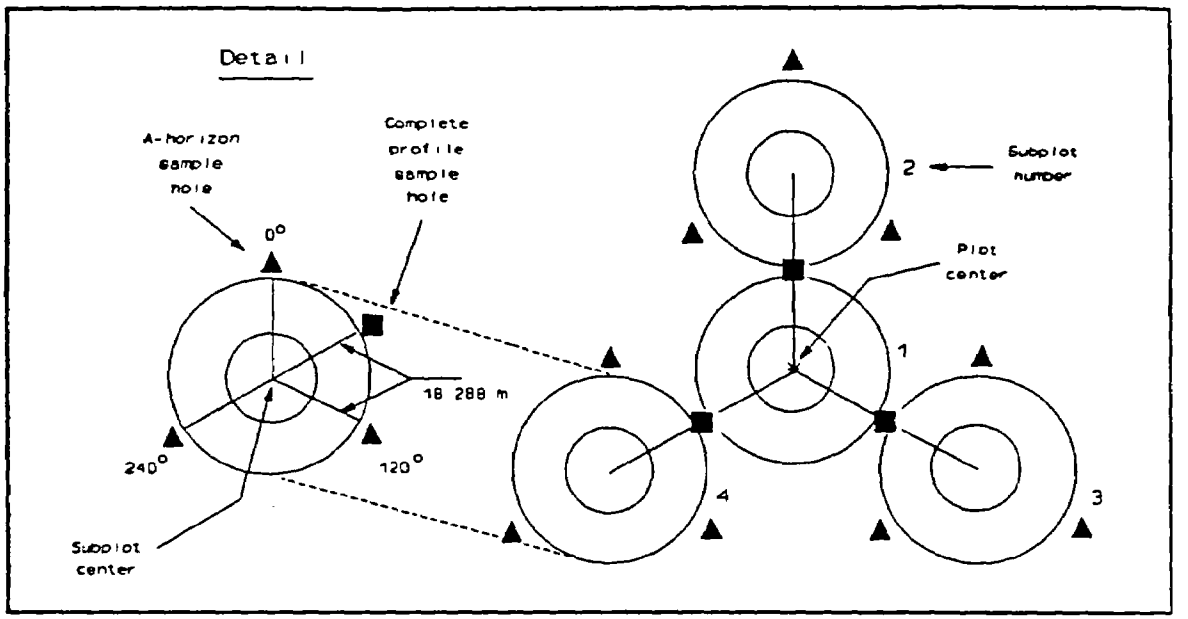

Figure 1-3 SAMPLING DESIGN FOR SOIL MEASUREMENTS

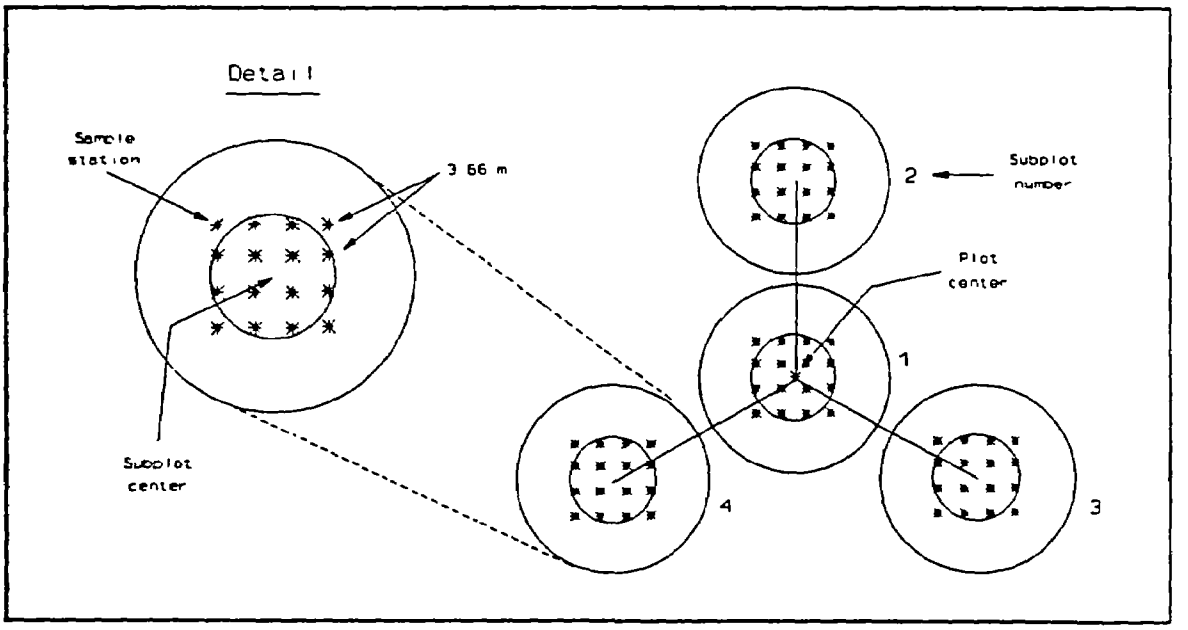

Figure 1-4 SAMPLING DESIGN FOR VEGETATION STRUCTURE AND PAR MEASUREMENTS VEGETATION STRUCTURE WAS MEASURED ONLY ON SUBPLOTS 1 AND 2

2 SITE AND STAND DESCRIPTIONS

Kurt Riitters, Rick Van Remortel, William Bechtold, and David Alerich

2.1 SITE DESCRIPTIONS

The purpose of this section is to describe briefly the sites and stands that were studied Some site attributes were recorded at each plot location, and others at each of the four 0.0169-ha subplots (Fig. 1-2) within each location. The stand descriptions come from the tree measurements made on trees with diameter at breast height (dbh) 7.62 cm and larger within the four 0.0169-ha circular subplots ("overstory") and on trees with dbh less than 7.62 cm within the eight 0 0014-ha circular subplots ("understory") (Fig. 1-2).

Table 2-1 lists site data, including plot number, state, county, elevation, and measurement date More detailed information about each of the four subplots is contained in Table A-1 (Appendix A). In terms of elevation, slope, aspect, terrain position, micro-relief, and landform, the New England sites were generally more variable than the Virginia sites. All stands were of natural origin, but past land uses are unknown. A few sites had been disturbed recently (Table A-1). The average stand age was 43 years (range 30 to 70) in Virginia Stand age is not known for the New England sites

The study encountered four Society of American Foresters (SAF) forest types (Eyre, 1980) representing three of the USFS FIA-type groups (Tables A-1 and 2-2). The red maple-northern hardwood and sugar maple-beech-yellow birch forest types (SAF) that were sampled in New England are part of the FIA maple-beech-birch type group (Eyre, 1980). The maple-beech-birch type group occurs throughout the region and occupies about 24 % of the ~13 million ha of forestland in New England (U.S. Forest Service, 1982).

The loblolly pine and loblolly pine-hardwood forest types (SAF) that were sampled in Virginia are part of the FIA loblolly-shortleaf pine and oak-pine type groups, respectively (Eyre, 1980). The loblolly-shortleaf pine and oak-pine types occur primarily on the Atlantic coastal plain and Piedmont and occupy about 28% and 13%, respectively, of the ~20 million ha of forestland in the south Atlantic region (VA, NC, and SC; U.S. Forest Service, 1982).

Table 2-1. DESCRIPTIONS OF FIELD PLOT LOCATIONS (see also Table A-1)

Plot no	State	County	Elev * (m)	Meas date (mm-dd)
New England				
16	MA	Franklin	305	8-27
117	VT	Chittenden	244	8-15
122	ME	Waldo	91	7-31
155	VT	Addison	518	8-13
159	NH	Grafton	366	8-07
160	VT	Windham	335	8-24
166	NH	Carroll	488	8-22
173	CT	Litchfield	427	8-29
174	VT	Orange	427	8-09
181	VT	Essex	610	8-17
267	ME	Franklin	213	7-26
270	NH	Merrimack	183	8-03
289	ME	Washington	30	8-01
321	ME	Aroostock	396	7-20
347	NH	Coos	610	8-21
420	ME	Penobscot	183	7-18
508	ME	Somerset	366	7-25
692	ME	Piscataquis	213	9-12
902	ME	Aroostock	183	7-17
3270	ME	Oxford	610	9-11
Virginia				
1839	VA	Northumberland	30	8-17
1841	VA	Gloucester	30	8-15
1843	VA	Isle of Wight	30	8-14
1954	VA	Richmond	0	8-21
1955	VA	King & Queen	30	8-16
1957	VA	Surry	30	8-14
1958	VA	Sussex	61	8-06
1959	VA	Southampton	152	8-07
2072	VA	Charles City	30	8-15
2074	VA	Sussex	61	8-06
2075	VA	Greensville	30	8-13
2185	VA	Westmoreland	30	8-22
2186	VA	Caroline	91	8-21
2187	VA	King William	61	8-17
2188	VA	Henrico	30	8-10
2189	VA	Chesterfield	61	8-10
2190	VA	Dinwiddie	61	8-07
2191	VA	Brunswick	91	8-13
2192	VA	Brunswick	91	8-08
2303	VA	Caroline	61	8 22

* Elevation from U S Geological Survey topographic maps rounded up to the nearest 100 ft

Table 2-2 DESCRIPTIONS OF FOREST TYPES

Forest type	FIA* type-group	Forest type description (Dwire et al , 1990)
Sugar maple-beech-yellow birch	Maple-beech-birch	Associates include basswood, red maple, hemlock, northern red oak, white ash, white pine, black cherry, sweet birch, American elm, rock elm, and eastern hophornbeam Sites are fertile, moist, and well drained
Red maple-northern hardwood	Maple-beech birch	The type is dominated by red maple and some of the wide variety of northern hardwood associates including sugar maple, beech, birch, aspen, white pine, red pine, and hemlock The type is often manmade and may be the result of repeated cuttings Sites are generally uplands
Loblolly-hardwood	Oak-pine	Associates on moist and wet site include blackgum, sweetgum, yellow-poplar, red maple, white ash, green ash, and American elm On drier sites the associates include southern red oak, northern red oak, white oak, post oak, scarlet oak, persimmon, and hickory. Sites are usually moist to very moist though not wet all year, also found on drier sites
Loblolly pine	Loblolly-shortleaf*	Associates include sweetgum, southern red oak, post oak, blackjack oak, blackgum, pine yellow-poplar, and pond pine Sites in MD and DE are both upland with abundant moisture but good drainage and on poorly drained depressions

* FIA type groups are from the USFS FIA and are the major type groups identified by FHM for national reporting

2.2 STAND DENSITY

Table 2-3 reports stem density of overstory and understory trees, and the stand density in terms of basal area per unit area of overstory trees. Typical sizes of individual trees are indicated by the quadratic average dbh (the dbh of a tree with average basal area) of overstory trees, and by the average height of dominant and co-dominant overstory trees. The range of overstory stem density was 534 to 1305 trees/ha in New England, and 415 to 1557 trees/ha in Virginia. Understory stem density varied by at least an order of magnitude in both regions. Basal area (cross-sectional area of live trees at breast height) per unit area was between 19 and 48 m^2/ha in New England, and between 13 and 47 m^2/ha in Virginia.

The main canopy was between 14 and 23 m tall in New England, and between 15 and 27 m in Virginia. The quadratic average tree dbh was about 20 cm in both regions. The largest (dbh) trees measured in each region were an 81.8-cm northern red oak on plot 174 in New England and a 75.2-cm willow oak on plot 2188 in Virginia.

Overall, the stem density, stand density, average tree size, and main canopy heights were similar for the two regions. Almost all of these stands would be characterized as mature, fully stocked, pole- to saw timber-sized stands, with ample regeneration The stand density statistics were similar to those compiled from the most recent USFS FIA forest inventory for Virginia. Although no comparisons with forest inventory were made for the New England stands, the locations were drawn from existing FIA plots and are therefore presumably representative of the FIA sample.

2.3 SPECIES COMPOSITION

Table A-2 (Appendix A) summarizes species composition of the overstory trees of the stands in terms of stem density, basal area, and quadratic average dbh by species. Twenty-four species were found in New England and 31 in Virginia Comparisons of quadratic average dbh suggest that some of these species appeared mainly in the lower-canopy positions in these forest types (New England eastern hophornbeam, black cherry, balsam fir, striped maple, and common choke cherry; Virginia: American holly, sweetbay, persimmon, flowering dogwood, sourwood, bluebeech, red maple, and eastern redcedar). The composition of the upper-canopy trees was not consistent between stands. In four New England stands, the species selected for intensive sampling (sugar maple) was not on the plot but was available for sampling in the adjacent stand

Table 2-3. MENSURATION OF OVERSTORY AND UNDERSTORY TREES BY PLOT

Plot no.	Overstory: No. trees (ha⁻¹)	Overstory: Basal area (m²/ha)	Overstory: Avg dbh[a] (cm)	Overstory: Avg height[b] (m)	Understory: No. trees (ha⁻¹)
New England					
16	652	28 29	23 5	20 0	11305
117	534	28 20	25 9	21 4	18348
122	1305	38 38	19 4	21 0	93
155	593	19 55	19 5	15 0	10008
159	993	30 38	19 7	20 6	9822
160	890	41 20	24 3	22 6	2780
166	771	27 72	21 4	20 1	8062
173	1023	32 54	20 1	20 0	—
174	786	47 52	27 7	20 4	2039
181	712	19 61	18 7	14 0	12232
267	860	23.26	18 6	16 1	12417
270	904	35 06	22 2	19 8	3336
289	1082	19 84	15 3	17 1	2687
321	756	29 03	22 1	15 7	13529
347	904	30 83	20 8	19 2	11490
420	712	25 07	21 2	18 1	26409
508	1156	31 30	18 6	17 4	7228
692	890	22.37	17 9	16 8	6857
902	—	—	—	—	—
3270	1216	28 14	17 2	15 1	6394
Virginia					
1839	949	35 54	21 8	23 2	3521
1841	1201	39 83	20 5	25 4	4911
1843	1142	26 25	17 1	19 4	3243
1954	1038	46 73	23 9	22 5	2965
1955	563	24 82	23 7	20 2	6209
1957	771	25 35	20 5	23 4	19367
1958	415	13 14	20 1	19 0	21869
1959	1156	36 12	19 9	20 4	2687
2072	1260	30 08	17 4	20 2	14085
2074	1260	26 38	16 3	15 0	8988
2075	801	39 24	25 0	26.2	12973
2185	1053	38 75	21 6	21 2	8803
2186	1171	38 59	20 5	20 2	12880
2187	1394	30 11	16 6	17 7	8988
2188	1067	27.19	18 0	17.6	7042
2189	1245	27.77	16 8	19 2	8340
2190	964	24 15	17 9	19 8	21035
2191	1334	27 00	16 0	20 4	10564
2192	1557	42 60	18 7	18 0	6116
2303	756	26 39	21 1	26 3	5375

[a] Diameter at 1 37 m of a tree of average basal area

[b] Average height of dominant and co-dominant trees only

There are many statistics that represent species diversity and stand species composition (e.g., Magurran, 1988). Two of the simpler statistics, the numbers of species (a measure of species richness) and the Shannon evenness index (Pielou, 1969 - a measure of the proportional abundances of species) will be used here to illustrate species diversity.

The range and average of the number of overstory species per location were similar for the two regions (Table 2-4), but both the largest (14) and smallest (2) number of species per location were found in Virginia. The average number of understory species per location was higher in Virginia than in New England (9.1 vs. 6.6), but a two-tailed *t*-test (assuming independent samples, unequal variances, and 17 effective degrees of freedom) suggests that the difference is only marginally significant ($0.05 < p < 0.10$).

The Shannon evenness index (ϵ) can be calculated in terms of either the numbers of individuals (ϵ_N), or the sizes of individuals (ϵ_B) of each species, as follows:

$$\epsilon = - \Sigma (P_i \ln P_i) / \ln(S) \qquad (1)$$

where

i subscripts species,

P_i is the proportion by number or by basal area, and S is the total number of species.

When the proportion is calculated by number, evenness is defined by the relative numbers of individuals of different species. When the proportion is calculated by basal area, evenness is defined by the relative site occupancy of different species. Both ϵ_N and ϵ_B have a maximum value of 1.0 that is obtained when evenness is the highest possible for the given number of species. Because both ϵ-statistics are adjusted for differences in numbers of species and for total numbers of trees (or total basal area), they may therefore be compared among plots and among forest types.

The values of ϵ_N and ϵ_B for overstory trees, although not compared statistically, were both larger in New England than in Virginia (Table 2-4). This difference suggests that the numbers of overstory individuals and site resources were more equitably distributed among species on plots in New England.

Table 2-4 NUMBER OF SPECIES AND THEIR PROPORTIONAL ABUNDANCE BY PLOT

	Overstory			Understory	
Plot no	No. species	ϵ_N	ϵ_B	No species	ϵ_N
New England					
16	6	0 851	0 741	8	0 664
117	8	0 870	0 831	6	0 634
122	9	0 826	0 825	1	n/a
155	6	0 883	0 856	8	0 843
159	7	0 895	0 872	13	0 797
160	9	0 780	0 751	4	0 756
166	7	0 805	0.863	6	0 848
173	11	0 833	0.824	—	—
174	7	0 747	0 823	4	0 634
181	8	0 723	0.518	10	0 832
267	9	0 776	0 711	8	0 837
270	10	0 871	0 856	7	0 800
289	9	0 685	0 752	4	0 920
321	5	0 686	0 858	6	0 662
347	10	0 884	0 786	6	0 566
420	8	0 773	0 751	10	0 851
508	7	0 889	0 839	9	0 752
692	6	0 804	0 948	8	0 702
902	—	—	—	—	—
3270	10	0 888	0 864	7	0 622
Average	8 0	0 814	0 804	6 6	0 707
Virginia					
1839	6	0 745	0 586	6	0 710
1841	4	0 742	0 702	4	0 852
1843	8	0 829	0 580	5	0 843
1954	6	0 720	0 392	2	0 896
1955	6	0 633	0 426	8	0 708
1957	9	0 765	0 562	13	0 784
1958	2	0 811	0 382	10	0 665
1959	9	0 768	0 774	5	0 657
2072	14	0 757	0 450	17	0 813
2074	11	0 637	0 460	8	0 855
2075	11	0 614	0 549	10	0 723
2185	6	0 562	0 446	13	0 789
2186	5	0 579	0 413	11	0 671
2187	9	0 829	0 735	12	0 842
2188	9	0 701	0 637	9	0 866
2189	10	0 720	0 648	11	0 847
2190	13	0 850	0 717	13	0 860
2191	8	0 370	0 317	9	0 873
2192	7	0 629	0 388	8	0 864
2303	8	0 840	0.553	8	0 706
Average	8 1	0 705	0 536	9 1	0 791

* See text for explanation of the Shannon ϵ-statistics for numbers (ϵ_N) and basal area (ϵ_B) of individuals per species

Furthermore, the evenness of the New England species was about equal in terms of the numbers and the basal area of individuals, suggesting that species occupy sites in proportion to their number. In contrast, the same comparison for Virginia suggests that the evenness in terms of numbers of individuals was higher than the evenness in terms of basal area; this could imply that sites are less equitably occupied by different species in the Virginia plots. In summary, individuals of a given species were likely to occur as both large and small individuals in a stand in New England, whereas in Virginia, some species were likely to occur as either large or small individuals (but not both). There was no large difference between regions for the values of ϵ_N and ϵ_B for understory trees (Table 2-4)

2.4 STAND STRUCTURE

The numbers of overstory trees per unit area in different size classes is shown for each plot in Table 2-5. In general, there were more smaller trees than larger trees, and the majority of trees were less than 17.5 cm dbh Ideally, uneven-aged stand structure have frequency distributions that are unimodal, and the number of trees is a decreasing function of size class In even-aged stands, frequency distributions are also unimodal but the number of trees is not strictly a decreasing function of size class (e g., Husch et al., 1972). In multi-aged or irregular stands, many forms of frequency distributions may be obtained.

It appears that there is some structure tending towards an uneven-aged condition in that the frequency distributions appeared neither uniform nor typical of an even-aged condition But the evidence does not point to either a strictly uneven- or even-aged situation in either region. It may be speculated that the sample sizes were too small to accurately portray stand structure. The actual number of trees counted ranged from 36 to 88 in New England, and from 28 to 105 in Virginia. Thus, some plots were too small, for the sizes of trees and mixtures of species that were sampled, to permit a good characterization of stand structure (see Curtis, 1983).

Table 2-5. FREQUENCY OF OVERSTORY TREES BY SIZE CLASS AND PLOT *

New England

Dbh class	Plot number 16	117	122	155	159	160	166	173	174	181
(cm)										
7.7-12.4	133.4	74.1	326.2	118.6	296.5	148.3	326.2	385.5	281.7	489.3
12.7-17.5	133.4	148.3	326.2	177.9	237.2	118.6	163.1	207.6	118.6	44.5
17.8-22.6	192.7	89.0	311.3	133.4	222.4	222.4	74.1	118.6	44.5	0.0
22.9-27.7	118.6	59.3	222.4	59.3	118.6	118.6	74.1	207.6	133.4	44.5
27.9-32.8	44.5	59.3	59.3	74.1	29.7	148.3	89.0	44.5	59.3	29.7
33.0-37.8	0.0	29.7	59.3	29.7	89.0	74.1	0.0	29.7	29.7	59.3
> 37.8	29.7	74.1	0.0	0.0	0.0	59.3	44.5	29.7	118.6	44.5

Dbh class	Plot number 267	270	289	321	347	420	508	692	902	3270
(cm)										
7.7-12.4	355.8	252.0	489.3	341.0	311.3	237.2	370.7	444.8	–	652.3
12.7-17.5	192.7	192.7	311.3	118.6	222.4	192.7	266.9	103.8	–	207.6
17.8-22.6	89.0	177.9	177.9	59.3	163.1	118.6	296.5	163.1	–	163.1
22.9-27.7	133.4	89.0	89.0	103.8	89.0	89.0	103.8	89.0	–	44.5
27.9-32.8	44.5	74.1	14.8	14.8	29.7	29.7	103.8	59.3	–	89.0
33.0-37.8	29.7	59.3	0.0	29.7	29.7	14.8	0.0	14.8	–	44.5
> 37.8	14.8	59.3	0.0	89.0	59.3	29.7	14.8	14.8	–	14.8

Virginia

Dbh class	Plot number 1839	1841	1843	1954	1955	1957	1958	1959	2072	2074
(cm)										
7.7-12.4	266.9	533.7	474.4	355.8	148.3	385.5	133.4	415.1	548.6	563.4
12.7-17.5	148.3	192.7	341.0	207.6	59.3	74.1	118.6	237.2	341.0	444.8
17.8-22.6	266.9	118.6	148.3	118.6	118.6	44.5	74.1	252.0	177.9	103.8
22.9-27.7	74.1	148.3	89.0	89.0	89.0	118.6	44.5	74.1	103.8	59.3
27.9-32.8	89.0	89.0	59.3	103.8	59.3	44.5	0.0	103.8	29.7	29.7
33.0-37.8	59.3	74.1	14.8	44.5	44.5	74.1	14.8	14.8	29.7	44.5
> 37.8	44.5	44.5	14.8	118.6	44.5	29.7	29.7	59.3	29.7	14.8

Dbh class	Plot number 2075	2185	2186	2187	2188	2189	2190	2191	2192	2303
(cm)										
7.7-12.4	177.9	222.4	192.7	637.5	578.2	489.3	415.1	785.8	578.2	296.5
12.7-17.5	118.6	341.0	311.3	296.5	148.3	400.3	192.7	222.4	341.0	177.9
17.8-22.6	163.1	118.6	370.7	207.6	148.3	222.4	207.6	89.0	222.4	29.7
22.9-27.7	133.4	148.3	177.9	192.7	148.3	59.3	59.3	133.4	237.2	74.1
27.9-32.8	29.7	103.8	89.0	44.5	29.7	44.5	44.5	59.3	148.3	59.3
33.0-37.8	103.8	89.0	14.8	14.8	0.0	14.8	29.7	44.5	29.7	74.1
> 37.8	74.1	29.7	14.8	0.0	14.8	14.8	14.8	0.0	0.0	44.5

* Entries in the table are numbers of trees per hectare

2.5 SOIL AND LANDFORM

Soils in the New England region have developed mainly from glacial till derived from igneous and metamorphic rocks on moderately to strongly sloping and glaciated upland hillslopes. Soils in the study region of Virginia have developed mainly from marine deposits on level to gently sloping alluvial plains, and in local alluvium/residuum derived from crystalline rocks on gently to moderately sloping piedmonts (Table 2-6).

Soil taxonomic classifications in the New England region are dominated by coarse-textured Spodosols and Inceptisols with mixed mineralogy, a frigid or mesic soil temperature regime, and a udic or aquic soil moisture regime. Soil taxonomic classifications in the study region of Virginia are dominated by loamy- to fine-textured Ultisols with mixed or siliceous mineralogy, a thermic soil temperature regime, and a udic or aquic soil moisture regime (Table 2-7).

Soil water characteristics in the New England region are dominated by shallow or moderate depths to water table, moderate to rapid saturated hydraulic conductivity, moderate to poor drainage, and infrequent flooding or ponding. Soil water characteristics in the study region of Virginia are dominated by shallow or moderate depths to water table, moderate saturated hydraulic conductivity, moderate to poor drainage, and infrequent flooding or ponding (Table 2-8).

The field plot locations provide good representation of the types of soils that occur in the two regions. Thus, the recommended soil sampling designs derived from these locations will be useful be useful for soil characterization efforts as part of future regional monitoring.

Table 2-6 SLOPE, PHYSIOGRAPHY, AND SOIL PARENT MATERIAL BY PLOT

Plot no	Slope		Physiography		Parent material	
	Percent	Aspect	Regional[a]	Local[b]	Mode[c]	Origin[d]
16	16	NE	GU	HS	T	I4
117	20	N	GU	HS	T	I4
122	3	SE	GU	RI	T	I4/M7
155	6	S	GU	HS	T	I4
159	7	NE	FH	HS	T	M5
160	7	NE	GF	OT	G	I4
166	22	S	GU	MO	T	I4
173	30	W	GU	HS	T	I4
174	45	SW	GU	MO	T	H0
181	2	S	GU	HS	T	M7
267	5	SE	GU	HS	T	I0
270	5	N	GU	RI	T	I4/M7
321	15	SW	GU	HS	T	H0
347	25	W	GU	MO	T	Y0/H0
420	6	N	GU	HS	T	H0
508	10	W	GU	HS	T	I4
902	43	NE	GU	MO	T	H0
1839	1	N	CP	BS	M	S0
1841	1	N	CP	FT	M	S0
1843	1	N	CP	AP	M	S0
1954	1	N	CP	AP	M	S0
1955	1	SE	CP	FT	M	S0
1957	4	SE	CP	MT	M	S0
1958	5	W	CP	MT	M	S0
1959	2	SE	CP	AP	M	S0
2072	1	N	CP	MT	M	S0
2074	1	N	CP	HS	M	S0
2075	2	SW	CP	MT	M	S0
2185	1	NE	CP	MT	M	S0
2186	5	E	CP	HS	A	S0
2187	6	W	CP	HS	M	S0
2188	1	W	CP	MT	M	S0
2189	2	N	CP	RI	M	S0
2190	6	N	CP	HS	M	I0
2191	4	W	PI	HS	X	I4
2192	5	N	PI	FT	A	Y5
2303	3	E	CP	HS	M	S0

[a] CP = coastal plain, FH = foothills, GF = glaciofluvial landform, GU = glaciated upland, PI = piedmonts

[b] AP = alluvial flat (plain), BS = backswamp, FT = fluvial terrace, HS = hillside, MO = mountainside, MT = marine terrace, OT = outwash terrace, RI = ridge

[c] Mode of parent material deposition A = alluvium, G = glacial outwash, M = marine, T = glacial till, X = residuum

[d] H0 = shale (unspecified), I0 = igneous (unspecified), I4 = igneous-granite, M5 = schist (unspecified), M7 = schist-basic, S0 = sedimentary (unspecified), Y0 = mixed (unspecified), Y5 = mixed-igneous and metamorphic

Table 2-7 SOIL CLASSIFICATION CHARACTERISTICS BY PLOT

Plot no.	Soil series	Subgroup[a]	Family classification			
			PSC[b]	MIN[c]	TEMP[d]	MR[e]
16	Paxton	Typic Dystrochrept	Coarse-loamy	Mixed	Mesic	Udic
117	Berkshire	Typic Haplorthod	•	•	Frigid	•
122	Marlow	• •	•	•	•	•
155	Peru	Aquic Haplorthod	•	•	•	•
159	Wilmington	Typic Haplaquod	•	•	•	Aquic
160	Adams	Typic Haplorthod	Sandy	•	•	Udic
166	Monadnoc	• •	Coarse-loamy over sandy	•	•	•
173	Chatfield	Typic Dystrochrept	Coarse-loamy	•	Mesic	•
174	Macomber	• •	•	•	Frigid	•
181	Stratton	Lithic Haplaquod	Loamy	•	•	•
267	Westbury	Typic Fragiaquod	Coarse-loamy	•	•	Aquic
270	Marlow	Typic Haplorthod	•	•	•	Udic
321	Plaisted	• •	•	•	•	•
347	Marlow	• •	•	•	•	•
420	Plaisted	• •	Loamy	•	•	•
508	Berkshire	• •	Coarse-loamy	•	•	•
902	Thorndike Var	Lithic Haplorthod	Loamy-skeletal	•	Isofrigid	•
1839	Tomotley	Typic Ochraquult	Fine-loamy	•	Thermic	Aquic
1841	Roanoke	• •	Clayey	Siliceous	•	Udic
1843	Myatt	• •	Fine-loamy	•	•	•
1954	Tomotley	• •	•	Mixed	•	Aquic
1955	Slagle	Aquic Hapludult	•	Siliceous	•	Udic
1957	Mattaponi	Typic Hapludult	Clayey	Mixed	•	•
1958	Craven	Aquic Hapludult	•	•	•	•
1959	Portsmouth	Typic Umbraquult	Coarse-loamy	•	•	Aquic
2072	Mattaponi	Typic Hapludult	Clayey	•	•	Udic
2074	Emporia	• •	Fine-loamy	Siliceous	•	•
2075	Craven	Aquic Hapludult	Clayey	Mixed	•	•
2185	Craven	• •	•	•	•	•
2186	Tetotum	• •	Fine-loamy	•	•	•
2187	Bama	Typic Hapludult	•	Siliceous	•	•
2188	Lynchburg	Aeric Paleaquult	•	•	•	Aquic
2189	Emporia	Typic Hapludult	•	•	•	Udic
2190	Rumford	• •	Coarse-loamy	•	•	•
2191	Appling	• •	Clayey	Glauconitic	•	•
2192	Alta Vista	Aquic Hapludult	Fine-loamy	Siliceous	•	•
2303	Kempsville	Typic Hapludult	•	Gibbsitic	•	•

[a] U S Department of Agriculture Comprehensive Soil Survey System
[b] Particle size class
[c] Mineralogy class.
[d] Temperature regime
[e] Moisture regime.

Table 2-8 SOIL WATER CHARACTERISTICS BY PLOT

Plot no.	Water table depth (cm)	Hydraulic conductivity	Drainage class	Frequency of	
				Flooding	Ponding
16	>100	Moderately slow	Well drained	None	None
117	>100	Moderate	"	"	"
122	>100	Slow	"	"	"
155	42	"	Moderately well drained	"	"
159	16	Very slow	Poorly drained	Rare	Rare
160	>100	Rapid	Well drained	None	None
166	72	Moderate	"	"	"
173	>100	"	"	"	"
174	>100	Moderately slow	"	"	"
181	40	Moderate	Poorly drained	"	"
267	>100	Slow	Somewhat poorly drained	"	Rare
270	>100	"	Well drained	"	None
321	>100	"	"	"	"
347	>100	"	"	"	"
420	>100	"	"	"	"
508	>100	Moderate	"	"	"
902	>100	Very slow	Somewhat excessively drained	"	"
1839	15	Moderate	Poorly drained	Occasional	Frequent
1841	>100	Slow	"	None	Common
1843	0	"	"	"	"
1954	30	Moderately slow	"	Rare	Rare
1955	75	"	Moderately well drained	"	"
1957	75	"	Well drained	None	None
1958	10	"	Moderately well drained	"	"
1959	90	Moderately rapid	Poorly drained	Rare	Rare
2072	>100	Moderately slow	Well drained	None	None
2074	45	Moderate	"	"	"
2075	75	"	Moderately well drained	Rare	"
2185	>100	Moderately slow	"	None	"
2186	>100	"	"	"	"
2187	>100	Moderately rapid	Well drained	"	"
2188	12	Slow	Somewhat poorly drained	Rare	Rare
2189	>100	Moderately rapid	Well drained	None	None
2190	>100	"	"	"	"
2191	>100	Moderately slow	"	"	"
2192	>100	"	Moderately well drained	Rare	"
2303	>100	Moderate	Well drained	None	"

3 COMPONENTS OF VARIANCE AND SAMPLING EFFICIENCY

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3.1 INTRODUCTION

One of the primary objectives of the 1990 pilot test was to estimate the components of variance and cost for each stage of sampling for the measured variables. These results provide the ingredients for evaluating the efficiency of the sampling design and sampling unit design. In addition, it is possible to investigate the spatial variability under several intensities of subsampling for several measurements. Spatial variability is important because, if the data for a set of measurements were spatially correlated, then the observations on those measurements could not be assumed independent for the variance analyses.

3.2 SAMPLING EFFICIENCY

Sampling efficiency was investigated by using standard statistical equations to combine information obtained about sample variances with different assumptions of sampling cost to estimate optimum sample sizes for the different sampling stages. A hierarchical sampling model was used in all cases. References to different sampling stages, and reduced or full sampling models, all pertain to certain levels and combinations of levels from this general hierarchical model. The actual physical entities associated with the sampling stages in specific models for different measurements are identified in Table 3-1.

The models are labelled A, B, or C in Table 3-1. Model A is always the three-stage model that incorporates plots, subplots, and stations. Model B is always a variant of model A that omits one of the stages. For the soil measurements, model B includes only plots and soil pits. For the mensuration measurements, model A is not defined and model B includes only plots and subplots, because the response variables are defined on either a per-unit area or an average per-tree basis. For foliar chemistry measurements, model B omits subplots but adds another sampling stage of branches within trees. Model C is only used for examining the foliar chemistry measurements in Virginia, where it was possible to use a four-stage model with plots, subplots within plots, trees within subplots, and branches within trees.

3.2.1 Sample Variances

Sample variances for each stage of sampling were estimated for all response variables as reported in Sections 5 through 9. Estimates were made separately for the New England and Virginia plot locations. For some measurements, the estimates were also made separately for subsets of the data that had apparently different variance structures.

Table 3-1. SAMPLE UNITS FOR DIFFERENT SAMPLING STAGES AND MODELS*

	Sampling model		
Sample unit	A	B	C
Visual Symptoms			
Plot	1	1	–
Subplot	2	–	–
Tree	3	2	–
Mensuration			
Plot	–	1	–
Subplot	–	2	–
Soils			
Plot	1	1	–
Subplot	2	–	–
Soil pit	3	2	–
Foliage			
Plot	1	1	1
Subplot	2	–	2
Tree	3	2	3
Branch	–	3	4
Vegetation Structure			
Plot	1	–	–
Subplot	2	–	–
Vegetation station	3	–	–
PAR			
Plot	1	–	–
Subplot	2	–	–
PAR station	3	–	–

* Numbers in the table refer to sample stage

For example, the photosynthetically active radiation (PAR) analyses (see Section 9) suggested estimating sampling variances under both clear and cloudy sky conditions, with and without adjustments for serial correlation, because the variances were quite different in these situations. For some other measurements, the estimates were made for different sampling models by deleting an intermediate sampling stage in the analysis (e.g., reducing a three-stage model to a two-stage model). This was useful where an instability of variance estimates (probably caused by very small variance components or small sample sizes) precluded a meaningful analysis using the fuller model.

3.2.2 Cost Components

The cost components (Table 3-2) are based on the average times required to set up and make measurements on a new plot location, a new subplot at a given location, and further subsampling units. The subsampling costs for each set of measurements are as follows: digging soil pits and collecting samples, locating and measuring PAR stations, locating and climbing trees, and obtaining and processing branches and foliage, mapping tree locations and measuring dbh and height, scoring individual trees for a variety of visual symptoms measures, and locating and measuring vegetation structure stations.

Two cost scenarios were explored for each measurement in each region. In the first scenario, the cost associated with a new plot was the same for all measurements but was higher in New England than in Virginia because it took longer to locate new plots there (§4). The cost associated with a new subplot was the same for a given measurement in both regions, but the subplot cost was higher for the mensuration and vertical vegetation measurements than for the other measurements. Third-stage and, where applicable, fourth-stage sampling costs were the same in the two regions for a given measurement, but the costs varied for the different measurements.

The second scenario was different in that the cost of the last stage of sampling was set equal to one-half of the cost actually required in the field test. These reduced-cost scenarios were investigated to test the sensitivity of optimum solutions to the relatively high-cost activities associated with each measurement (e.g., digging soil pits, climbing trees) or by the practice of making many concurrent (but possibly unnecessary) measurements on each tree, station, or laboratory sample. Some reduction of effort would be needed to realize the lower costs in these scenarios

Table 3-2 COST SCENARIOS FOR EACH REGION*

	Southeast cost		Northeast cost	
Cost item	model 1	model 2	model 1	model 2
Visual Symptoms				
Plot	3 33	3 33	4 50	4 50
Subplot	0 21	0 21	0 21	0 21
Tree	0 19	0 10	0 19	0 10
Mensuration				
Plot	3 33	3 33	4 50	4 50
Subplot	2 00	1 00	2 00	1 00
Soils				
Plot	3 33	3 33	4 50	4 50
Subplot	0 21	0 21	0 21	0 21
Soil pit	2 00	1 00	2 00	1 00
Foliage				
Plot	3 33	3 33	4 50	4 50
Subplot	0 21	0 21	0 21	0 21
Tree	0 90	0 45	0 90	0 45
Branch	0 05	0 05	n/a	n/a
Vegetation Structure				
Plot	3 33	3 33	4 50	4 50
Subplot	0 42	0 21	0 42	0 21
Vegetation station	0 05	0 05	0 05	0 05
PAR				
Plot	3 33	3 33	4 50	4 50
Subplot	0 21	0 21	0 21	0 21
PAR station	0 02	0 01	0 02	0 01

* Hours per unit sampled

3.2.3 Sample Size Calculations

Variances and costs were obtained for the measurements as discussed in Sections 5 through 9 and were substituted into the optimum sample size equations provided by Sukhatme (1954) and Cochran (1977) (Table 3-3). Solutions to these equations are sensitive to the ratios of costs and variances between different stages of sampling and to the absolute values of those variables. The equations estimate the optimum number of second-, third-, and fourth-stage samples for a given scenario of costs, variances, and sampling model. The first-stage sample here refers to the number of field plots; optimum solutions for this stage of sampling were beyond the scope of this study (§3.2.4).

Table 3-3. SAMPLE SIZE EQUATIONS FOR FOUR-STAGE SAMPLING*

Second stage

$$m_{opt} = (C_1/C_2)^{0.5} \times [(MS_2 - MS_3/k) / (MS_1 - MS_2/m)]^{0.5}$$

Third stage

$$k_{opt} = (C_2/C_3)^{0.5} \times [(MS_3 - MS_4/l) / (MS_2 - MS_3/k)]^{0.5}$$

Fourth stage

$$l_{opt} = (C_3/C_4)^{0.5} \times [MS_4 / (MS_3 - MS_4/l)]^{0.5}$$

In these equations

m_{opt}, k_{opt}, and l_{opt} are the estimated optimum sample sizes,

m, k, and l are the sample sizes used to estimate variances in the field study,

C_1, C_2, C_3, and C_4 are the per-unit sampling costs for stages 1 through 4, respectively (Table 3-2), and,

MS_1, MS_2, MS_3, and MS_4 are the mean squares for stages 1 through 4 obtained in the field study

* The equations are condensed for three- and two-stage sampling models

By convention, the second-, third-, and fourth-stage sample sizes are denoted by m, k, and l, respectively. Note that for some sampling models, only m, or m and k, are estimated. For example, a fourth-stage recommendation would not exist in a two-stage sampling model. Table 3-1 lists the physical entities associated with m, k, and l for each sampling model.

The optimization equations were applied for each defined scenario (cost, variance, sampling model) for each response variable. This procedure generated a large number of "optimum" solutions for m, k, and l, and it was necessary to reduce the number of solutions to a manageable size to arrive at recommendations. For example, grouping the soil response variables and making one overall recommendation for "soil" was preferable to recommending different numbers of soil pits for different soil measurements. Refinements of the analyses may be warranted by further study, and the full set of solutions is provided (Table 3-4) for this purpose.

Thus, the measurements and associated optimum sample sizes were grouped into several measurement categories, and recommendations were made for different sampling models for each category. The sets and the number of response variables contained within them were.

- visual symptoms variables for all species and for selected subsets of species (6)
- mensurational variables (3)
- soils (21)
- foliage (28)
- vegetation structure (30)
- PAR (1)

Within categories that had a large number of measured variables, frequency distributions of the optimum solutions were charted and a suggested allocation was made by choosing an upper limit above which 10% of the optimum solutions were excluded. The choice of 10% was arbitrary, but we believe that the suggested allocations satisfy at least 90% of the solutions which fall in each set of measurements There will be cases for which the suggestions may not be optimum In other cases, allocations were suggested by judgement There seems to be little alternative to experienced judgement when it comes down to making a recommendation

3.2.4 Important Considerations

The optimum first-stage sample size is not provided by the equations. The first-stage sample size corresponds to the number of plot locations. This determination is possible given the desired precision for a parameter over the population of plots under study, or given a total fixed cost for surveying the population. But the solution should utilize alternate optimization techniques that are appropriate for the FHM first-stage sampling design. The resource allocation formulas used here are appropriate for simple random sampling; the FHM design uses systematic sampling with post-stratification which requires different formulas. These techniques have not been specified in detail at this time. Although the Sukhatme-Cochran estimators could be used, but the solutions would ignore much of the design philosophy of FHM.

This emphasizes that the objective of this study -- determining an optimum plot design once a plot location has been selected -- gives little insight as to how many plots are needed to characterize regional forest health at some specified level of precision. On the other hand, an optimum single-plot design is valid no matter how many plots are ultimately selected for measurement.

Another important consideration is that the optimality of plot design is evaluated for the objective of estimating a population parameter over many plot locations, and not for the objective of estimating that parameter for any particular plot contained in that population. Optimality of plot design for a regional survey does not imply that every site-specific estimate will meet other precision requirements. This trade-off between obtaining precise answers for each site versus for all sites in a population is a fact that at once makes large-scale surveys practical and limits the inferences that can be made about any one location.

A final consideration is that statistical optimality is not the only criterion for plot design. For example, it is sometimes necessary to ensure that some measurements "cover the area" so that they may be related to other measurements made in the area. For example, suppose that the optimum number of soil pits was two and the optimum number of mensuration subplots was six. Judgment is needed to decide whether two soil pits are sufficient to represent the soil on all six mensuration subplots. In many instances, a case can be built for "over-sampling" to obtain the required coverage of the plot The optimization analysis does not preclude this effort, but it does make it clear why extra effort is being made. These situations should be rationalized individually as the roles and inter-relationships of the measurements are clarified.

3.3 RECOMMENDED ALLOCATIONS

Table 3-4 lists, for each measurement that could be analyzed as a continuous variable, the values of the mean squares for each stage of sampling and the calculated optimum values of m (m_{opt}), k (k_{opt}), and l (l_{opt}) for the two cost models. Results are given for different regions and sampling models To assist interpretations of Table 3-4, subheadings within the table identify the physical entities associated with the sampling stages for the particular sampling models, and Table 3-5 provides abbreviated definitions of response variables.

Table 3-4 gives values of m_{opt}, k_{opt}, and l_{opt} to the second decimal place. This is so that the relative sizes of the computed values may be seen In practice, fractional sample sizes are rounded up to the next largest integer. If the computed numbers are between 0 and 1, and it is desired to retain that stage in the sampling design, then the number is rounded up to 2 so that a variance can be estimated for that stage of sampling.

3.3.1 Visual Symptoms

Under the three-stage sampling model for all species, the visual symptoms allocations indicate one to two trees per each of three to four subplots, or a total of three to eight trees per field plot location. The two-stage sampling model yields comparable values of two to five trees per field plot location, a reflection of the fact that although subplot-to-subplot variation is sometimes significant, it is not practically important (§5). However, a two-stage sample design cannot be recommended automatically based on these results because the two-stage analysis ignores any clustering that was built into the three-stage sampling design that was used. In general, these results compare favorably with the Innes and Boswell (1990) recommendations (§5).

The results obtained for selected species were similar to the results for all species combined. Thus, if interest centers on estimation by species, then the recommendation should be applied for each species, and this will provide more than sufficient numbers for the estimates based on all species combined. On the other hand, a plan for sampling just one tree per each of six species would probably not give reliable estimates for any one species alone.

3.3.2 Mensuration

The two-stage sampling model suggested an allocation of one to two subplots. This result is highly dependent on the "rotation" of subplots into uniform forest types, and more subplots would probably be required if subplots were not "rotated." In 1991, a decision was made to *not* rotate plots, and so the suggested allocations would apply to each identified forest type at each plot location

3.3.3 Soils

Analyses of the soil response variables suggest that two to three soil pits will be sufficient, regardless of the region or cost model. The model of the nine soil pits as three clusters of three pits was compared with the model treating all nine pits as the second stage of sampling. In this comparison, no evidence was found to indicate that clusters of pits were more efficient than single pits. It is therefore recommended that three soil pits be systematically arranged so as to represent the field plot location.

3.3.4 Foliage

The four-stage sampling model including branches was estimable only for the Virginia data, and in that case the suggested allocation is for 5 to 6 branches from each of 1 to 2 trees taken from each of 2 to 3 subplots, or a total of 15 to 30 branch samples. The three-stage model that did not include subplots suggested about the same number of branches per tree but fewer trees overall, apparently subplot-to-subplot variation was relatively unimportant. The three-stage sampling model for New England suggested one to two trees per each of two to three subplots, or a total of about five trees. The branch-to-branch variation was not estimable for New England (§7). Generalizations of these results to untested species may be tenuous.

If interest centers on a subset of elements, for example the macronutrients N, P, K, Ca, and Mg, then the four-stage model for Virginia suggests that only two branches from each of two to three trees per plot are sufficient (except for potassium, which exhibited relatively large branch-to-branch variation). If interest centers on heavy metals, then the same model suggests relatively large numbers of branches per tree (at least four), but not necessarily more trees or subplots It has been suggested that a distinction between routine monitoring of foliar nutrients and special monitoring of foliar contaminants will enable a practical number of branches to be sampled for routine monitoring.

3.3.5 Vegetation Structure

Table 3-4 indicates that four stations per subplot and six subplots will satisfy 90% of the 30 vertical vegetation variables under cost model 1, and that three stations per subplot and nine subplots will satisfy cost model 2 in both regions. If variables FT1, FT11, and FT21 (Table 3-5) are used as examples, then three stations and five subplots will satisfy the optimization requirements.

3.3.6 PAR

The PAR measurements require between two and six subplots, with a minimum of two sampling stations per subplot. Under "ideal" sampling conditions (i.e , clear sky and homogeneous canopy), two subplots are sufficient. More subplots are required under cloudy sky conditions, and six subplots would be appropriate for the most variable canopies that were encountered in the study. The use of 4 subplots and 19 stations per subplot in the 1991 pilot test is more than adequate for regional survey purposes. The extra effort is justifiable if PAR will ultimately be combined with growth data obtained over a relatively large area at each field plot location and the extra PAR measurements are needed to represent this larger area.

3.4 SPATIAL ANALYSIS

There were three types of measurements that were made on regular grids that were fixed across all plots: soils, vegetation structure, and PAR. The consistent grid across plots permitted combining information across plots to explore spatial structure

3.4.1 Soils

Some soil measurements have been shown to have spatial structure that can be effectively modeled by spatial statistical methods (e.g , Robertson, 1987). Therefore, the possibility of spatial correlation was explored in this study. The data for these analyses came from the eight field plot locations in each region at which nine additional soil pits were sampled (Fig. 1-3). The nine pits were arranged in isosceles triangles about each of the outlying subplots, which permitted a spatial analysis.

3.4.2 PAR and Vegetation Structure

There was concern that the 3.66-m separation among sample stations used for these measurements might not be enough to avoid spatial correlation among stations. The natural structure of the forest stands and its associated gap-phase dynamics might cause measurements taken close together to be correlated.

The PAR and vertical vegetation structure measurements were both sampled on 4 × 4 square grids overlaid on the subplots (Fig. 1-4) Data for the spatial analyses of PAR came from all four subplots at each plot location, whereas data from subplots 1 and 2 only were available for vegetation structure analyses.

3.4.3 Spatial Statistical Methodology

The methodology used to analyze these problems is the standard method of computing semivariograms (e.g., Ripley, 1981). A semivariogram allows one to visualize the variability between observations as a function of the distance between the observations In essence, for a pair of data points a given distance apart, the variance is calculated as half the square of their difference. Then the variance for all pairs of data points a given distance apart is calculated as the average of these pairwise calculations.

It is reasonable to calculate the variance for a pair of numbers as half the square of their difference. Consider two numbers, x and y, with a mean of z. Then z must be halfway between x and y, and the variance of the pair $\{x,y\}$ is:

$$(x - z)^2 + (y - z)^2 \qquad (2)$$

$$= ((x - y)/2)^2 + ((x - y)/2)^2$$

$$= (1/4) \times (x - y)^2 + (1/4) \times (x - y)^2$$

$$= (1/2) \times (x - y)^2 \qquad (3)$$

The semivariograms permit one to visualize at what distance the spatial correlation levels off, that is, how far away the measurements can be when the correlation is roughly the same as for two points on opposite sides of the plot

3.4.4 Results of the Spatial Analyses

The semivariogram analysis indicated that the measurements examined in this study were taken sufficiently far apart to be regarded as independent Thus, spatial correlation of the measurements does not affect the recommended sample allocation calculations. Also, the independence of measurements implies that geostatistical estimation will not be necessary for the aggregation of individual measurements to the subplot level. This result may or may not be obtained in other forest or soil types that were not sampled in this study.

The soil measurements analyzed in this report consistently showed no spatial structure. This is due largely to the types of variables analyzed The soil measurements that have been traditionally analyzed with geostatistical methods are measurements for which substantial theory exists to indicate spatial structure, for example hydraulic conductivity. In addition, the shortest distance between soil pits in this study was approximately 42.2 m, and thus the spatial analysis would not detect correlation at a finer scale All of the soil measurements appeared to be free of spatial structure that could have complicated the development of the plot sampling design. Thus, the soil sampling design for the 1991 field study appears to be reasonable.

The vegetation structure measurements were analyzed separately for each of the 30 vertical foot levels. The semivariograms consistently indicated that the 3.66-m distance between sample stations was sufficient to avoid spatial correlation problems. This makes sense if one envisions the gap-phase dynamics of the forest stands as a homogeneous stochastic process over an area. In this case, distances between gaps are random and will therefore not appear consistently at specified distances. Thus, spatial correlation is probably not a problem for this set of measurements.

The PAR measurements were analyzed in terms of percentage of transmitted PAR. They showed a strong spatial structure under "cloudy" sky conditions but not under "clear" sky conditions. The spatial structure detected under cloudy sky conditions was an artifact; what was detected as spatial structure was actually the result of serial (temporal) correlation on cloudy days (§9). It may be speculated that stochastic gap-phase dynamics operate in the forest stands sampled (see above). Another possibility is simply that there were no gaps in the canopy that were large enough to be detected as such by the sampling protocols. In any event, the absence of a spatial structure in these stands at distances greater than 3.66 m indicates that spatial correlation will not affect the recommended sample sizes.

Table 3-4 OPTIMUM SAMPLE SIZES FOR SCENARIOS OF COSTS AND VARIANCES

Response variable	Sampling model	Forest region	Mean square for stage 1	2	3	4	Cost model 1 l_{opt}	k_{opt}	m_{opt}	Cost model 2 l_{opt}	k_{opt}	m_{opt}
Mensuration									subplot			subplot
BA/ha	B	VA	259 829	77 265	—	—	—	—	0 73	—	—	1 03
BA/ha	B	NE	220 872	127 036	—	—	—	—	1.23	—	—	1 74
AVG_HT_D&CD	B	VA	30 766	8 013	—	—	—	—	0 68	—	—	0 96
AVG_HT_D&CD	B	NE	26 178	5 910	—	—	—	—	0 73	—	—	1 04
AVG_HT_ALL	B	VA	12 893	3 095	—	—	—	—	0 65	—	—	0 92
AVG_HT_ALL	B	NE	10 489	3 548	—	—	—	—	0 91	—	—	1 29
PAR								stanon	sub-plot		stanon	sub-plot
Ln(PTPAR+1)												
Serial correlation	A	VA	0 55552	0 05870	0 00361	—	—	0 81	1 30	—	1 14	1 30
Serial corr. adj	A	SE	0 54102	0 03182	0 00324	—	—	1 04	0 97	—	1 47	0 97
Serial correlation	A	NE	1 03478	0 17032	0 00753	—	—	0 68	1 92	—	0 96	1 92
Serial corr. adj.	A	NE	1 04607	0 09865	0 00542	—	—	0 76	1 44	—	1 08	1 44
Max subplot var.	A	VA	0 56552	0 54000	0 03300	—	—	0 80	4 45	—	1 14	4 45
Max subplot var.	A	NE	1 04607	0 95566	0 05929	—	—	0 81	5 03	—	1 14	5 03
Vegetation Structure												
FT1	A	NE	1 830	0 225	0 128	—	—	2 22	1 16	—	1 57	1 65
FT2	A	NE	0 38972	0 26406	0 15052	—	—	2 23	3 25	—	1 58	4 60
FT3	A	NE	0 563816	0 209375	0 124792	—	—	2.28	2 17	—	1 61	3 07
FT4	A	NE	0 2891	0 1000	0 1017	—	—	3 02	2 05	—	2 14	2 90
FT5	A	NE	0 1184	0 1313	0 0825	—	—	2 34	5 06	—	1 66	7 15
FT6	A	NE	0 179194	0 101563	0 066354	—	—	2 39	2 85	—	1 69	4 03
FT7	A	NE	0 244326	0 270313	0 083229	—	—	1 62	5 10	—	1 15	7 21
FT8	A	NE	0 17072	0 16875	0 07688	—	—	1 98	4 51	—	1 40	6 38
FT9	A	NE	0 158799	0 070313	0 073646	—	—	3 07	2 39	—	2 17	3 37
FT10	A	NE	0 15551	0 06406	0 08760	—	—	3 54	2 25	—	2 51	3 19
FT11	A	NE	0 102878	0 107813	0 079688	—	—	2 55	4 74	—	1 80	6 71

Table 3-4 (CONTINUED)

Response variable	Sampling model	Forest region	Mean square for stage 1	2	3	4	Cost model 1 l_{opt}	k_{opt}	m_{opt}	Cost model 2 l_{opt}	k_{opt}	m_{opt}
								stanon	sub-plot		stanon	sub-plot
Vegetation Structure												
FT12	A	NE	0 07730	0 06875	0 07208	—	—	3 07	4 00	—	2 17	5 66
FT13	A	NE	0 211431	0 089063	0 090313	—	—	3 02	2 31	—	2 13	3 27
FT14	A	NE	0 083799	0 023438	0 060521	—	—	5 09	1.71	—	3 60	2 42
FT15	A	NE	0 102878	0 123438	0 092604	—	—	2 57	5 53	—	1 82	7 83
FT16	A	NE	0 192352	0 067188	0 069896	—	—	3 06	2 06	—	2 16	2 91
FT17	A	NE	0 190461	0 131250	0 103750	—	—	2 64	3.27	—	1 87	4 63
FT18	A	NE	0 070395	0 190625	0 071042	—	—	••	••	—	••	••
FT19	A	NE	0 197368	0 106250	0 080833	—	—	2 59	2 74	—	1 83	3 88
FT20	A	NE	0 122615	0 145313	0 077813	—	—	2 16	5 49	—	1 53	7 76
FT21	A	NE	0 179194	0 085938	0 069688	—	—	2 68	2 53	—	1 89	3 58
FT22	A	NE	0 089145	0 081250	0 065625	—	—	2 67	4 13	—	1 89	5 84
FT23	A	NE	0 057237	0 103125	0 068750	—	—	2 42	13 66	—	1 71	19 32
FT24	A	NE	0 114803	0 140625	0 079583	—	—	2 22	5 72	—	1 57	8 08
FT25	A	NE	0 261431	0 123438	0 092813	—	—	2 57	2 51	—	1 82	3 55
FT26	A	NE	0 053947	0 031250	0 047917	—	—	3 77	2 81	—	2 67	3 97
FT27	A	NE	0 106826	0 057813	0 070104	—	—	3 32	2 71	—	2 35	3 83
FT28	A	NE	0 129934	0 056250	0 070833	—	—	3 39	2 34	—	2 40	3 30
FT29	A	NE	0 079852	0 107813	0 074896	—	—	2 47	6 53	—	1 75	9 23
FT30	A	NE	0 035855	0 015625	0 027500	—	—	4 08	2 31	—	2 88	3 26
FT1	A	VA	1 338816	0 465625	0 199375	—	—	1 92	1 80	—	1 36	2 55
FT2	A	VA	0 630263	0 237500	0 150625	—	—	2 36	1 88	—	1 67	2 66
FT3	A	VA	0 356168	0 123438	0 109896	—	—	2 81	1 77	—	1 99	2 51
FT4	A	VA	0 230263	0 043750	0 107917	—	—	4 95	1 19	—	3 50	1 68
FT5	A	VA	0 349013	0 065625	0 110833	—	—	3 98	1 21	—	2 82	1 72
FT6	A	VA	0 223355	0 131250	0 102708	—	—	2 63	2 50	—	1 86	3 54
FT7	A	VA	0 173026	0 084375	0 076875	—	—	2 85	2 20	—	2 01	3 11
FT8	A	VA	0 162500	0 090625	0 098333	—	—	3 13	2 39	—	2 21	3 38
FT9	A	VA	0 136431	0 120313	0 094271	—	—	2 63	3 45	—	1 86	4 88
FT10	A	VA	0 087171	0 128125	0 096875	—	—	2 58	6 47	—	1 83	9 15
FT11	A	VA	0 101563	0 082813	0 077813	—	—	2 90	3 21	—	2 05	4 53
FT12	A	VA	0 087089	0 148438	0 081563	—	—	2 19	9 40	—	1 55	13 29
FT13	A	VA	0 101563	0 120313	0 076563	—	—	2 36	4 70	—	1 67	6 65
FT14	A	VA	0 129194	0 164063	0 085104	—	—	2 12	5 17	—	1 50	7 31
FT15	A	VA	0 074013	0 078125	0 071875	—	—	2 86	4 09	—	2 02	5 78
FT16	A	VA	0 128290	0 103125	0 083125	—	—	2 67	3 18	—	1 89	4 50
FT17	A	VA	0 123273	0 120313	0 084063	—	—	2 48	3 80	—	1 75	5 38
FT18	A	VA	0 136184	0 109375	0 093333	—	—	2 75	3 17	—	1 95	4 49
FT19	A	VA	0 155510	0 104688	0 091563	—	—	2 79	2 76	—	1 97	3 90
FT20	A	VA	0 072697	0 096875	0 076875	—	—	2 65	5 49	—	1 87	7 76
FT21	A	VA	0 129194	0 114063	0 078646	—	—	2 46	3 46	—	1 74	4 90
FT22	A	VA	0 178947	0 087500	0 092708	—	—	3 09	2 19	—	2 18	3 10
FT23	A	VA	0 144408	0 068750	0 086458	—	—	3 39	2 14	—	2 39	3 02
FT24	A	VA	0 061184	0 078125	0 063750	—	—	2 69	5 15	—	1 90	7 29
FT25	A	VA	0 075658	0 121875	0 084167	—	—	2 46	7 93	—	1 74	11 21
FT26	A	VA	0 126563	0 085938	0 082396	—	—	2 93	2 77	—	2 07	3 91
FT27	A	VA	0.319984	0 073438	0 100313	—	—	3 54	1 37	—	2 50	1 94
FT28	A	VA	0 086431	0 120313	0 051354	—	—	1 92	5 94	—	1 36	8 41
FT29	A	VA	0 085855	0 065625	0 066250	—	—	3 01	3 03	—	2 13	4 29
FT30	A	VA	0 152878	0 142188	0 082396	—	—	2 25	3 64	—	1 59	5 15

Table 3-4 (CONTINUED)

Response variable	Sampling model	Forest region	Mean square for stage 1	2	3	4	Cost model 1 l_{opt}	k_{opt}	m_{opt}	Cost model 2 l_{opt}	k_{opt}	m_{opt}
Visual Symptoms								tree	sub-plot		tree	sub-plot
PLC	A	VA	1442 24	538 06	159 97	—	—	0 58	2 53	—	0 80	2 53
	A	NE	544 614	265 484	78 898	—	—	0 58	3 41	—	0 80	3 41
PDB	A	VA	8 292	16 697	3 397	—	—	••	••	—	••	••
	A	NE	86 385	30 704	27 312	—	—	1 05	2 87	—	1 45	2 87
PTRN	A	VA	186 102	105 758	59 569	—	—	0 84	3.34	—	1 15	3 34
	A	NE	49 373	72 254	24 726	—	—	0 63	10 58	—	0 87	10 58
PDIS	A	VA	0 0	0 0	0 0	—	—	••	••	—	••	••
	A	NE	16 122	9 258	6.131	—	—	0 89	3 98	—	1 23	3 98
PDEN	A	VA	1460 263	112 223	115 429	—	—	1.20	1 00	—	1 65	1 00
	A	NE	683 954	162 730	102 994	—	—	0 87	2 31	—	1 20	2 31
PDEFOL	A	VA	329 458	153 493	125 160	—	—	1 04	2 84	—	1 43	2 84
	A	NE	329 458	153 493	125 160	—	—	1 00	3 42	—	1 38	3 42
PLC-loblolly	A	VA	1377 049	182 96	68 572	—	—	0 66	1 45	—	0 91	1 45
PDB-loblolly	A	VA	0 879	1 987	0 609	—	—	••	••	—	••	••
PTRN-loblolly	A	VA	176 534	43 063	50 109	—	—	1.35	1 77	—	1 86	1 77
PDIS-loblolly	A	VA	0 0	0 0	0 0	—	—	••	••	—	••	••
PDEN-loblolly	A	VA	1543 082	52 362	81 321	—	—	1 68	0 58	—	2 31	0 58
PDEFOL-loblolly	A	VA	278 854	19 647	58 739	—	—	3 62	0 54	—	4 99	0 54
PLC-map+bch+brch	A	NE	374 486	118 243	50 132	—	—	0 70	2 65	—	0 97	2 65
PDB-map+bch+brch	A	NE	91 816	32 038	33 303	—	—	1 25	2 59	—	1 72	2 59
PTRN-map+bch+brch	A	NE	18 538	16 307	12 917	—	—	1 04	5.19	—	1 44	5 19
PDIS-map+bch+brch	A	NE	16 524	7 236	7 687	—	—	1 26	2 97	—	1 74	2 97
PDEN-map+bch+brch	A	NE	483 698	78 125	73 604	—	—	1 17	1 70	—	1 61	1 70
PDEFOL-map+bch+brch	A	NE	280 485	91 305	108 446	—	—	1 37	2 42	—	1 88	2 42
PLC-VA oaks	A	VA	305 313	192 574	89 824	—	—	0 74	3.36	—	1 02	3 36
PLC-other VA hdwds	A	VA	446 716	312 414	140 524	—	—	0 72	3 57	—	1 00	3 57
PLC-NE spruce+fir	A	NE	495 338	157 560	37 440	—	—	0 55	2 55	—	0 75	2 55
PLC-other NE hdwds	A	NE	204 376	46 354	38 181	—	—	1 24	1 74	—	1 71	1 74
									tree			tree
PLC	B	VA	1442 239	176 138	—	—	—	—	1 46	—	—	2 02
	B	NE	544 614	88 479	—	—	—	—	1 96	—	—	2 71
PDB	B	VA	8 292	4 925	—	—	—	—	3 33	—	—	4 59
	B	NE	86 385	27 548	—	—	—	—	2 78	—	—	3 83
PTRN	B	VA	186 102	64 878	—	—	—	—	2 52	—	—	3 47
	B	NE	49 373	28 046	—	—	—	—	3 73	—	—	5 15
PDIS	B	VA	0 0	0 0	—	—	—	—	••	—	—	••
	B	NE	16 122	6 349	—	—	—	—	3 09	—	—	4 26
PDEN	B	VA	1460 263	115 061	—	—	—	—	1 18	—	—	1 63
	B	NE	683 954	107 167	—	—	—	—	1 94	—	—	2 67
PDEFOL	B	VA	198 023	71 128	—	—	—	—	2 56	—	—	3 52
	B	NE	329 458	127 139	—	—	—	—	3 06	—	—	4 22
Soil								pit	sub-plot		pit	sub-plot
CEC_OAC	A	VA	127 878	24 914	13 148	—	—	0 26	1 65	—	0 37	1 65
	A	NE	475 463	44 075	82 683	—	—	0 73	0 88	—	1 03	0 88
CA_OAC	A	VA	10 905	3 096	3 823	—	—	0 47	1 71	—	0 66	1 71
	A	NE	84 079	12 824	9 478	—	—	0 32	1 61	—	0 45	1 61
MG_OAC	A	VA	0 238	0 026	0 042	—	—	0 61	0 91	—	0 86	0 91
	A	NE	0 586	0 118	0 068	—	—	0 27	1 93	—	0 39	1 93

Table 3-4 (CONTINUED)

Response variable	Sampling model	Forest region	Mean square for stage 1	2	3	4	Cost model 1 l_{opt}	k_{opt}	m_{opt}	Cost model 2 l_{opt}	k_{opt}	m_{opt}
									sub-plot			sub-plot
Soil								pit			pit	
K_OAC	A	VA	0 0167	0 0022	0 0051	—	—	1 03	0 70	—	1 46	0 70
	A	NE	0 0702	0 0073	0 0053	—	—	0 32	1.32	—	0 45	1 32
NA_OAC	A	VA	0 00144	0 00034	0 00028	—	—	0 35	1 72	—	0 49	1 72
	A	NE	0 00178	0 00025	0 00017	—	—	0 30	1 56	—	0 43	1 56
AC_BACL	A	VA	243 228	54 888	12 203	—	—	0 16	1 89	—	0 22	1 89
	A	NE	510 444	54 898	65 473	—	—	0 46	1 20	—	0 64	1 20
AC_KCL	A	VA	14 981	4 001	1 494	—	—	0 21	2 02	—	0 30	2 02
	A	NE	21 344	6 340	3 300	—	—	0 26	2 42	—	0 36	2 42
AL_KCL	A	VA	17.640	3 265	1 498	—	—	0 24	1 63	—	0 34	1 63
	A	NE	24 507	5 686	2 208	—	—	0 22	2 17	—	0 31	2 17
N_MIN	A	VA	207.576	5 258	2 742	—	—	0 26	0 58	—	0 36	0 58
	A	NE	9452 287	647 900	538 829	—	—	0 35	1 04	—	0 49	1 04
P_BI	A	VA	96 612	44 747	56 369	—	—	0 48	2 24	—	0 68	2 24
	A	NE	399 674	169 447	299 584	—	—	0 67	2 08	—	0 95	2 08
SO4_H2O	A	VA	80 220	17 102	14 317	—	—	0 35	1 62	—	0 49	1 62
	A	NE	105 331	28 858	16 688	—	—	0 27	2 28	—	0 39	2 28
SO4_PO4	A	VA	134 464	74 711	37 945	—	—	0 25	3 00	—	0 36	3 00
	A	NE	19866 780	1802 580	2070 202	—	—	0 44	1 11	—	0 63	1 11
C_TOT	A	VA	8 479	2 359	1 566	—	—	0 30	1 95	—	0 42	1 95
	A	NE	85 808	5 738	5 930	—	—	0 41	0 98	—	0 58	0 98
N_TOT	A	VA	0 0153	0 0031	0 0033	—	—	0 42	1 49	—	0 59	1 49
	A	NE	0 3055	0 0178	0 0189	—	—	0 42	0 91	—	0 59	0 91
S_TOT	A	VA	0 00027	0 00005	0 00006	—	—	0 46	1 37	—	0 65	1 37
	A	NE	0 00291	0 00019	0 00021	—	—	0 43	0 95	—	0 61	0 95
SAND	A	VA	4116 619	198 276	88 244	—	—	0 23	0 81	—	0 33	0 81
	A	NE	442 004	60 462	59 041	—	—	0 39	1 44	—	0 55	1 44
SILT	A	VA	2858 736	165 406	54 300	—	—	0 20	0 91	—	0 28	0 91
	A	NE	404 156	42 252	46 091	—	—	0 42	1 22	—	0 60	1 22
CLAY	A	VA	132 583	11 416	15 044	—	—	0 50	0 89	—	0 70	0 89
	A	NE	17 878	6 941	6 512	—	—	0 38	2 56	—	0 54	2 56
EC_H2O	A	VA	0 0440	0 0017	0 0013	—	—	0 33	0 68	—	0 46	0 68
	A	NE	0 0343	0 0009	0 0014	—	—	0 58	0 52	—	0 82	0 52
PH_H2O	A	VA	1 4400	0 3130	0 1092	—	—	0 20	1 81	—	0 29	1 81
	A	NE	2 3301	0 2421	0 1486	—	—	0 28	1 35	—	0 40	1 35
PH_01M	A	VA	1 1413	0 2690	0 1096	—	—	0 22	1 87	—	0 31	1 87
	A	NE	2.5002	0 2406	0 1707	—	—	0 31	1 28	—	0 44	1 28
Soil									pit			pit
CEC_OAC	B	VA	127 878	16 339	—	—	—	—	0 46	—	—	0 66
	B	NE	475.463	71 451	—	—	—	—	0 59	—	—	0 83
CA_OAC	B	VA	10 905	3 626	—	—	—	—	0 76	—	—	1 07
	B	NE	84 079	10 451	—	—	—	—	0 53	—	—	0 75
MG_OAC	B	VA	0 238	0 038	—	—	—	—	0 52	—	—	0 74
	B	NE	0 586	0 083	—	—	—	—	0 57	—	—	0 80
K_OAC	B	VA	0 0167	0 0043	—	—	—	—	0 66	—	—	0 94
	B	NE	0 0702	0 0059	—	—	—	—	0 44	—	—	0 62
NA_OAC	B	VA	0 00144	0 00029	—	—	—	—	0 59	—	—	0 83
	B	NE	0 00178	0 00019	—	—	—	—	0 49	—	—	0 70
AC_BACL	B	VA	243 228	23 779	—	—	—	—	0 41	—	—	0 57
	B	NE	510 444	62 396	—	—	—	—	0 53	—	—	0 75
AC_KCL	B	VA	14 981	2 186	—	—	—	—	0 50	—	—	0 70
	B	NE	21 344	4 185	—	—	—	—	0.67	—	—	0 95

Table 3-4 (CONTINUED)

Response variable	Sampling model	Forest region	Mean square for stage 1	2	3	4	Cost model 1 l_{opt}	k_{opt}	m_{opt}	Cost model 2 l_{opt}	k_{opt}	m_{opt}
Soil									*plt*			*plt*
AL_KCL	B	VA	17 640	1 977	—	—	—	—	0 43	—	—	0 61
	B	NE	24 507	3 220	—	—	—	—	0 55	—	—	0 77
N_MIN	B	VA	207 576	3 424	—	—	—	—	0 17	—	—	0 23
	B	NE	9452 287	570 559	—	—	—	—	0 37	—	—	0 52
P_BI	B	VA	96 612	53 217	—	—	—	—	0 99	—	—	1 40
	B	NE	399 674	261 727	—	—	—	—	1 26	—	—	1 78
SO4_H2O	B	VA	80 220	15 072	—	—	—	—	0 57	—	—	0 80
	B	NE	105 331	20 294	—	—	—	—	0 67	—	—	0 94
SO4_PO4	B	VA	134 464	47 915	—	—	—	—	0 79	—	—	1 11
	B	NE	19866 780	1990 907	—	—	—	—	0 48	—	—	0 68
C_TOT	B	VA	8 479	1 781	—	—	—	—	0 60	—	—	0 85
	B	NE	85 808	5 874	—	—	—	—	0 39	—	—	0 56
N_TOT	B	VA	0 0153	0 0032	—	—	—	—	0 60	—	—	0 84
	B	NE	0 3055	0 0186	—	—	—	—	0 37	—	—	0 53
S_TOT	B	VA	0 00027	0 00006	—	—	—	—	0 62	—	—	0 87
	B	NE	0 00291	0 00020	—	—	—	—	0 39	—	—	0 56
SAND	B	VA	4116 619	117 586	—	—	—	—	0 22	—	—	0 31
	B	NE	442 004	59 447	—	—	—	—	0 55	—	—	0 78
SILT	B	VA	2858 736	83 928	—	—	—	—	0 22	—	—	0 31
	B	NE	404 156	44 994	—	—	—	—	0 50	—	—	0 71
CLAY	B	VA	132 583	14 077	—	—	—	—	0 42	—	—	0 60
	B	NE	17 878	6 635	—	—	—	—	0 93	—	—	1 32
EC_H2O	B	VA	0 044	0 0014	—	—	—	—	0 23	—	—	0 33
	B	NE	0 0343	0 0013	—	—	—	—	0 29	—	—	0 41
PH_H2O	B	VA	1 4400	0 1645	—	—	—	—	0 44	—	—	0 62
	B	NE	2 3301	0 1758	—	—	—	—	0 41	—	—	0 59
PH_01M	B	VA	1 1413	0 1528	—	—	—	—	0 48	—	—	0 67
	B	NE	2 5002	0 1911	—	—	—	—	0 42	—	—	0 59
Foliage									*tree*	*sub-plot*		*tree*	*sub-plot*
C	A	NE	2 006804	0 234368	0 246129	—	—	—	0 72	1 11	—	1 02	1 11
N	A	NE	0 405718	0 107428	0 013414	—	—	—	0 18	2 42	—	0 25	2 42
S	A	NE	0 006545	0 001348	0 000699	—	—	—	0 40	1 87	—	0 57	1 87
SI	A	NE	8373542	524503	301267	—	—	—	0 43	0 99	—	0 61	0 99
HG	A	NE	294 788	142 000	118 611	—	—	—	0 58	2 68	—	0 82	2 68
ZN	A	NE	42 71078	51 86667	36 34722	—	—	—	0 50	5 33	—	0 71	5 33
P	A	NE	345323 4	63904 5	80735 6	—	—	—	0 89	1 25	—	1 27	1 25
FE	A	NE	657 9451	102 1333	108 4722	—	—	—	0 73	1 28	—	1 03	1 28
CU	A	NE	6 266667	4 966667	5 944444	—	—	—	0 83	3 04	—	1 18	3 04
MN	A	NE	614578 7	266580 8	185360 7	—	—	—	0 50	2 66	—	0 71	2 66
MG	A	NE	358595 5	120480 4	67028 7	—	—	—	0 42	2 42	—	0 60	2 42
NA	A	NE	32341 31	10385 77	8328 67	—	—	—	0 56	2 15	—	0 79	2 15
CO	A	NE	4 962	2 200	2 486	—	—	—	0 78	2 20	—	1 10	2 20
AL	A	NE	1313 930	65 633	98 903	—	—	—	1 19	0 52	—	1 69	0 52
NI	A	NE	9 507	2 633	2 819	—	—	—	0 73	1 74	—	1 04	1 74
CA	A	NE	85852128	3703944	2950420	—	—	—	0 56	0 75	—	0 79	0 75
K	A	NE	12520476	1203495	1686706	—	—	—	1 05	0 80	—	1 48	0 80
TI	A	NE	588 4363	25 4333	13.4306	—	—	—	0 41	0 83	—	0 58	0 83
CR	A	NE	135 3069	7 5333	5 5972	—	—	—	0 53	0 87	—	0 74	0 87
PB	A	NE	480 51	51 70	79 90	—	—	—	1 26	0 74	—	1 78	0 74
CD	A	NE	4 96177	1.70000	1.76389	—	—	—	0 71	2 00	—	1 00	2 00
SR	A	NE	2010 593	113 167	72 847	—	—	—	0 47	0 91	—	0 67	0 91

Table 3-4 (CONTINUED)

Response variable	Sampling model	Forest region	Mean square for stage 1	2	3	4	Cost model 1 l_{opt}	k_{opt}	m_{opt}	Cost model 2 l_{opt}	k_{opt}	m_{opt}
Foliage								tree	sub-plot		tree	sub-plot
AS	A	NE	398 4	236 1	249 5	—	—	0 72	2 73	—	1 02	2 73
MO	A	NE	45 47157	7 93333	12 48611	—	—	1 31	0 92	—	1 86	0 92
LI	A	NE	6014 464	1537 267	1464 181	—	—	0 65	1 77	—	0 92	1 77
BA	A	NE	11213 59	3951 37	4056 135	—	—	0 70	2 04	—	0 99	2 04
V	A	NE	57 90	23 70	12 76	—	—	0 41	2 72	—	0 59	2 72
B	A	NE	778 4637	166 1667	77 6806	—	—	0 38	1 94	—	0 53	1 94
								branch	tree		branch	tree
C	B	VA	6 539817	0 536545	0 217495	—	—	3 03	0 50	—	2 14	0 70
N	B	VA	0 130519	0 035704	0 003601	—	—	1 38	1 00	—	0 98	1 42
S	B	VA	0 085073	0 051016	0 050076	—	—	5 89	1 12	—	4 17	1 58
SI	B	VA	1106330	301815	72292	—	—	2 21	0 96	—	1 56	1 36
HG	B	VA	88 548	219 169	192 393	—	—	5 31	2 96	—	3 75	4 18
ZN	B	VA	499 9286	149 8476	31 9286	—	—	2 07	1 02	—	1 47	1 44
P	B	VA	2056935	65038	4709	—	—	1 16	0 34	—	0 82	0 48
FE	B	VA	2216 468	414 171	31 810	—	—	1 20	0 83	—	0 85	1 17
CU	B	VA	2254 492	120 352	79 762	—	—	4 22	0 37	—	2 99	0 52
MN	B	VA	962181 3	48718 5	3591.4	—	—	1 17	0 43	—	0 83	0 60
MG	B	VA	40004 27	23364 47	8486 63	—	—	2 83	1 40	—	2 00	1 98
NA	B	VA	38771 44	10301 23	7591 25	—	—	4.58	0 81	—	3 24	1 14
CO	B	VA	6 31746	1 09524	0 76191	—	—	4 38	0 66	—	3 10	0 93
AL	B	VA	256400 9	29565 3	1448 9	—	—	0 95	0 65	—	0 67	0 92
NI	B	VA	16 57937	2 78810	0 77381	—	—	2 41	0 74	—	1 70	1 05
K	B	VA	16736017	1163007	1333591	—	—	6 96	0 33	—	4 92	0 47
TI	B	VA	259 873	22 893	23 773	—	—	6 24	0 40	—	4 41	0 56
CR	B	VA	221 873	8 581	12 857	—	—	10 37	0 19	—	7 33	0 27
PB	B	VA	494 2341	34 1476	38 2381	—	—	6 77	0 34	—	4 79	0 48
CD	B	VA	168 0397	19 8167	32 3452	—	—	12 64	0 29	—	8 94	0 40
SR	B	VA	304 0833	8 7190	12 7619	—	—	9 91	0 17	—	7 01	0 24
AS	B	VA	207 9563	196 8595	108 8690	—	—	3 71	1 73	—	2 62	2 45
MO	B	VA	28 67857	8 29762	8 10714	—	—	5 86	0 76	—	4 15	1 07
LI	B	VA	856 1786	83 2119	50 7024	—	—	3 97	0 50	—	2 81	0 71
BA	B	VA	8938 329	6985 776	6435 548	—	—	5 54	1.34	—	3 92	1 89
B	B	VA	116 3016	38 2286	10 5952	—	—	2 41	1 05	—	1 70	1 49
CA	B	VA	3917473	382916	57114	—	—	1 70	0 58	—	1 20	0 82
V	B	VA	51 51567	37 78268	26 81707	—	—	4 45	1 41	—	3 15	2 00
							branch	tree	sub-plot	branch	tree	sub-plot
C	C	VA	6 539817	0 612767	0 485730	0 217495	3 22	0 49	0 96	2 28	0 69	0 96
N	C	VA	0 130519	0 046871	0 028260	0 003601	1 57	0 43	2 13	1 11	0 61	2 13
S	C	VA	0 085073	0 050651	0 051260	0 050076	5 86	0 49	2 41	4 15	0 70	2 41
SI	C	VA	1106330 0	317480 5	291371 3	72292 1	2 26	0 59	1 65	1 60	0 83	1 65
HG	C	VA	88 54762	253 22620	196 46430	192 39290	5 88	0 39	24 37	4 16	0 55	24 37
ZN	C	VA	499 92860	263 01190	74 40476	31 92857	3 14	0 25	2 95	2 22	0 35	2 95
P	C	VA	2056935 0	53448 8	72764 8	4709 6	1 10	0 98	0 36	0 78	1 39	0 36
FE	C	VA	2216 468	484 036	367 595	31 810	1 28	0 52	1 52	0 90	0 74	1 52
CU	C	VA	2254 492	267 345	22 357	79 762	**	**	**	**	**	**
MN	C	VA	962181 3	60898 5	40598 5	3591 4	1 29	0 47	0 83	0 91	0 67	0 83
MG	C	VA	40004 27	15136 24	28849 96	8486 63	2 49	2 84	0 57	1 76	4 02	0 57
NA	C	VA	38771 44	11104 26	9765 87	7591 25	4 78	0 47	1 68	3.38	0 67	1 68

Table 3-4 (CONTINUED)

Response variable	Sampling model	Forest region	Mean square for stage 1	2	3	4	Cost model 1 l_{opt}	k_{opt}	m_{opt}	Cost model 2 l_{opt}	k_{opt}	m_{opt}
Foliage							branch	tree	sub-plot	branch	tree	sub-plot
CO	C	VA	6 31746	1 48810	0 83333	0 76191	5 51	0 31	1.71	3 89	0 44	1 71
AL	C	VA	256400 9	27653 7	30839 6	1448 9	0 93	0 76	0 89	0 66	1 07	0 89
NI	C	VA	16 57937	4 27381	1 79762	0 77381	3.14	0 31	1.88	2 22	0 44	1 88
K	C	VA	16736017	1207083	1133623	1333591	7 17	0 41	0 79	5 07	0 58	0 79
TI	C	VA	259.87	20 11	24 75	23 77	5 77	0 62	0 70	4 08	0 88	0 70
CR	C	VA	221 873	10 738	7 143	12 857	18 00	0 15	0 72	12 73	0 22	0 72
PB	C	VA	494 2341	35 4048	33 3095	38 2381	6 96	0 42	0 79	4 92	0 59	0 79
CD	C	VA	168 0397	19 4167	20 0833	32 3452	12 20	0 31	0 96	8 63	0 44	0 96
SR	C	VA	304 0833	5 4405	10 9048	12 7619	**	**	**	**	**	**
AS	C	VA	207 956	240 345	167 869	108 869	4 16	0 41	4 40	2 94	0 58	4 40
MO	C	VA	28 67857	10 08333	7.10714	8 10714	6 91	0 33	2 02	4 89	0 47	2 02
LI	C	VA	856 1786	70 1905	91 8929	50 7024	3 70	0 80	0 68	2 62	1 13	0 68
BA	C	VA	8938 329	8061 905	6268 357	6435 548	6 16	0 38	3 54	4 36	0 54	3 54
B	C	VA	116 3016	27 6071	45 3095	10 5952	2 18	1 37	0 86	1 54	1 94	0 86
CA	C	VA	3917473	253486	469202	57114	1 53	2 33	0 28	1 08	3 30	0 28
V	C	VA	51 51567	36 65909	38 53175	26 81707	4 38	0 58	2 65	3 10	0 82	2 65

* Astensks in a sample size column indicate that the sample size equations yielded indefinite solutions See Table 3-1 for definitions of sampling models and stages See Table 3-2 for definitions of cost scenarios

Table 3-5 RESPONSE VARIABLE DEFINITIONS*

Response variable	Description	Response variable	Description
Visual Symptoms		Foliage	
PLC	Percentage of live crown	C	Carbon
PDB	Percentage of crown dieback	N	Nitrogen
PTRN	Percentage of foliated crown transparency	S	Sulfur
		SI	Silicon
PDIS	Percentage of foliar discoloration	HG	Mercury
PDEN	Percentage of crown density	ZN	Zinc
PDEFOL	Percentage of crown defoliation	P	Phosphorus
		FE	Iron
		CU	Copper
Soils		MN	Manganese
		MG	Magnesium
CEC_OAC	Cation exchange capacity by ammonium acetate	NA	Sodium
		CO	Cobalt
CA_OAC	Exchangeable calcium in ammonium acetate	AL	Aluminum
		NI	Nickel
MG_OAC	Exchangeable magnesium in ammonium acetate	K	Potassium
		TI	Titanium
K_OAC	Exchangeable potassium in ammonium acetate	CR	Chromium
		PB	Lead
NA_OAC	Exchangeable sodium in ammonium acetate	CD	Cadmium
		SR	Strontium
AC_BACL	Exchangeable acidity in barium chloride triethanolamine	AS	Arsenic
		MO	Molybdenum
AC_KCL	Exchangeable acidity in potassium chloride	LI	Lithium
		BA	Barium
AL_KCL	Exchangeable aluminum in potassium chloride	B	Boron
		CA	Calcium
N_MIN	Mineralizable nitrogen by incubation (ammonium nitrogen)	V	Vanadium
		Mensuration	
P_BI	Extractable phosphorus in Bray & Kurtz No 1 extractant		
SO4_H2O	Extractable sulfate in deionized water	BA/ha	Basal area per hectare
SO4_PO4	Extractable sulfate in sodium phosphate	AVG_HT_D&CD	Average height of dominant and co-dominant trees
C_TOT	Total carbon		
N_TOT	Total nitrogen	AVG_HT_ALL	Average height of all trees
S_TOT	Total sulfur		
SAND	Sample fraction with particle diameter between 0 05 mm and 2 00 mm	Vegetation structure	
		FTx, x = 1, 2, 3 30	Presence or absence of vegetation (any class) at the indicated height (ft)
SILT	Sample fraction with particle diameter between 0 002 mm and 0 050 mm		
CLAY	Sample fraction with particle diameter less than 0 002 mm	Growth efficiency	
EC_H2O	Electrical conductivity in deionized water	Ln(PTPAR + 1)	Natural logarithm of (1 + the estimated fraction of PAR transmitted through the canopy)
PH_H2O	pH in deionized water		
PH_01M	pH in 0 01M calcium chloride		

* See Sections 5 through 9 for details

4 SYNTHESIS OF LOGISTICS ANALYSES

Mike Papp and John Pemberton

4.1 INTRODUCTION

One of the objectives of the pilot test was to quantify the time and fiscal constraints of making the measurements (Palmer et al., 1990). It is also important to report on the development of the infrastructure for field implementation and to recommend improvements. This section will discuss the operations that occurred at the following stages of logistics:

- staffing and personnel
- procurement and inventory control
- training
- reconnaissance
- sampling
- communications
- safety

Much of the discussion and many recommendations are based on a debriefing of field crews that was conducted in Richmond, VA, on September 5 through 7, 1990, near the end of the field season.

4.2 STAFFING AND PERSONNEL

Figure 4-1 depicts the organizational structure of the field staff.

4.2.1 Description

During the field measurement phase of the study, the project manager ensured that monitoring was accomplished in the region and that information vital to the field monitoring effort was disseminated properly.

Regional project leaders supervised the daily field monitoring activities. These individuals disseminated information (progress and problems) to the project manager and to the field crew. They were available for daily communications with the field crews. The Virginia project leader also performed reconnaissance and assisted the crews by shipping samples.

A member of the field crew was designated a crew leader. The crew leader supervised all field operations and resolved any discrepancies or issues at the measurement site. Other duties of the crew leader were:

- maintaining and revising sampling schedules and travel itineraries,
- assigning duties to crew members according to sampling priorities,
- ensuring that all sampling protocols were followed,
- ensuring proper use and maintenance of field equipment,
- maintaining the integrity of the site and samples collected,
- reporting any problems or difficulties to the proper management staff, and
- returning all field equipment and supplies.

Sampling required a five-person field crew comprised of the following individuals

- Two foresters for measuring core variables and visual symptoms These individuals were FIA foresters with work-related experience in mensurational type measurements.
- One soil scientist for sampling soils and describing pedons. These individuals were Soil Conservation Service (SCS) soil scientists that were familiar with National Soil Survey characterization and sampling methods.
- Two foliage samplers for obtaining foliage samples and for measuring vegetation structure and PAR The individuals were professional tree climbers.

One field crew was used in New England and two field crews were used in Virginia.

4.2.2 Discussion and Recommendations

The organizational structure of the field staff was appropriate. The field crews were adequately staffed to meet the measurement objectives of the project. Two professional tree climbers worked in each crew. They were obtained from a contractor and made several measurements. Two (rather than just one) were hired for safety precautions but this may not be mandatory. The climbers had no experience identifying species for the vegetation structure measurements, but this knowledge would have been beneficial. The tree climbers were the most

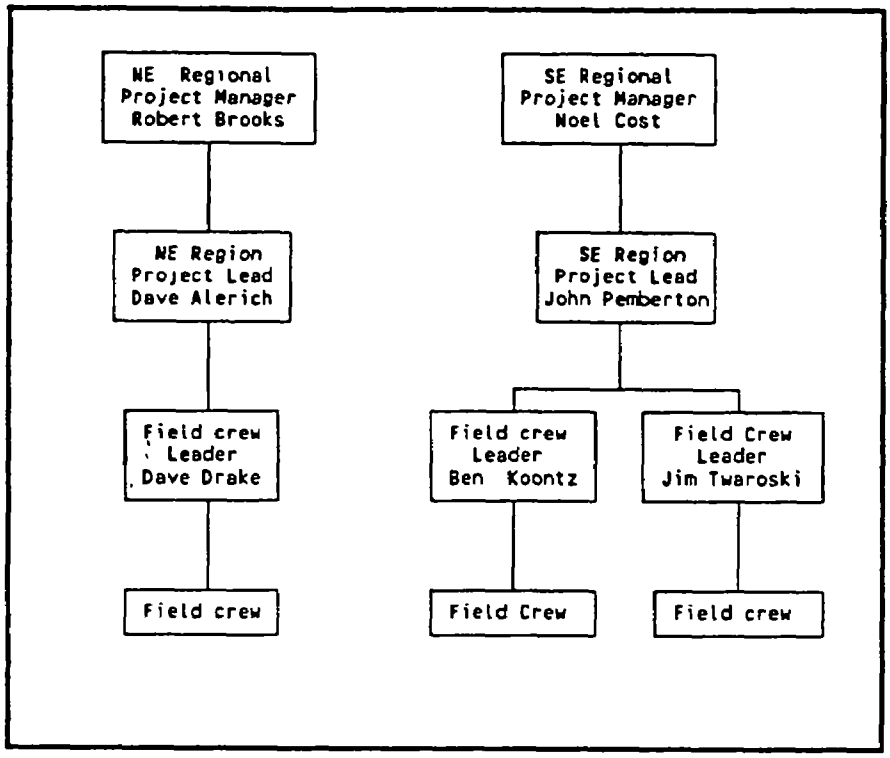

Figure 4-1 ORGANIZATIONAL CHART FOR FIELD STAFFING.

expensive personnel, and the measurements they made could have been made less expensively by forest technicians or undergraduate forestry students. Since tree climbers were required only for foliage sampling, it is recommended that methods other than tree climbing be evaluated for collecting foliage. If tree climbing is the only viable method, then it may be beneficial to train personnel within the Forest Service to climb trees. If another foliage sampling method can be developed, then forest technicians or undergraduate foresters are a better choice as field crew members.

The SCS soil scientists worked through an Interagency Agreement with the USFS. Funding had not been transferred to the SCS by the time sampling began. It is recommended that requirements for the project be evaluated with enough lead time to ensure the transfer of funds before the field work begins.

The field crews were responsible for preparing and shipping samples of roots, branches, tree cores, foliage, and soil. This task was accomplished after field sampling each day and it took one person approximately 1 h to complete. Shipping these samples to the appropriate laboratories was time-consuming and it occurred at the convenience of the field crew. Sample integrity can be improved if samples are shipped at more frequent intervals. It is recommended that the crews be assisted by another person in the preparation and shipment of samples Perhaps one person could assist a number of crews working in a specified area.

4.3 PROCUREMENT AND INVENTORY CONTROL

4.3.1 Description

EPA and the USFS procured supplies for the study. About 3 months before field sampling began, a letter was sent to each measurement coordinator asking for a list of the specific equipment and consumables that would be needed for the measurements. This list was compiled and sent to the

regional project leaders, who in turn indicated what equipment was already available for use in the study. The remaining equipment and consumables were then purchased. The list of all equipment and consumables is reproduced in Dwire et al. (1990).

Two weeks before field sampling activities began, all equipment and consumables (except coolers and gel-pacs) were sent to the project leaders An inventory that was provided with each shipment was checked upon receipt. The equipment was separated by field measurement and then divided among the field crews. After sampling activities were completed, EPA equipment and consumables were shipped back to the Environmental Monitoring Systems Laboratory at Las Vegas (EMSL-LV) for inspection and inventory. The majority of items were available before field sampling and in appropriate quantities. Therefore, calls for resupply were infrequent.

4.3.2 Discussion and Recommendations

Measurement coordinators were fairly responsive in supplying information on the equipment and consumable needs for their measurements. Three items – sample labels, disposable gloves for foliage sampling, and the vegetation structure data entry form – were in short supply at the beginning of sampling and were supplied later. This was caused by insufficient lead time for acquiring these consumables. It is recommended that measurement coordinators be more specific about the items they require and that all their equipment and consumable requirements be provided to the logistics coordinators at least 3 months prior to the start of field sampling.

One of the radiometers malfunctioned during field sampling and was replaced with a spare that was on hand. Certain items were lost during field activities (garden trowels, knives, etc.), but these were not critical items. It is recommended that spare equipment be available for all items; a rule of thumb for expensive and/or critical equipment (portable data recorders, radiometers, laptop computers, etc.) may be one extra unit for each four field crews. Replacements for less expensive equipment should be available in higher quantities. Replacement equipment should be located strategically to be available to field crews within 1 day. The proposed assistant (discussed in the staffing section) could facilitate the resupply of lost or damaged equipment.

Root sampling equipment can be cleaned by either alcohol or bleach. Due to the fire hazard of alcohol, a 1:5 dilution of bleach was the more acceptable cleaning agent. In Virginia, the spray bottle that held the bleach leaked and stained some clothing. Alcohol should be re-evaluated as an agent for cleaning root sampling equipment.

The coolers and gel-pacs needed for storing and shipping samples were resupplied to the crews from the receiving laboratory. It was difficult to maintain the gel-pacs in a frozen state. The refrigerators that were supplied to each field crew were not identical. The New England field crew received a refrigerator in which the entire compartment could be frozen, thereby maintaining the gel-pacs in a frozen state. The Virginia refrigerators had smaller freezing compartments and could not always maintain frozen gel-pacs All refrigerators were cumbersome, yet they had to be moved into and out of hotel rooms. Gel-pacs had to be changed daily to preserve the samples.

The proposed assistant should be made responsible for receiving samples from field crews and maintaining them. The crew should be supplied with a refrigerator/freezer that can be used to maintain gel-pacs or samples for 1 or 2 days until the assistant receives the samples. The assistant can also resupply the field crews with frozen gel-pacs

After the completion of field sampling, the field sampling equipment and consumables were sent back to the agency that purchased the equipment or back to the regional Forest Service Experiment Station. This equipment will be used within each region in the future. Once a region is ready for full implementation, equipment for field sampling should be stored in one location in each region and be inspected and inventoried at the completion of sampling. Defective equipment should be repaired or replaced as soon as possible. New items and consumables should be ordered for sampling in following years.

In some instances, the vehicles used to transport personnel and equipment were not large enough or did not contain an enclosed area where equipment and consumables could be protected One vehicle, with an enclosed area large enough to transport equipment, consumables and samples should be available for each field crew to prevent loss, theft, or destruction.

4.4 TRAINING

4.4.1 Description

A pretraining workshop and a training workshop were conducted prior to field activities. The pretraining session enabled trainers (the measurement coordinators) to test the planned field sampling methods under realistic conditions. Two weeks after the pretraining session, the trainers conducted the field crew training session This meeting included an overview of the FHM project, discussions of each measurement and of quality assurance and logistics. The field training of crew members included a full day sampling exercise and testing and certification (Burkman and Mickler, 1990). The last day of training was used for debriefing crews and revising methods as needed.

4.4.2 Discussion and Recommendations

The pretraining workshop was useful for identifying potential sampling problems and for assisting the trainers in developing their training procedures. As more regions become involved in FHM, more trainers will be needed. It is recommended that the pretraining session be continued to train a set of trainers since measurement coordinators cannot be present at all regional training sessions. This procedure will ensure consistent training and sampling protocols across regions.

The training workshop accomplished its objective of training field crews in the correct sampling methodologies. All field crews members were evaluated by the trainers and certified for competency in the methods for which they were responsible. Crew members did not receive training in every sampling method nor were they briefed in general about other methods or the samples deriving from those sampling methods. Field sampling in Virginia began about 1 month after training. The interval between training and implementation led to some confusion during the first week of sampling as to the number and types of samples needed as well as the protocol for sample collection.

The training session should allow time for crew members to observe all sampling techniques in order to get a better "feel" for what the field crew must accomplish in a day. It may also be worthwhile to train at least two crew members for each sampling technique in case one crewperson becomes ill during the field season. Additional training of crew leader responsibilities is necessary. If sampling methods or any information affecting field sampling are revised during training, these revisions should be discussed up during the debriefing session, documented, and sent to all field crew members for insertion into the field sampling manual. It is recommended that the training session be conducted shortly before the field season begins. In addition, safety training should be included in the training agenda

4 5 RECONNAISSANCE

4.5.1 Description

Reconnaissance activities include acquiring the most recent aerial photos, topographic maps, and prior field tally sheets (if applicable), determining cover types from the aerial photos, identifying and contacting landowners to gain access, and marking the travel routes to the plots for the field crews to follow.

In New England, reconnaissance included the relocation of the FIA plot monuments In Virginia, new plots were established and it was not necessary to relocate plot monuments.

4 5 2 Discussion and Recommendations

The Virginia regional project leader performed the reconnaissance activities for Virginia. In New England, reconnaissance was not conducted for the nine plots in Maine, but a person was identified to help with reconnaissance for the remainder of the plots.

Reconnaissance proved to be beneficial and cost effective. The Virginia crews did not have to spend any time locating the "starting point" before proceeding to the plot location. In Maine, on the other hand, it required an average of 1.5 h to locate the starting point. This translates to 7.5 h of lost sampling time for a five-person crew. Some starting points were never located by the New England crew without reconnaissance. Although the New England and Virginia regions had different distances between plots and different weather conditions, the difference in the weekly average number of plots completed by a crew in New England (2.3 without reconnaissance

and 3.0 with reconnaissance) as compared to Virginia (3.7 with reconnaissance for all sites) partly reflect the difference in reconnaissance. With reconnaissance, more of the field crew's time is available for sampling, and this may improve data quality.

Reconnaissance information should include lodging facilities closest to the plot, express mail facilities in the vicinity, and emergency facilities. Some of this information may be provided by a logistical support group at regional or national centers.

Because the plots in Maine were not reconnoitered before sampling, the field crews spent time locating these plots rather than measuring them. In some instances, plots were not found even after considerable effort. One location that was never located was on a steep slope and this made it difficult for crew members to carry some of the heavy and cumbersome equipment to the starting point. Because certain crew members were under contract for either a fixed period of time (SCS soil scientists) or for a fixed funding limit (professional tree climbers) the crew leader was sometimes uncertain as to how much time to expend finding a site vs. moving to an alternate site. The crew leader was asked to balance the constraints of the sampling design against the measurement objectives that required 20 sites be visited within the time and funding constraints.

Criteria for eliminating plot locations should be developed by the measurement coordinators in cooperation with the statistical design and logistics coordinators. Accessibility, hazardous situations, or the length of time or funds required to locate and sample a site may be considered as criteria to determine the appropriateness of a given site

4.6 SAMPLING

4.6.1 Description

Plot sampling included the following activities (Table 4-1):

- travel to site
- site location
- plot establishment
- data collection activities
- sample maintenance and transport
- data saving and transmission

Travel to the site included outfitting (checking for all equipment and consumables needed at the site) as well as the travel from the place of lodging to the place where walking was necessary. Two vehicles were typically used for travel to the sites Travel times were comparable in New England and in Virginia. Travel between sites was greater in New England because the sites were widely distributed across New England whereas in Virginia the sites were confined to the eastern third of the state.

Site location included the time required to find the starting point and the plot center once out of the vehicle. The FIA foresters took responsibility for plot establishment. This task entailed locating all four subplot center points, establishing four vegetation structure-PAR plots, locating three soil sampling holes, and identifying four or six sample trees. The sequence of plot establishment was as follows (Dwire et al., 1990).

1. Establish subplot number 1 center location.
2. Locate the first soil sampling hole and subplot number 1 sample trees.
3. Set up witness trees at subplot number 1 and collect data on regeneration plot and vegetative profile. Establish PAR grid on subplot 1.
4. Locate subplots 2, 3, and 4. Establish subplot centers and locate soil sampling holes 2 and 3 and remaining sample trees. Tally regeneration plots and select sample trees. Install PAR grid

Table 4-1 SUMMARY OF TIME REQUIRED FOR CREW ACTIVITIES

	Region	
Activity	New England	Virginia
Start time	7 00 a m	7 30 a m
Travel time (r t)	3 h	3 h
Plot location	1 5 h	20 min[a]
Plot establishment	50 min	50 min
Data collection	6 h	6 h
Average length of workday	11 3 h	10 2 h
Sample maintenance and transport	1 h	0 h[a]
Data saving and transmission	20 min	20 min
Number of sites per crew per week	2 75[b]	3 7

[a] Accomplished by a non-crew reconnaissance person

[b] Average includes time with and without reconnaissance (see text)

Data collection activities included the measurements and sample collections for the five sets of measurement variables (Section 1). Table 4-2 highlights the approximate sampling times allocated for different measurements. Sampling crews used more than one measurement technique for some indicators. This information is presented in Sections 5 through 9 in more detailed discussions of time and feasibility.

The two foresters were responsible for mensuration and visual symptoms measurements. The soil scientist collected pedon data and soil samples. The two tree climbers measured vegetation structure and PAR, and collected samples of foliage, branches, tree cores, and roots. Figure 4-2 delineates the sequence of these sampling activities.

The samples of roots, tree cores, branches, leaves, and soils were transported from the field and stored in coolers with gel-pacs or refrigerators to preserve the samples. The samples were boxed with gel-pacs and shipped by overnight express to various locations for preparation and analysis. Express shipping was necessary to maintain sample integrity. Maps of the Federal Express main offices were given to the crew leaders to assist in locating drop-off facilities. Shipping labels and packing slips were preprinted to prevent shipping errors.

At the end of a field day, the crews transferred the measurements stored on the portable data recorder (the tree tally and soil characterization data) and the radiometer (PAR data) to a laptop computer. These files were then transferred via modem to a computer center. Data transfer was required to store data at a central location. It was also useful for sending data to the quality assurance staff so that verification programs could be run that could not have been run in the field. Data transfer can be used for sample shipment and tracking in the future.

The general work schedule was five 10-h days (50 h/week). Table 4-1 shows that a day averaged 11 h and 20 min in New England and 10 h and 10 min in Virginia. The difference was the time required to locate plots. This time estimate does not include sample maintenance and transport, or data transfer, activities that required just one person and 1 h and 20 min in New England and 20 min in Virginia. The Virginia estimate is lower because the regional project leader performed this activity.

Table 4-2 TIME ALLOCATED FOR DATA COLLECTION BY MEASUREMENT

Measurement set	No. people	Hours/ person	Total hours
Soils	1	8	8
Foliage	1	3	3
Vegetation structure	2	2.5	5
Growth efficiency (PAR)	1	2	2
Mensuration and visual symptoms	2	5	10
Total			28

4.6.2 Discussion and Recommendations

In New England, travel time was higher because of a lack of extensive road systems and a lack of knowledge of the lodging facilities that were close to the plots. Reconnaissance should identify adequate lodging facilities as close to the plots as possible. In the future, sampling crews may attempt to sample a number of sites from one lodging location. This is considered efficient if lodging is equidistant from all sampling sites.

In New England, site location averaged 1.5 h (range 0.5 to 5 h). Most of this time was for locating the starting points from the FIA tally sheets. In some instances, the crew left their vehicles and walked to the starting point, at other sites, crews drove to the starting point. Crews had difficulty finding starting points for various reasons. Some starting points had been removed by logging or natural disturbances. Crews received insufficient information about the starting points. For example, factors such as lack of aerial photographs or insufficient detail on sketch maps made locating starting points problematic. Obscure tree scribes also made the task difficult. Once the starting point was located, travel to the plot center was accomplished quite efficiently.

The Virginia project leader located sites prior to sampling. There, approximately 20 min was required for the crew to reach plot center.

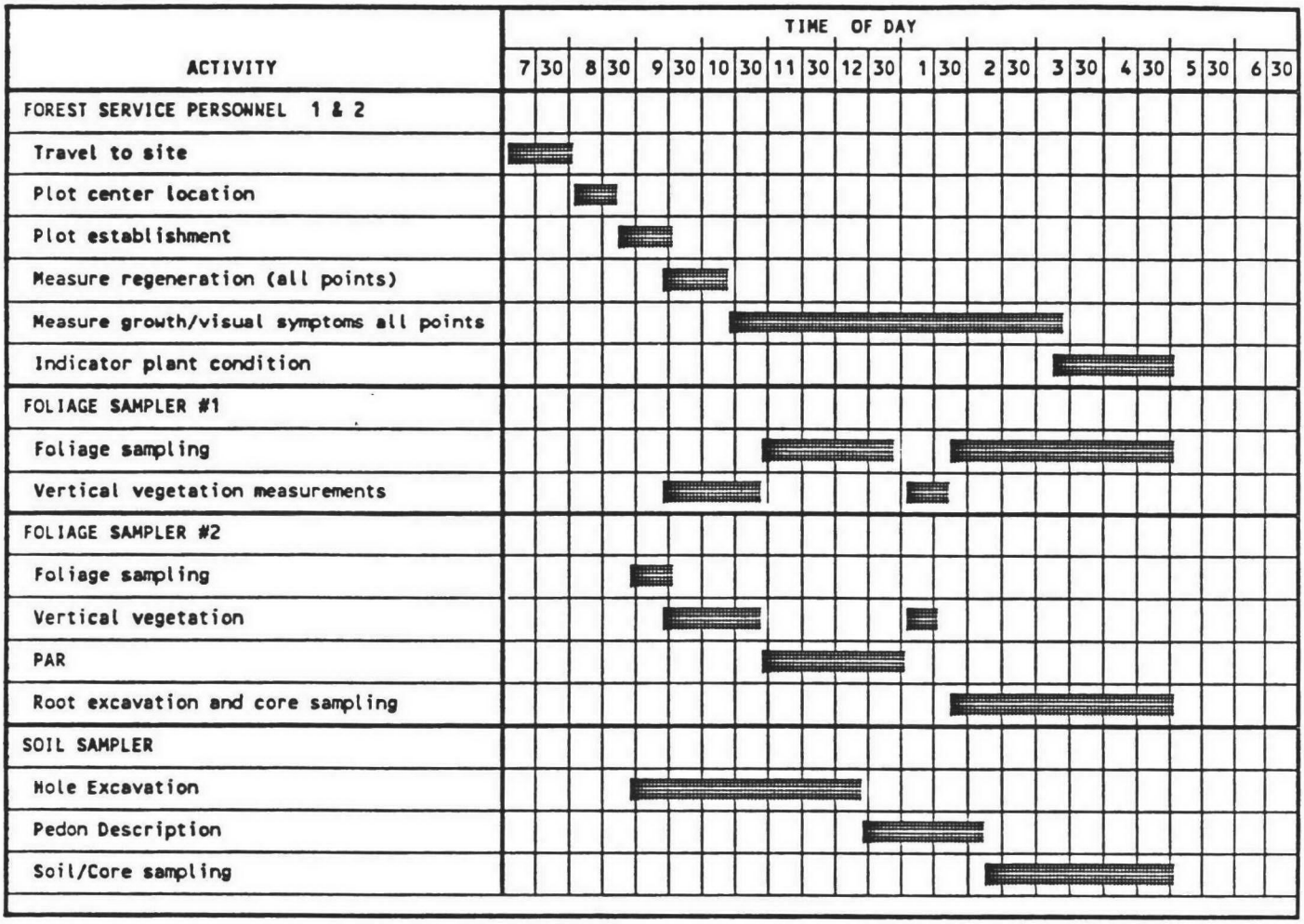

Figure 4-2. A TYPICAL DAY'S SAMPLING SEQUENCE.

It is recommended that reconnaissance of the sampling sites occur prior to sampling. If necessary, new aerial photos and more detailed information on starting points should be acquired. New methods for establishing starting points that remain anonymous to the public (e.g., global positioning systems) should be investigated.

Crew leaders found that it was more efficient to set up the complete plot before the FIA foresters collected any of their data. It is recommended that the measurement procedures proceed with plot establishment before data collection activities. However, an evaluation needs to be made as to whether or not field crew members who are responsible for vegetation structure measurements should be allowed on subplots before the regeneration plots are tallied (to prevent trampling).

The time requirements for data collection were similar in New England and Virginia. When specific methods have been approved, the time requirements for some measurements should be reduced. The sequence for the sampling activities was appropriate. The most time-consuming activities were soil sampling and tree climbing (when climbing spikes were not used). With a reduction in data collection for other measurements, field crew members may be able to help complete these activities. It is recommended that alternative methods of foliage collection be investigated as well as the use of tree-climbing spikes.

Because the project had two types of plots (half that had foliage sampling and "intensive" soil sampling, and half that did not), field crew members were sometimes uncertain about the types and numbers of samples that were needed on a particular plot. It is recommended that all data and samples to be collected on a plot be listed concisely and placed on a laminated sheet for each field crew member, and/or programmed on the portable data recorder for the field crew leader to check before leaving the plot.

In New England, the field crew was responsible for maintaining and transporting samples. After a day of sampling, a crew member accounted for all samples collected and placed them either in the refrigerator or in coolers that contained frozen gel-pacs. This procedure took approximately 1 h. Some samples had to be maintained for as long as 4 days under these conditions. Crew members shipped samples only when inclement weather forced a shutdown of field work or when they had a free time (after finishing a plot in half a day or during travel to another site). Express shipping facilities were usually not difficult to locate; more facilities were available than were identified on the maps that were provided.

In Virginia, the regional project leader handled the maintenance and transport of the samples. Crew members who had already worked a 10-h day were relieved of this responsibility.

It is recommended that crews be assisted by an individual who maintains equipment, stocks consumable goods, and receives, maintains, and transports samples. This person could visit the crews daily or every other day.

A sample tracking and shipment form was used to identify samples that were shipped. The plot location identification and the number of samples were recorded on the form. This information was placed in one of the transported containers. Upon arrival at its destination, the samples were checked against the shipping form. This procedure accomplished the goals of sample tracking and chain-of-custody, but due to the number of samples, different types of samples, and the number of facilities to which they were sent, this task was time consuming. When samples arrived at the receiving facility, the labels had to be re-entered into a computer system.

It is recommended that a bar coding system be developed to label, track, and archive samples In the field, the crews would place bar codes on samples and the portable data recorder would associate the written label (state, plot location, sample number, etc.) with the bar code. This information would then be stored in the portable data recorder and the laptop computer. When a shipment is made, the laptop computer would identify what types of samples, the number of samples, and the locations that need to be shipped. The samples would be located and the bar codes scanned as they are packed. The information would then be compared to the original sample list to assure that all samples were accounted for. The information would be printed as well as sent electronically to the receiving facility. At the receiving facility, the bar codes on the samples would be scanned and electronically compared to the shipping file. This would make sample tracking and chain-of-custody more efficient and reliable. Also, the sample identification would not have to be re-entered at the receiving facility.

The data saving and transfer procedure was efficient, usually requiring only 20 min to complete. During the first transfer in New England (plot number 902), data was lost during the transfer from the portable data recorder to the laptop computer because of a programming error that did not allow commas to be entered into the free-form "field note" field. A new program was sent to the field crew to fix the problem At times, data could not be transferred daily because the phones at some hotels were incompatible.

It is recommended that all data verification programs be available on the portable data recorder or the laptop computer This will allow on-site verification and correction of data before transfer and would alleviate the need for immediate transfer in the event phones are incompatible.

Unless field assistants are provided and the measurements are reduced, the field sampling activities described in this report cannot be completed in 1 day. Long field days and inclement weather can induce field crew "burnout" which, in turn, can lead to careless sampling techniques, safety problems, and poor data quality.

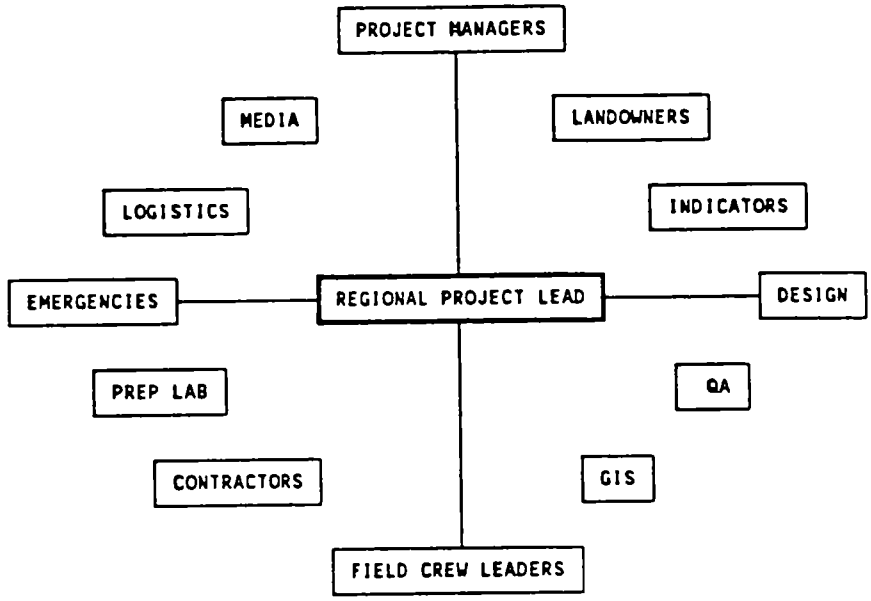

Figure 4-3 FLOW OF INFORMATION TO AND FROM THE REGIONAL PROJECT LEADERS

It is recommended that crew leaders be aware of field crew "burnout" and its effect on data quality. A suggestion would be to task the crew with a certain number of plots to sample and allow the crew the flexibility of completing these within a specified time. In any case, work schedules should be designed to maintain high field crew morale.

4.7 COMMUNICATIONS

4.7.1 Description

The communications network in this project was similar to the organizational chart (Fig. 4-1). Details of the communications procedure are discussed by Dwire et al. (1990). Generally, communication would lead from the crew members to the crew leader who would then contact the regional project leader. The regional project leaders would attend weekly conference calls with national technical coordinators. At this level, discussions would include progress on all operational phases, problems, and protocol changes. Issues would be resolved and the results disseminated consistently to all field crew leaders.

4.7.2 Discussion and Recommendations

The communications for the project was adequate in most cases. Logistics personnel attempting to send supplies sometimes had difficulty locating field crews. As the FHM program expands, strategically located, regional base sites may be necessary to send equipment and consumables to field crews.

The most important communications link is between the field crew leader and the regional project leader. The field crew leader informs regional project leaders about sampling progress and communicates problems (e.g., equipment damage or supplies needed etc.) or emergencies.

Crew leaders should submit weekly travel itineraries to the regional project leaders and immediately inform the regional project leader of changes. Crew leaders should also be responsible for the direct communication of emergencies to the appropriate authorities unless personally injured. All field crew members should be trained to handle emergencies properly.

Regional project leaders are important links between the field and other groups (Figure 4-3). They should be available for phone communication during the hours of sampling. Due to other commitments, the New England regional project leader was not always available to field crews or for weekly conference calls. At the debriefing session, it was mentioned that the regional project leaders were unsure of where to find the appropriate expertise when specific questions arose.

It is recommended that the regional project leaders identify replacements when they are not available. Also, phone recorders should be used so that field crew leaders can leave messages during evening hours. It may be advantageous to develop an electronic mail system. It is also recommended that the leaders of each group in Figure 4-3 be readily available during sampling to respond to questions

4.8 SAFETY

4.8.1 Description

Emphasis must be placed on safety in any field operation. Field personnel must be aware of potential safety hazards, follow all project safety protocols and equipment guidelines, and be prepared for emergency situations. A safety plan, developed specifically for the program, was intended to address the potential safety hazards of field sampling and to identify required safety protocols This safety plan was developed from EPA and USFS information. All participants in the study were required to abide by specific agency safety regulations.

4.8.2 Discussion and Recommendations

During the training workshops the safety plan was mentioned but was not reviewed. Proper safety gear (e.g., hardhats, safety glasses, gloves) was available, but was not often used. Some of the FIA crew members had been trained in basic first aid, but this was not a prerequisite.

It is recommended that more emphasis be placed on safety and that the safety plan be reviewed as part of training. Crew members should be required to read the plan and to document their review. It is recommended that safety gear be supplied to all crew members for mandatory use. It is also recommended that more than one individual on each crew be trained in basic first aid including cardiopulmonary resuscitation

Maps that identify fire and police stations in the vicinity of the plot locations were given to the field crews. Hospital information was not supplied but should be in the future. It is recommended that the regional project leaders and crew leaders identify the kinds of information they would like to have on maps.

4.9 SUMMARY

In New England and in Virginia, it is feasible for a five-person crew to make the measurements described in this report in a 10-h day. If certain sampling methods can be streamlined, then a four-person crew may be feasible. The following recommendations are made to improve the efficiency of field activities

- Determine the criteria for eliminating sampling sites prior to reconnaissance
- Provide reconnaissance prior to field sampling to reduce the time it takes a field crew to locate a sampling site.
- Review all equipment and consumable items with measurement coordinators to determine exactly what is required
- Determine staff requirements early and ensure that contracts are established before field sampling activities commence.
- Provide an assistant to the field crews. This individual will stock equipment and consumables and will receive, maintain, transport and track samples.
- Provide a better communications network. Field crews must be able to get answers to their questions rapidly. The regional project leader or an identified assistant should be responsible for all communication with the field crew leader in order to maintain the proper lines of communication.
- The logistics teams need to maintain close communication with other groups (design, indicators, QA, information management) in order to develop efficient field implementation. These groups' plans and their logistics arrangements need to be identified and worked into logistics plans with as much lead time as possible

5 VISUAL SYMPTOMS

Kurt Riitters, Sam Alexander, Robert Anderson, Robert Kucera, and Margaret Miller-Weeks

5.1 INTRODUCTION

Large-scale forest monitoring systems commonly evaluate tree health in terms of the outward appearance of tree crowns and boles (e g , United Nations Economic Commission for Europe, 1987; Magasi, 1988). Despite the inherent problems of interpretation (e g , Innes, 1988a, 1988b; see below), these measures are potentially useful because they are easy to implement and because their meaning is universal. In one sense, a tree that looks "unhealthy" probably is "unhealthy", *provided* that "health" is gauged with reference to a baseline or normal condition for that species, growth stage, and location.

Appearances can be misleading, because trees cannot move about to seek their best exposure, soil, moisture regime, nutrition, or protection. The requirements and therefore the outward appearances of trees differ over time and space, even when conditions are normal everywhere. The health of any particular tree must be assessed in relation to normality for that tree's circumstances, and this makes it difficult to use visual symptoms for site-specific assessments.

The aggregate appearance of a healthy regional population of trees may be more stable If all individuals of a population appear less healthy over time, relative to their previous appearances, then either their health has changed, or the circumstances that define their normality have changed. The capability to detect of either of these events would be valuable, and would lead to follow-up studies and assessments of what caused the changes.

The FHM program has given a high priority to measures of appearance (e.g., Wentworth and Joyner, 1987; Riitters et al., 1990, Brooks et al , 1991b). This reflects their potential utility, their prior testing, and their relative ease of application. Yet apparently only Innes and Boswell (1990) have investigated their reliability. Therefore, one objective of the field study was to develop estimates of reliability with a view towards deciding upon appropriate plot designs.

The purpose of this section is to summarize the sampling optimization results obtained for the measurements that could be analyzed as continuous variables. Categorical variables were not analyzed here. Average values obtained for the different variables in each forest type will be given The analyses of variance of these measurements will be documented as they are the basis for plot design recommendations made in Section 3. Finally, the analyses of variance of selected mensurational measurements will be documented for application in Section 3.

5.2 DESCRIPTION AND APPLICATION OF THE MEASUREMENTS

As used here, the term "visual symptoms" refers to a suite of measurements and observations of appearance that were made on trees $\geq$ 7.62 cm dbh within the 0 0169-ha subplots at each location (Fig. 1-2). Detailed descriptions of each measurement are given by Dwire et al (1990). Briefly, on all live trees on all four subplots, the percentage of live crown (PLC) was estimated, and the occurrence of crown and bole damage (CBD) was noted. Live crown percent and crown and bole damage are fairly standard measures in forest inventory (U.S. Forest Service, 1985a) and in forest damage surveys (Millers and Lachance, 1989, Alexander and Carlson, 1988).

Additional measurements were made on dominant, co-dominant, and open-grown trees on two of the four subplots The additional measurements included the percentage of crown dieback and percentage of foliated crown transparency (PDB and PTRN, both adapted from Millers and Lachance, 1989), the percentage of foliar discoloration (PDIS, Alexander and Carlson, 1988), the percentage of crown density (PDEN, Anderson and Belanger, 1986), and the percentage of crown defoliation (PDEFOL, adapted from the United Nations Economic Commission for Europe, 1987)

Defoliation, transparency, dieback, and related measures are non-specific measures of condition Although they may be useful for detecting change in tree condition over time, they are not diagnostic measurements and they reflect the particular combination of stresses, natural and manmade, that also changes over time.

Three additional measures that will not be reported here are the years of needle retention, the percentage of discoloration by the "European" method, and the horizontal crown diameter (see Dwire et al. [1990] for a description of these measures.)

In practice, these measurements are sometimes combined as indices of crown condition. For example, defoliation and discoloration are combined to estimate a single damage index in the European system (United Nations Economic Commission for Europe, 1987), but that index has not been generally adopted (e.g., Innes and Boswell, 1987, 1990). The measurements of crown dieback and transparency are sometimes combined (Millers and Lachance, 1989) but that practice also appears to be optional (e.g., Brooks et al., 1991b). In another example, it is a common practice to estimate crown volume by combining measurements of the percent live crown, total tree height, and crown diameter. Because it appears that there is no agreement on any of these combined indices, the measurements will be analyzed separately in this section

It is expected that these measures of tree appearance would be augmented by concurrent or follow-up visits by trained forest pathologists to evaluate the importance of observed changes and, if possible, to identify plausible causes (e.g., insects and diseases) of those changes. These procedures were not tested in this study, but they are an important part of the overall FHM program (Palmer et al., 1991).

5.3 SUMMARY OF VISUAL SYMPTOMS

Tables 5-1 and 5-2 summarize the measurements of the visual symptoms variables. The total number of trees sampled and the number of live trees are shown (columns 1 and 2). The number of live trees is the sample size for the variable PLC. The number of trees rated by other crown measures is also shown (column 4); this is the sample size for the variables PDB, PTRN, PDIS, PDEN, and PDEFOL. The number of trees for which crown and bole damage was observed is shown (column 10). Finally, the arithmetic averages of the variables PLC, PDB, PTRN, PDIS, PDEN, PDEFOL, and CBD are shown (columns 3, 5-9, and 11).

It was not the objective of this study of variance components to use these measurements to classify forest "health", because such interpretations require more complete assessments of all biotic pathogens, insects, and other indicators of plant stress (Skelly et al., 1987). But a brief review of the quantitative results obtained for the subset of measurements tested will put into perspective the analyses of variance components (Section 5.4).

Considering first the New England stands, most species had (on average) less than 30% live crowns, and (not surprisingly) shade-intolerant species appeared to have less than shade-tolerant species (Tables 5-1 and 5-2). For the species with at least 10 crown-rated trees, it is notable that nearly 80% of the American beech had at least one (but rarely more) incident of crown or bole damage; values for other species were considerably less. Also for these species, average dieback was less than about 10% and average discoloration was less than about 3%. Average transparency was typically less than 15%, average defoliation was consistently about 30 to 40%, and average crown density was between 30 and 60%. The variety among the averages obtained for the different species suggests, at least, that the percentages are not directly comparable measures of health, yet they still may be highly correlated (Innes and Boswell, 1990). Without more information, it is not possible to ascribe values of "good" or "poor" health for these variables.

Overall, the average percentages of live crown appeared larger in Virginia (Tables 5-1 and 5-2). For 6 of the 7 species measured in both regions (red maple, American beech, bigtooth aspen, cherry, white oak, and northern red oak, but not yellow birch), the average percent live crown values in Virginia were at least twice the values in New England. Deciding whether this represents a real difference among regions or is simply a difference among crew measurement techniques requires further analysis.

The Virginia species appeared to exhibit the same pattern of percent live crown for shade-tolerant vs shade-intolerant species. Loblolly pine was the only Virginia species for which a substantial number of trees were crown-rated. The results for dieback, discoloration, transparency, defoliation, and crown density were similar to results mentioned earlier for selected New England species, with the same caveats.

Table 5-1 NUMBER OF MEASURED TREES AND SPECIES AVERAGE CROWN RATINGS IN NEW ENGLAND

Species	Total trees (no.) (1)	Live trees (no.) (2)	Live crown (PLC) (%) (3)	Crown rated trees (no.) (4)	Dieback (PDB) (%) (5)	Transparency (PTRN) (%) (6)	Discoloration (PDIS) (%) (7)	Crown density (PDEN) (%) (8)	Defoliation (PDEFOL) (%) (9)	Trees with symptoms (no.) (10)	Avg no of symptoms (CBD) (no.) (11)
Balsam fir	92	87	22 5	4	5 0	8 8	2.5	55 0	32 5	9	1 4
White spruce	5	5	39.0	1	10 0	25 0	5 0	70 0	60 0	3	1 0
Red spruce	95	78	18 5	11	5 5	8 6	0.5	56 8	30 5	24	1.1
Eastern white pine	36	31	19 7	8	7.5	14 4	0 6	39 4	31 9	4	1 0
Northern white-cedar	3	3	28.3	0	–	–	–	–	–	1	1 0
Eastern hemlock	126	119	27 9	9	4 4	6 1	0 0	63 9	19 4	13	1 0
Striped maple	29	22	16 1	3	3 3	11 7	3.3	50 0	33 3	13	1 1
Red maple	215	205	19 1	76	8 0	11 5	1.2	44 2	37 1	77	1 0
Sugar maple	180	171	24 2	38	6 7	9 5	1.2	50 5	28 6	39	1 1
Yellow birch	96	89	23 5	37	8 0	10 7	1 6	46 2	31 9	33	1 2
Sweet birch	17	17	20 6	1	5 0	10.0	0 0	40 0	35 0	2	1 0
Paper birch	53	49	18 0	24	5 4	11.3	2.5	44 2	31 5	7	1 1
American beech	105	99	23 1	17	10 6	12 7	0 9	45 3	43 2	80	1 2
White ash	20	20	15 8	5	7 0	14 0	1 0	41 0	34 0	5	1 0
Eastern hophornbeam	11	11	30 0	1	5 0	15 0	5.0	35 0	30 0	4	1 0
Bigtooth aspen	27	27	13 5	17	5 9	15 3	0 0	32 1	35 0	6	1 0
Quaking aspen	21	20	11 5	15	6 3	18 7	0 3	44 0	34 3	2	1 0
Prunus spp.	4	4	12 5	3	20 0	23 3	0 0	28 3	38 3	3	1 0
Black cherry	22	17	17 9	9	8 3	12 2	2 2	40 0	33 9	11	1 3
Common choke-cherry	26	26	14 4	2	5 0	15 0	5 0	27 5	30 0	13	1 0
White oak	4	3	18.3	1	5 0	10 0	0 0	50 0	25 0	2	1 0
Northern red oak	19	18	18 3	7	5 0	22 9	2 1	39 3	44 3	8	1 3
American mountain-ash	7	7	12 9	2	7 5	15 0	0 0	37 5	35 0	7	1 0
American basswood	1	1	15 0	0	–	–	–	–	–	0	–

The possibility of regional differences in percent of live crown was also suggested by the data expressed on an average per-plot basis (Table 5-3). Other comparisons between the two regions are probably not worthwhile, since they would in effect be comparisons of loblolly pine (in Virginia) with all sampled species (in New England). The variation among plots within the same region is a topic for the analyses of variance in Section 5.4.

The possibility of regional differences in the implementation of the same measurements was suggested for the results for defoliation and crown density in Table 5-3. In Virginia, the simple correlation between the two variables was -0.843 ($p<0.01$), but in New England the variables were independent ($r=0.069$, $p>0.1$). It seems logical that defoliation and crown density are inversely related, and therefore one may question the New England result. But the available evidence does not necessarily imply that either the measurements or the crews are somehow at fault for the differences observed. For example, the logic for finding a correlation may vanish when data are aggregated to plot averages of different species, as they were in this case. It has been suggested that several similar measures of crown condition would permit cross-validation of each, but these procedures have not yet been specified These and other associations among the different measures of crown condition will be reported in a separate publication.

The data in Tables 5-1 through 5-3 are not strictly comparable to any other survey results from these regions, because sampling designs and measurement methods may have been different. An appropriately qualified comparison with the monitoring results obtained by Brooks and others (1991a, 1991b) in New England may be worthwhile, however.

Table 5-2 NUMBER OF MEASURED TREES AND SPECIES AVERAGE CROWN RATINGS IN VIRGINIA

Species	Total trees (no.) (1)	Live trees (no.) (2)	Live crown (PLC) (%) (3)	Crown rated trees (no.) (4)	Dieback (PDB) (%) (5)	Transparency (PTRN) (%) (6)	Discoloration (PDIS) (%) (7)	Crown density (PDEN) (%) (8)	Defoliation (PDEFOL) (%) (9)	Trees with symptoms (no.) (10)	Avg no of symptoms (CBD) (no.) (11)
Eastern redcedar	6	5	58 0	0	–	–	–	–	–	1	1 0
Shortleaf pine	8	8	37.5	4	0 0	16 3	0 0	48 8	25 0	0	–
Loblolly pine	641	636	25.5	157	0 1	19 9	0 0	54 8	22 6	132	1 2
Virginia pine	96	96	20 6	8	0 0	22 5	0 0	62 5	22 5	35	1 3
Red maple	111	110	37 8	3	0 0	13.3	0 0	78.3	10 0	58	1 3
Yellow birch	7	7	20 0	0	–	–	–	–	–	2	1 0
Bluebeech	9	9	38 9	0	–	–	–	–	–	0	–
Hickory spp	13	13	36 2	1	0 0	15 0	0.0	65.0	15 0	8	1 3
Flowering dogwood	8	8	42 5	0	–	–	–	–	–	4	2 0
Common persimmon	2	2	32.5	0	–	–	–	–	–	2	1 0
American beech	8	8	55 6	1	0 0	15.0	0 0	70 0	30 0	5	1 0
American holly	18	18	51 4	0	–	–	–	–	–	4	1 3
Black walnut	1	1	65 0	0	–	–	–	–	–	0	–
Sweetgum	185	185	36 7	5	6 0	26 0	0 0	55 0	21 0	45	1 2
Yellow-poplar	78	78	37 5	5	0 0	9 0	0 0	70 0	12 0	4	1 5
Sweetbay	5	5	30 0	0	–	–	–	–	–	1	1 0
Upland blackgum	1	1	40 0	0	–	–	–	–	–	0	–
Lowland blackgum	23	23	35 9	0	–	–	–	–	–	12	1 2
Sourwood	13	13	41.2	0	–	–	–	–	–	4	1 3
Bigtooth aspen	10	10	37 5	1	0 0	10 0	0 0	60 0	15 0	0	–
Black cherry	1	1	45 0	0	–	–	–	–	–	1	1 0
White oak	59	58	43 5	2	0 0	12 5	0 0	60 0	12 5	17	1 1
Scarlet oak	5	5	39 0	0	–	–	–	–	–	1	2 0
Southern red oak	58	58	38 8	3	0 0	26 7	0 0	60 0	18 3	5	1 0
Water oak	13	13	41 2	0	–	–	–	–	–	9	1 1
Willow oak	17	17	44 4	3	0 0	21 7	0 0	68 3	13 3	9	1 4
Northern red oak	1	1	40 0	0	–	–	–	–	–	0	–
Post oak	3	3	45 0	0	–	–	–	–	–	2	1 5
Black oak	15	15	38 7	1	0 0	10 0	0 0	60 0	15 0	7	1 3
Sassafras	2	2	37 5	0	–	–	–	–	–	1	1 0
Elm	14	14	33 6	0	–	–	–	–	–	3	1 0

These comparisons are qualified by the fact that different forest types were sampled, yet similar sampling designs and the same observation methods were used for measurements of percentage dieback, percentage transparency, percentage discoloration, and crown and bole damage. Brooks et al. (1991a, 1991b) noted an apparently high percentage of dieback in American beech and tentatively attributed it to the beech-bark disease complex. They also reported that this species had the highest percentage of trees with crown and bole damage. These results are consistent with the data in Table 5-1; American beech had the highest average percentage dieback of any species (10 6%) and a very high percentage of trees with crown and bole damage.

In terms of transparency, Brooks et al (1991a, 1991b) report the possibility of unusual values for yellow birch, American beech, and northern red oak. The average transparency values reported for these species in Table 5-1 are unremarkable in comparison, and the high value for northern red oak must be tempered by the rather small sample size. Brooks et al (1991a, 1991b) report no indications of health concerns based on discoloration, a result that is consistent with the low average values of discoloration obtained here. Full interpretation is difficult without a reference by which to gauge changes over time.

Table 5-3 NUMBER OF SAMPLE TREES AND AVERAGE CROWN RATINGS FOR ALL SPECIES BY PLOT

Plot no.	Total trees (no.) (1)	Live trees (no.) (2)	Live crown (PLC) (%) (3)	Crown rated trees (no.) (4)	Dieback (PDB) (%) (5)	Trans-parency (PTRN) (%) (6)	Discolor-ation (PDIS) (%) (7)	Crown density (PDEN) (%) (8)	Defoliation (PDEFOL) (%) (9)	Trees with symptoms (no.) (10)	Avg no of symptoms (CBD) (no.) (11)
New England											
16	48	44	20 1	15	5 0	12 7	1 7	37 7	27 7	11	1 2
117	36	36	25 7	11	5 0	8 6	2 7	51 4	31 8	10	1 1
122	93	88	19 6	19	7 9	11 8	1 6	53 7	32 4	25	1 1
155	48	40	27 4	16	12 8	11 3	2.2	42 2	38 8	24	1 1
159	70	67	21 7	15	6 3	11 7	1.7	49 7	33 0	23	1 0
160	69	60	17 8	11	5 0	10 5	0 5	46 8	35.0	18	1 1
166	56	52	21 7	8	10 0	11 9	0 0	41 3	33 8	25	1 1
173	75	69	23 0	10	7 0	12 0	4.0	37 5	36 5	18	1 2
174	54	53	21 1	7	5 0	11 4	0 7	53 6	32 9	14	1 2
181	50	48	26 2	16	9 4	11 6	1.9	39 7	28 1	24	1 1
267	64	58	19 0	24	6 3	11 9	1 5	47.1	42 7	28	1 1
270	67	61	23 9	10	4 5	19 0	2 5	42 0	42 5	10	1 0
289	73	73	19 9	27	5 4	13 0	0 0	33.5	33 7	11	1 0
321	58	51	26 4	13	10 4	10 8	2 3	53 5	39 6	27	1 3
347	73	61	17 8	16	9 4	12 5	1 6	46 9	35 0	30	1 1
420	50	48	20 8	15	5 7	10 3	0 3	50 3	29 3	15	1 0
508	84	78	24 1	30	6 7	14 0	0 7	52 0	30 3	32	1 1
692	63	60	18 7	8	12 5	11 3	0 0	46 9	36 9	8	1 0
3270	83	82	17 3	20	6 3	11 3	0 0	38 5	29 3	13	1 1
Virginia											
1839	64	64	25 8	6	0 0	16 7	0 0	69 2	15 0	36	1 1
1841	81	81	36 7	12	0 0	19 6	0 0	42 9	27 1	4	1 3
1843	80	77	37 3	8	0 0	16 9	0 0	46 3	25 0	13	1 0
1954	70	70	26 1	11	0 0	17 3	0 0	73 6	15 9	30	1 3
1955	38	38	28 2	3	0 0	13 3	0 0	68 3	11 7	17	1 3
1957	52	52	33 3	6	5 0	25 0	0 0	69 2	17 5	34	1 4
1958	28	28	32 0	6	1 7	28 3	0 0	40 8	25 8	18	1 4
1959	78	78	31 1	11	0 0	24 1	0 0	69 1	21 8	30	1 2
2072	85	85	30 1	10	0 0	19 5	0 0	75 0	14 5	32	1 3
2074	85	85	32 9	13	0 0	29 6	0 0	48 1	27.7	8	1 0
2075	54	54	23 7	11	0 0	20 0	0 0	68 6	19 6	33	1 4
2185	71	71	20 7	13	0 0	20 8	0 0	74 6	16 2	27	1 4
2186	81	79	31 7	13	0 0	11 9	0 0	48 5	21 9	3	1 0
2187	94	94	33 0	12	0 0	16 3	0 0	48 8	23 3	14	1 0
2188	72	72	28 9	8	0 0	18 8	0 0	53 8	16 9	34	1 4
2189	84	84	35 0	11	0 0	20 5	0 0	50 0	25 0	7	1 0
2190	65	65	35.3	5	0 0	22 0	0 0	49 0	24 0	6	1 0
2191	93	90	33 6	8	0 0	18 1	0 0	48 8	27 5	13	1 1
2192	105	105	33.7	19	0.3	17 6	0 0	46 8	23 7	8	1 0
2303	51	51	38.3	8	0 0	17 5	0 0	45 0	23 8	5	1 2

5.4 ANOVA OF VISUAL SYMPTOMS MEASUREMENTS

The components of sampling variation were estimated for the percentages of live crown, dieback, transparency, discoloration, crown density, and defoliation. They were not estimated for crown and bole damages because that variable is based on counts and was not amenable to the analyses of variance (ANOVA) models employed for the other variables. The ANOVA models utilized were two- and a three-stage nested, completely random designs. The two-stage model included the effects of plots and trees within plot. The three-stage model had the effects of plots, subplots within plot, and trees within subplot.

Each region was analyzed separately. In one analysis, both the two- and three-stage models were applied to all species combined In another analysis, subsets of well-represented species groups (loblolly pine in Virginia, and maple plus beech plus birch species in New England) were selected and analyzed with the three-stage model only. Although it may be inappropriate to combine species, the other species were not sampled intensively enough to warrant this separate analysis.

An exception was for the percent of live crown, for which there was a sufficient sample size to warrant a separate three-stage analysis of other species groups (all oak species and all non-oak deciduous species in Virginia, and spruce plus fir species and all deciduous species other than maple, beech, or birch in New England). Sample sizes were not uniform for these analyses and therefore average sample sizes need to be applied in developing *sampling recommendations* The *results* are discussed together with the results from other measurements in Section 3.

The results may also be compared to those obtained by Innes and Boswell (1990) for a measurement ("crown density") that is defined similarly to the variable PDEFOL in this study. Table 1 in Innes and Boswell (1990) contains estimates of within- and between-stand variance components for five species based on data from the British long-term monitoring program on forest conditions (Innes and Boswell, 1987). The species are Sitka spruce, Norway spruce, Scots pine, oak species (i.e., sessile oak, English oak, and hybrids between the two), and European beech. About half (range 48 to 65%) of the total variance is attributable to tree-to-tree variation within stands, and there are important (*F-statistics between 6 and 17*) *stand-to-stand* differences in average "crown density."

In comparison, the three-stage ANOVA's of the variable PDEFOL (Table 5-4) yield estimates of the percentages of variance attributable to tree-to-tree variation within stands of about 62% for loblolly pine only, 85% for the three species group maple + beech + birch, 89% for all New England species, and 82% for all Virginia species (these results are not shown) The loblolly pine result is within the range reported by Innes and Boswell (1990), the other results are probably inflated simply because more than one species is included. The *F*-statistics (not shown) for the null hypothesis of no stand-to-stand variation in average PDEFOL range from about 2 for all New England species to about 14 for loblolly pine only Again the loblolly pine result is consistent with the British study; results for other species groups are probably again *affected* by including more than one species.

Innes and Boswell (1990) also reported the percentages of variance attributable to *different* "edges" within stands; these "edges" are (roughly) equivalent to the "subplots" in the present study. Although "edge" differences were significant, the percentages of the total variance were comparatively small (range 4 to 14%). In comparison, the percentage of total variance attributable to subplots in the present study ranged from 0 (for loblolly pine only and for maple plus beech plus birch species) to about 4% (for all Virginia species combined) Both of these lines of evidence suggest that subplot-to-subplot variance is relatively unimportant for PDEFOL.

Table 5-4 ANOVA OF VISUAL SYMPTOMS VARIABLES FOR TWO SAMPLING MODELS

Variable	Forest region	Model	Species group	Degrees of freedom: Plot	Subplot	Tree	Mean square for: Plot	Subplot	Tree
PLC	New England	B	All	18	–	1110	544 614	–	88 479
		A	All	18	57	1053	544 614	265 484	78 898
		A	Spruce + fir	12	20	50	495 338	157 560	37 444
		A	Maple + beech + birch	18	57	576	374 486	118 243	50 132
		A	Other hardwoods	18	27	108	204 376	46 354	38 181
	Virginia	B	All	19	–	1403	1442 239	–	176 138
		A	All	19	60	1343	1442 239	538 057	159 968
		A	Loblolly pine	19	58	558	1377.049	182 960	68 572
		A	Oaks	13	26	130	305 313	192 574	89 824
		A	Other hardwoods	19	56	432	446 716	312 414	140 524
PDB	New England	B	All	18	–	272	86 384	–	27 548
		A	All	18	19	253	86.384	30 704	27 312
		A	Maple + beech + birch	18	18	159	91 816	32 038	33 303
	Virginia	B	All	19	–	174	8 292	–	4 925
		A	All	19	20	154	8 292	16 697	3 397
		A	Loblolly pine	19	17	120	0 879	1 987	0 609
PTRN	New England	B	All	18	–	272	49 373	–	28 046
		A	All	18	19	253	49 373	72 254	24 726
		A	Maple + beech + birch	18	18	159	18 538	16 307	12 917
	Virginia	B	All	19	–	174	186 102	–	64 878
		A	All	19	20	154	186 102	105 758	59 569
		A	Loblolly pine	19	17	120	176 534	43 063	50 109
PDIS	New England	B	All	18	–	272	16 122	–	6 349
		A	All	18	19	253	16 122	9 258	6 131
		A	Maple + beech + birch	18	18	159	16 524	7 236	7 687
	Virginia	B	All	19	–	174	0 000	–	0 000
		A	All	19	20	154	0 000	0 000	0 000
		A	Loblolly pine	19	17	120	0 000	0 000	0 000
PDEN	New England	B	All	18	–	272	683 954	–	107 167
		A	All	18	19	253	683 954	162 730	102 994
		A	Maple + beech + birch	18	18	159	483 698	78 125	73 604
	Virginia	B	All	19	–	174	1460 263	–	115 061
		A	All	19	20	154	1460 263	112 223	115 429
		A	Loblolly pine	19	17	120	1543 082	52 362	81 321
PDEFOL	New England	B	All	18	–	272	329 458	–	127 139
		A	All	18	19	253	329 458	153 493	125 160
		A	Maple + beech + birch	18	18	159	280 485	91 305	108 446
	Virginia	B	All	19	–	174	198 023	–	71 128
		A	All	19	20	253	198 023	83 598	69 508
		A	Loblolly pine	19	17	120	278 854	19 647	58 739

[a] The three-stage model (A) has effects of plots, subplots within plot, and trees within subplot, and the two-stage model (B) has effects of plots and trees within plot. The variables are percent live crown (PLC), percent dieback (PDB), percent transparency (PTRN), percent discoloration (PDIS), percent crown density (PDEN), and percent defoliation (PDEFOL). See text for explanations of variables and species groups.

5.5 ANOVA OF MENSURATION VARIABLES

The mensurational characteristics of the stands have been discussed in Section 2 of this document. This section presents the results of the ANOVAs of stand basal area (BA); average height of dominant, co-dominant, and open-grown trees only (HTDCD); and average height of all trees (HT). The basic data were the live trees larger than 7.62 cm dbh from the 0.0169-ha subplots, and the analysis was done on a per-subplot basis. Thus, the response variables are subplot BA, HTDCD, and HT. Sample sizes were balanced for these variables, with observations on four subplots within each plot. A two-stage, nested, completely random design with the effects of plots and subplots within plot were used in the ANOVA. Each region was analyzed separately (Table 5-5). The results are discussed in Section 3.

Table 5-5 ANOVA OF MENSURATION VARIABLES*

Forest region	Source	df	Mean square BA	HTDCD	HT
New England	Plot	18	220 8724	26 1784	10 4891
	Subplot	57	127.0360	5 9098	3 5483
	Total	75			
Virginia	Plot	19	259 8292	30 7659	12 8925
	Subplot	60	77 2651	8 0131	3 0950
	Total	79			

* Basal area (BA, m^2/ha), average height of dominant, co-dominant, and open-grown trees (HTDCD, m), and average height of all trees (HT, m) A completely random, nested design is assumed Response variables are on a per-subplot basis

5.6 DISCUSSION

Visual symptoms measurements should be made by trained professionals with strict adherence to quality assurance procedures. The suggestions of regional differences in associations among the visual symptoms measurements found in this study point to a need for greater emphasis on training, testing, and inter-regional comparative studies. It makes little difference that the visual measurements are relatively inexpensive and easy to justify if, in application, the numbers obtained are not comparable

Comparability also requires that the visual symptoms measures be gauged relative to an established baseline or normal condition. Although a reference can be established over time based on the accumulated data from monitoring, it may be worthwhile to conduct additional tests to judge the efficacy of these measures under different environmental conditions.

Ultimately, the visual symptoms measures must be augmented by observations of natural stresses, such as insects and diseases, that are known to cause changes in visual symptoms. Unless this is done, it will not be possible to ascribe any plausible causes to the observations of changing visual conditions. These additional observations must be made by trained pathologists at the right time of the growing season It will probably be worthwhile to include trained pathologists on the regional monitoring staff, perhaps even on every field crew, to ensure that these measurements are made appropriately.

6 SOIL PRODUCTIVITY

Rick D. Van Remortel and Mohammed J. Miah

This section describes preliminary results for the soil productivity measurements that were made during the 1990 pilot study in the eastern United States. Measurements of key soil physical and chemical parameters have been used to "optimize" the plot sampling design for variability, logistical, and cost-benefit considerations. The data are also being used in simulations to evaluate possible interactions of soil productivity with other measurements of forest condition, and to estimate soil productivity baseline condition.

6.1 BACKGROUND AND OVERVIEW

Soil productivity is generally defined as the capacity of a given volume of soil to produce a vegetative response under a specified system of management (SEA-AR, 1981). Productive capacity is affected by many physical and chemical factors. Topographic features such as slope, aspect, and elevation have been incorporated into models to predict stand composition (Fralish, 1988) and have been shown to influence growth responses of Douglas-fir (Steinbrenner, 1963). It is expected that these parameters could affect forest growth responses because they contribute to the overall hydrologic characteristics of a site.

The soil drainage classification, along with other moisture characteristics, has long been recognized as vital information in estimating soil productivity (Storie and Weislander, 1948; Mader, 1976; Hamilton and Krause, 1985; Green et. al., 1989). Topographic parameters are important in estimating the hydrologic contributions of runoff and lateral water flow (Hewlett, 1961), as well as such characteristics as soil texture, rock fragments, and bulk density. These parameters are also important for their effects on nutrient availability (Mader, 1976), aeration (Steinbrenner, 1963, Mader, 1976), and root distribution (Blanchar et al., 1978; Hillel, 1980), all of which directly affect vegetative response.

Various chemical parameters of soil sample analyses are expected to be useful for monitoring the soil nutrient status at each plot. Many of the analyses are routinely performed as part of standard soil testing programs because of their importance for plant nutrition and nutrient cycling. Parameters such as exchangeable cations, cation exchange capacity, pH, and exchangeable acidity have all been incorporated into response studies for species such as jack pine (Pawluk and Arneman, 1961; Hamilton and Krause, 1985) and Douglas-fir (Green et al., 1989) Total carbon, nitrogen, and sulfur have been used to characterize the soil organic matter, which is a key component of the forest ecosystem (Wilde, 1964; Mader, 1976).

Iron, manganese, magnesium, copper, zinc, and boron are all essential elements to tree growth, and metals such as lead, cadmium, nickel, chromium, and vanadium are measured to evaluate toxic stresses Extractable sulfate can be an important constituent of the soil solution and, together with electrical conductivity, can be used to estimate ionic strength of the solution (Griffen and Jurinak, 1973). Ionic strength is used to calculate the activity of ions in solution, thereby allowing study of chemical equilibria in soil samples and modeling of long-term chemical weathering of soil minerals (Lindsay, 1979)

Based on previous variability studies, it was recognized that significant soil spatial variability can be present on virtually all micro- and macro-areal scales (Armson, 1977, Mausbach et al., 1980) It is possible, however, for uncertainty in the soil productivity values at a plot to be greatly reduced, by the use of a "composite" sample design that captures a significant amount of the within-plot variability in soil characteristics. It is anticipated that an optimal sampling design can be adopted whereby the samples that are collected control the within-plot uncertainty to a level that is negligible with respect to other sources of uncertainty, for example, from the measurement system or from the regional data aggregation framework. The resulting level of data quality would allow the data users to focus on discerning "real" temporal changes in soil productivity within a highly variable population of forest plots

6.2 STUDY OBJECTIVES

The overall goals of the soil productivity study were to estimate the within-plot spatial variability in soil characteristics and to test the overall feasibility of implementing the soil productivity sampling design on a multiregional scale. Using the results of this study, it is likely that an optimal sampling design can ultimately be identified that allows the "control" of within-plot data uncertainty to some level that is acceptable to users of FHM data Towards this end, the data analysis will eventually include an evaluation of uncertainty stemming from single-hole sampling as opposed to multiple-hole sampling, and the appropriateness (e.g., cost/benefit, utility, etc.) of compositing master horizon samples for laboratory analysis purposes. In addition, optimization algorithms have been applied to the data to evaluate whether the provision of destructive sampling zones outside the perimeters of the fixed-radius subplots will allow the collection of soil samples that are representative with respect to the subplot vegetative measurements.

Specifically, the soil sampling issues to be resolved as a result of the study include the determination of the number of soil holes within a plot that should be sampled, and the resources (e.g., time, personnel, funding, equipment, etc) required to perform field characterization and sampling on a given plot within a region In addition, we will later use these and other data to determine: (1) the depth of sampling and the types of horizons that should be sampled, (2) whether samples will be composited and at what stage; (3) the utility of laboratory preparation and analytical methods that have been selected; (4) parameter reporting units for the many different soil parameters; (5) ancillary data that may be needed to link the component parameters of the soil productivity indicator; and (6) the utility of various soil sample aggregation schemes in the stratification of data for interpretive reporting.

6.3 MATERIALS AND METHODS

6.3.1 Field Methods

Soil classification data for the selected study plots were obtained by on-site soil excavation and characterization augmented by existing soil survey information where available. Each plot was thoroughly characterized for physical soil parameters and landform features according to accepted National Cooperative Soil Survey standards. The 20 plots in each region were sampled in the manner intended for full implementation of the monitoring design in subsequent years. Eight of these same 20 test plots in each region were designated as variability plots in order to assess plot variability issues. The required staffing was one soil scientist per day per "routine plot" and two soil scientists per day per "variability plot".

The soil sampling plot design was as shown in Figure 1-3. The three soil holes were located equidistant between the subplot centers. Excavation of soil holes for characterization of the soil horizons and collection of soil samples for laboratory analysis is considered destructive sampling with respect to long-term ecological monitoring on forest plots. Therefore, soil sampling was done outside of the established fixed-area subplots but was intended to represent the soil characteristics across the whole plot area.

The field soil scientist was instructed to collect, where possible, composite samples for the O, A, E, B, and C master horizons from each of the 20 field plots in the 2 regions. The composite samples were combined using equal volumes of soil material from the three holes Each of the holes was excavated to a 1 m vertical depth (or to a restrictive layer, whichever was shallower) and a long-axis horizontal diameter of approximately 0.5 m A detailed profile description of the soil horizons on the plot was made for the most representative ("modal") hole.

In order to estimate within-plot variability of soil parameters, individual master horizon samples were collected from the eight variability plots in each of the two regions. On these plots, three additional holes encircling each of the three perimeter fixed-radius subplots were excavated to expose the A horizon (Fig 1-3). At each of these nine points, individual soil samples were collected from the A horizon, where possible, or from an E or B horizon if the A horizon was not present or could not be clearly delineated. The sampling strategy assumed that the estimates of variability about the three perimeter subplots would be comparable to the variability about the center subplot.

The field measurement and sampling methodology is documented in a field methods manual (Dwire et al., 1990). The soil samples were prepared and analyzed according to procedures described in a laboratory methods manual (Byers and Van Remortel, 1991). The field and laboratory parameters that were measured are listed in Table 6-1.

6.3.2 Statistical Methods

To meet the study objectives, two statistical techniques were applied to the verified and validated soils database:

1. a sampling theory algorithm to optimize resource allocations within plots (see Section 3.2),
2. semivariograms to study spatial structure (see Section 3.4.3).

To assess data quality and sources of measurement variation, statistical techniques described by Byers et al. (1989) and Byers et al. (1990) were used to explore the precision of measurements. A two-tiered system was used for characterizing measurement quality objectives (MQOs) and results. The MQO for the first tier (at low concentrations) is a constant value of the standard deviation. The MQO of the second tier (at higher concentrations) is a constant value of the relative standard deviation and thus varies as a linear function of the mean. A "knot" value is the concentration at which the MQOs for the two tiers coincide

Data quality was assessed by calculating the percent of samples that had either standard deviations or relative standard deviations, as appropriate for the mean concentration, above the MQO. The relative importance of analytical laboratory, preparation laboratory, and measurement system as sources of measurement variation was gauged by recalculating the data quality statistics for each of those sources. For comparison, the standard deviations and bias were calculated for the pooled field samples

6.4 RESULTS AND DISCUSSION

6.4.1 Optimum Allocation of Resources

This technique utilized a cost-benefit algorithm to analyze variance components. Summary results of the analysis for 20 of the 22 primary soil physical and chemical parameters, configured in eight parameter groups, are contained in Table 6-1. For all groups, it was found that the variance among pits within clusters was the same as the variance among pits among clusters. This indicates that the present sampling design with individual pits as the subsampling unit provides the better allocation of resources.

6.4.2 Semivariograms

This technique examined the spatial correlations within plots to determine whether the systematic design for soil pits provided sufficient separation between pits so that the soil for a single master horizon could be treated as coming from independent units. The calculations are discussed in Section 3.4. A distance value of zero was used as a reference value for examination of the semivariograms. This value was derived from QA data from the Direct/Delayed Response Project which used similar sampling protocols and a probability sample for selecting soil pedons (Byers et al , 1989, Byers et al , 1990). As a result, this value was uniformly lower than the estimates for the other distances.

None of the semivariograms gave evidence that the shorter distances had higher spatial correlation In fact, some of the semivariogram charts appeared to have an "up and down" behavior because of the low value at zero distance and chance fluctuations downward at higher distances The semivariograms suggest that the current distance between soil pits is sufficiently large to avoid undesirable correlations between measurements. There was no data on shorter distances, so it cannot be determined whether soil pits could be located even closer together should that become necessary.

6.4.3 Other Sources of Variation

An estimate of measurement uncertainty that is achievable for each soil analytical parameter may be derived from existing data (e.g., Van Remortel et al , 1988; Byers et al., 1989, Byers et al , 1990). For most of the analytical laboratory measurements, an average coefficient of variation (CV) of 10% or less is typical for replicate samples. The expected laboratory bias is ± 5% or less of the reference value. For the sample measurement system as a whole (sampling, preparation, and analysis), an average CV of 20% or less is typical.

In most cases, QA data from this study support these estimates (see Table 6-2). The precision and accuracy measurement quality objectives (MQOs) specified in the study plan were satisfied for most parameters. However, relatively few degrees of freedom for the measurement quality samples used in this study may restrict the reliability of the imprecision and bias estimates.

Although an assessment of seasonal variability was not an objective of the study, this source of heterogeneity may be significant for some soil parameters. It may be possible to control (to some degree) seasonal variation at each plot by conducting the cyclical sampling of each plot during a specified interval of the index period.

6.5 RECOMMENDATIONS

An issue for ongoing investigation is how to best minimize sources of variability so that "real" changes in soil productivity can be detected at regional levels. The evaluation techniques described in this Section have provided statistical estimates of the optimum number of samples that must be collected from a plot to control the overall variability of the mean of the measurements, as part of a multistage FHM sampling design. To address different scenarios relating to the intensity of sampling that is required to accomplish the FHM regional monitoring objectives, detailed assessments have been made of within-plot variability by statistically varying the number of soil samples collected from each variability plot. The data users ultimately must choose reasonable levels of uncertainty that can be tolerated and still allow the overall project objectives to be satisfied. Preliminary drafts of these data quality objectives will be developed following the 1991 field season.

Another issue that must continue to be addressed is the selection of soil physical and chemical parameters that should be measured in order to provide a sufficiently high resolution snapshot of soil productivity status. The soil productivity parameters defined in the laboratory methods manual (Byers and Van Remortel, 1991) are presently being measured to assess their utility for productivity associations with other indicators. These parameters have been identified through interactions with more than 60 forest soil scientists in the United States and Canada. Additional parameters, inappropriate parameters, or alternate methods might be identified as a result of information gained during these ongoing assessments As part of the sampling design, archived soil will be available for additional future analysis if it is deemed necessary.

Table 6-1 FIELD PLOT SOIL VARIANCE COMPONENTS BY REGION*

Parameter group	Parameter	Plot			Subplot			Hole		
		MS	V	%	MS	V	%	MS	V	%
Particle size	$SAND_{NE}$	442 0	47 8	45	60 5	0 5	1	59.0	59 0	54
	$SAND_{VA}$	4116 6	461 5	78	198 3	39 0	7	88 2	88 2	15
	$SILT_{NE}$	404 2	45 4	50	42 3	< 0	0	46 1	46 1	50
	$SILT_{VA}$	2958 7	317 2	77	165 4	39 4	10	54 3	54 3	13
	$CLAY_{NE}$	17 88	1 37	17	6 94	0 16	2	6 51	6 51	81
	$CLAY_{VA}$	132 58	14 28	49	11 42	< 0	0	15 04	15 04	51
Soil pH	PH_H2O_{NE}	2 330	0 265	59	0 242	0 037	16	0 149	0 149	25
	PH_H2O_{VA}	1.440	0 134	42	0 313	0.073	23	0 109	0 109	35
	PH_01M_{NE}	2 500	0 287	59	0 241	0 027	6	0 171	0 171	35
	PH_01M_{VA}	1 141	0.104	38	0 269	0.057	21	0 110	0 110	41
Exchangeable cations	CA_OAC_{NE}	84 08	9 03	46	12 82	1.31	7	9 48	9 48	47
	CA_OAC_{VA}	10 90	0 94	20	3 10	< 0	0	3.82	3 82	80
	MG_OAC_{NE}	0 586	0.059	40	0 118	0 019	13	0 068	0 068	47
	MG_OAC_{VA}	0 238	0 026	38	0 026	< 0	0	0 042	0 042	62
	K_OAC_{NE}	0 0702	0 0080	57	0 0073	0 0008	7	0 0053	0 0053	36
	K_OAC_{VA}	0 0167	0 0017	28	0 0022	< 0	0	0 0051	0 0051	72
	NA_OAC_{NE}	0 0018	0 0002	49	0 0002	0 0000	10	0 0002	0 0002	41
	NA_OAC_{VA}	0 0014	0 0001	30	0 0003	0 0000	5	0 0003	0 0003	65
Exchange capacity and acidities	CEC_OAC_{NE}	475 5	55 3	40	44 1	< 0	0	82 7	82 7	60
	CEC_OAC_{VA}	127 9	12 3	41	24 9	4.3	14	13 1	13 1	45
	AC_BACL_{NE}	510 4	58 1	47	54 9	< 0	0	65 5	65 5	53
	AC_BACL_{VA}	243 2	22 4	45	54 9	15 4	31	12 2	12 2	24
	AC_KCL_{NE}	21 34	1 88	30	6 34	1 19	18	3 30	3 30	52
	AC_KCL_{VA}	14 98	1 33	35	4 00	0 92	25	1 49	1 49	40
	AL_KCL_{NE}	24 51	2 36	40	5 69	1 36	23	2 21	2 21	37
	AL_KCL_{VA}	17 64	1 72	45	3 27	0 64	17	1.50	1 50	38
Mineralizable nitrogen	N_MIN_{NE}	9452	1119	66	647 9	42 6	2	538 8	538 8	32
	N_MIN_{VA}	207 6	24 2	87	5 26	0 91	3	2 74	2 74	10
Extractable phosphorus	P_B1_{NE}	399 7	30 5	9	169 5	< 0	0	299 6	299 6	91
	P_B1_{VA}	96 61	6 23	10	44 75	< 0	0	56 37	56 37	90
Extractable sulfate	$SO4_H2O_{NE}$	105 33	9 75	31	28 86	4 86	16	16 69	16 69	53
	$SO4_H2O_{VA}$	80 22	7 54	33	17.10	1 00	4	14 32	14 32	63
	$SO4_PO4_{NE}$	19867	2341	53	1803	< 0	0	2070	2070	47
	$SO4_PO4_{VA}$	134 46	7 07	12	74 71	13 25	23	37 95	37 95	65
Total elements	C_TOT_{NE}	85 81	10 19	63	5.74	< 0	0	5 93	5 93	37
	C_TOT_{VA}	8 48	0 73	28	2.36	0 29	11	1 57	1 57	61
	N_TOT_{NE}	0 306	0 037	66	0 018	< 0	0	0 019	0 019	34
	N_TOT_{VA}	0 0153	0 0015	31	0 0031	< 0	0	0 0033	0 0033	69
	S_TOT_{NE}	0 0029	0 0003	63	0 0002	< 0	0	0 0002	0 0002	37
	S_TOT_{VA}	0 0003	0 00003	29	0 0001	< 0	0	0 0001	0 00001	71

* MS = mean square, V = variance component, % = percent of total variance The approximate degrees of freedom (per region) are 7 for plots, 16 for subplots within plots, and 41 for holes within subplots See Table 3-5 for brief descriptions, and Dwire et al (1990) for complete descriptions of the parameters The subscripts NE and VA on parameters refer to New England and Virginia

Table 6-2 SOIL PARAMETER IMPRECISION AND BIAS POOLED ACROSS REGIONS*

		Below the knot				Above the knot				
Sample	Parameter	df	SD	MQO	>MQO %	df	%RSD	MQO	>MQO %	Bias
Parameter group Particle size (wt %)										
ALMR	MOIST	7	0 5689	0 3	28 6	–	–	–	–	–
	CLAY	5	0 3821	2	0 0	–	–	–	–	–
	SAND	6	1 1972	3	0 0	–	–	–	–	–
	SILT	6	0 9794	3	0 0	–	–	–	–	–
PLHD	MOIST	7	0 1570	0 45	0 0	–	–	–	–	–
	CLAY	5	2 3814	3	16 7	–	–	–	–	–
	SAND	5	2 8745	4 5	16 7	–	–	–	–	–
	SILT	5	3 7005	4 5	16 7	–	–	–	–	–
MSFD	MOIST	7	0 0622	0 6	0 0	–	–	–	–	–
	CLAY	5	0 5235	4	0 0	–	–	–	–	–
	SAND	5	0 7772	6	0 0	–	–	–	–	–
	SILT	5	1 1450	6	0 0	–	–	–	–	–
PLOT	MOIST	114	1 1701	–	–	–	–	–	–	no est
	CLAY	91	3 2456	–	–	–	–	–	–	1 334
	SAND	91	9 4951	–	–	–	–	–	–	-2 400
	SILT	91	8 1074	–	–	–	–	–	–	0 903
Parameter group Soil pH (pH units)										
ALMR	PH_H2O	7	0 0205	0 1	0 0	–	–	–	–	–
	PH_01M	7	0 0154	0 1	0 0	–	–	–	–	–
	EC_H2O	7	0 0256	1	0 0	–	–	–	–	–
PLHD	PH_H2O	7	0 0428	0 15	0 0	–	–	–	–	–
	PH_01M	7	0 1505	0 15	14 3	–	–	–	–	–
	EC_H2O	7	0 0038	1 5	0 0	–	–	–	–	–
MSFD	PH_H2O	7	0 0357	0 2	0 0	–	–	–	–	–
	PH_01M	7	0 0212	0 2	0 0	–	–	–	–	–
	EC_H2O	7	0 0100	2	0 0	–	–	–	–	–
PLOT	PH_H2O	114	0 4122	–	–	–	–	–	–	-0 023
	PH_01M	114	0 4139	–	–	–	–	–	–	0 013
	EC_H2O	114	0 0365	–	–	–	–	–	–	no est
Parameter group Exchangeable cations (meq/100 g)										
ALMR	CA_OAC	7	0 0063	0 02	0 0	–	–	–	–	–
	MG_OAC	7	0 0034	0 02	0 0	–	–	–	–	–
	K_OAC	7	0 0048	0 02	0 0	–	–	–	–	–
	NA_OAC	7	0 0031	0 02	0 0	–	–	–	–	–
PLHD	CA_OAC	4	0 0275	0 03	25 0	3	21 5	15	66 7	–
	MG_OAC	6	0 0474	0 03	16 7	1	1 1	15	0 0	–
	K_OAC	7	0 0093	0.03	0 0	–	–	–	–	–
	NA_OAC	7	0 0054	0 03	0 0	–	–	–	–	–
MSFD	CA_OAC	4	0 0047	0 04	0 0	3	23 4	20	33 3	–
	MG_OAC	6	0 0466	0 04	16 7	1	0 1	20	0 0	–
	K_OAC	7	0 0107	0 04	0 0	–	–	–	–	–
	NA_OAC	7	0 0060	0 04	0 0	–	–	–	–	–
PLOT	CA_OAC	21	0 0849	–	–	93	125 3	–	–	-0 015
	MG_OAC	59	0 0852	–	–	55	70 5	–	–	-0 003
	K_OAC	99	0 0615	–	–	15	38 7	–	–	-0 015
	NA_OAC	114	0 0174	–	–	–	–	–	–	0 000

Table 6-2 (CONTINUED)

		Below the knot				Above the knot				
Sample	Parameter	df	SD	MQO	>MQO %	df	%RSD	MQO	>MQO %	Bias
Parameter group Exchange capacity and acidities (meq/100 g)										
ALMR	CEC_OAC	–	–	–	–	7	33 2	10	42.9	–
	AC_BACL	–	–	–	–	7	3 0	10	0 0	–
	AC_KCL	7	0 2470	0 5	14 3	–	–	–	–	–
	AL_KCL	4	0 1328	0 5	0 0	3	7 3	15	0 0	–
PLHD	CEC_OAC	1	0.2348	0 37	0 0	6	77.8	15	33 3	–
	AC_BACL	4	0 4533	1 5	0 0	3	2 6	15	0 0	–
	AC_KCL	6	0 1408	0 75	0 0	1	3.9	15	0 0	–
	AL_KCL	5	0 0982	0 75	0 0	2	6 8	22	0 0	–
MSFD	CEC_OAC	1	0 0983	0 5	0 0	6	19 7	20	16 7	–
	AC_BACL	4	0 4749	2	0 0	3	1 5	20	0.0	–
	AC_KCL	6	0 2779	1	0 0	1	1 7	20	0 0	–
	AL_KCL	5	0 1104	1	0 0	2	9.7	30	0 0	–
PLOT	CEC_OAC	–	–	–	–	114	40 1	–	–	1 847
	AC_BACL	7	2 5601	–	–	107	34 2	–	–	-0 401
	AC_KCL	85	1 6658	–	–	29	95 1	–	–	no est
	AL_KCL	84	1 1770	–	–	30	52 1	–	–	no est
Parameter group Mineralizable nitrogen (meq/100 g)										
ALMR	N_MIN	6	0 0757	1	0 0	1	0 6	15	0 0	–
PLHD	N_MIN	7	0 5964	1 5	14 3	–	–	–	–	–
MSFD	N_MIN	7	0 2018	2	0 0	–	–	–	–	–
PLOT	N_MIN	100	0 4517	–	–	14	83 7	–	–	no est
Parameter group Extractable phosphorus (mg/kg)										
ALMR	P_BI	–	–	–	–	7	5 4	15	0 0	–
PLHD	P_BI	3	0 2458	0 75	0 0	4	5 8	22	0 0	–
MSFD	P_BI	3	0 2777	1	0 0	4	14 1	30	0 0	–
PLOT	P_BI	43	1 2384	–	–	71	190 1	–	–	no est
Parameter group Extractable sulfate (mg S/kg)										
ALMR	SO4_H2O	7	0 3906	1 5	0 0	–	–	–	–	–
	SO4_PO4	7	1 0487	1 5	28 6	–	–	–	–	–
PLHD	SO4_H2O	5	1 4455	2 2	20 0	2	5 2	15	0 0	–
	SO4_PO4	2	0 4046	2 2	0 0	5	5 6	15	0 0	–
MSFD	SO4_H2O	5	1 4215	3	0 0	2	4 8	20	0 0	–
	SO4_PO4	2	1 4685	3	0 0	5	5 3	20	0 0	–
PLOT	SO4_H2O	114	4 2186	–	–	–	–	–	–	1 697
	SO4_PO4	80	5 7260	–	–	34	90 6	–	–	-1 354

Table 6-2 (CONTINUED)

Sample	Parameter	Below the knot df	SD	MQO	>MQO %	Above the knot df	%RSD	MQO	>MQO %	Bias
Parameter group Total elements (wt %)										
ALMR	C_TOT	–	–	–	–	7	7 7	10	14.3	–
	N_TOT	7	0 0073	0 015	14.3	–	–	–	–	–
	S_TOT	7	0 0014	0 002	14 3	–	–	–	–	–
PLHD	C_TOT	4	0 0185	0 07	0 0	3	3 5	15	0 0	–
	N_TOT	6	0 0033	0 022	0 0	1	0 7	15	0.0	–
	S_TOT	6	0 0008	0 003	0 0	1	1 7	15	0 0	–
MSFD	C_TOT	4	0.0288	0 1	0 0	3	6 3	20	0 0	–
	N_TOT	6	0 0054	0 03	0.0	1	1 7	20	0 0	–
	S_TOT	6	0 0008	0 004	0 0	1	1 7	20	0.0	–
PLOT	C_TOT	–	–	–	–	114	47.2	–	–	-0 461
	N_TOT	49	0 0411	–	–	65	46 1	–	–	-0 024
	S_TOT	43	0 0051	–	–	71	44 2	–	–	-0 005

* See text for explanation of the "knot " ALMR refers to analytical laboratory, PLHD refers to preparation laboratory (confounded), MSFD refers to the total measurement system (confounded), PLOT refers to among-plot variability from pooled samples SD = standard deviation, %RSD = standard deviation divided by the mean, df = degrees of freedom, MQO is the measurement quality objective for SD or %RSD, >MQO is the percent of samples with SD or %RSD greater than the MQO

7 FOLIAR NUTRIENTS AND CHEMICAL CONTAMINANTS

Timothy E. Lewis

7.1 INTRODUCTION

This set of measurements has been termed "foliar nutrients and chemical contaminants," but will henceforth be referred to as "foliar chemistry." Foliar chemistry is an example of an exposure-habitat indicator. This class of indicator is designed to quantify stressors which may be associated with changes in forest condition (e.g., visible injury, growth, soil productivity). The foliar chemistry indicator is also a key component in the suite of indicators that make up the nutrient cycling assessment endpoint.

The elements that were determined in foliar samples during the study include macro- and micro-nutrients (e.g., Total N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Mo, and Cl) and potential contaminants (Na, Al, F, Cd, Pb, As, V, Cr, Ni, Sr, and Hg). Some essential nutrients may also enter the system in excessive amounts from anthropogenic sources (Total N, Fe, Mn, Zn, Cu, B, and Cl). For example, chromium smelters emit Mn, Cr, Fe, Al, Ca, Mg, Na, Zn, K, Pb, Ba, Ti, Hg, Cd, Be, V, and As. These were measured in particulates emanating from the stacks at the Chromasco smelter in Memphis, TN (Bowers and Melhuish, 1987).

Nutrient deficiencies or excesses and metal toxicity can often be detected as visual symptoms on foliage (e.g., copper deficiency: Will, 1972, boron deficiency: Carter et al., 1983; arsenic toxicity: Spiers et al., 1983). When nutrient deficiencies are severe, visible symptoms such as leaf yellowing and scorching become apparent. Other symptoms may include stem deformities and loss of leaves. Some symptoms may relate to a specific nutrient limitation, but they may also be confused with similar symptoms of other stresses. Foliar (and soil) chemical analysis is needed to diagnose or to eliminate chemical imbalances as a plausible cause of symptoms (Skelly et al., 1987). Foliar nutrient chemistry may also correlate with visible injury caused by gaseous pollutants such as ozone, sulfur dioxide, oxides of nitrogen, and peroxyacetylnitrates.

The primary objectives stated in the foliar chemistry study plan (Dwire et al., 1990) were to determine the within tree and within plot components of variance for foliar nutrients and chemical contaminants. A secondary objective was to determine the effect of compositing on elemental concentration variance. This information could then be extrapolated to the regional demonstrations to deduce estimates of cost and variance associated with each component of sample acquisition and analysis. This section reports the findings of the foliar chemistry study as related to the stated objectives.

7.2 METHODS

Ten northern hardwood stands in New England and 10 pine-oak stands in eastern Virginia were sampled. Two species were selected: sugar maple in New England and loblolly pine in Virginia. Within each stand, two dominant or co-dominant trees were selected at each of three of the four subplots. To select trees, two random azimuths were found from a subplot center, and a transect was followed out to the radius of the subplot. The first suitable tree encountered while moving in a clockwise direction from the transect was designated as the sample tree.

With the aid of a tree climber, two branch samples were obtained from the outer portion (i.e., "sun leaves") of the upper third of the crown. The foliage was removed from the branch and placed in a plastic bag for shipment to the preparation laboratory. The intent was to keep each branch sample separate. But in New England, the two branches from each tree were combined in a single sample bag. Thus, no within-tree variability could be estimated for sugar maple. In Virginia, foliar material from each branch was kept separate as planned.

The foliar material was air dried, macerated, and homogenized before microwave digestion in a mixture of concentrated nitric and hydrochloric acid. The microwave digest was analyzed by directly coupled plasma spectrometry for macro- and micronutrients and trace elements (Table 7-1). Fluorine, chlorine, and total carbon, nitrogen, and sulfur were determined by the methods shown in Table 7-1.

Table 7-1. FOLIAR CHEMISTRY PARAMETERS AND ANALYTICAL TECHNIQUES

Parameter	Type of sample	Method
Phosphorus Calcium Magnesium Potassium Sodium Iron Manganese Copper Zinc Boron Aluminum Lead Chromium Nickel	Liquid extract of microwaved foliar tissue	Cassette 1 DCP
Molybdenum Cadmium Arsenic Vanadium Mercury	Liquid extract of microwaved foliar tissue	Cassette 2 DCP
Nitrogen Sulfur Carbon	foliar tissue	CNS Analyzer
Fluorine Chlorine	foliar tissue	potentiometric

7.3 STATISTICAL ANALYSIS

Summary statistics were generated by utilizing the Statistical Analysis System program (SAS, 1985) To estimate the components of variance, linear models for nested designs were used in the ANOVA. Three- and four-stage models were evaluated for the effects of plot, subplot within plot, tree within subplot, and branch within tree.

7.4 RESULTS

Data from seven plots in Virginia and six plots in New England were available for reporting. Results of chemical analyses of four additional plots are still outstanding. Certain plots were not analyzed due to missing samples or unbalanced design. One plot in New England (number 270) had four trees from one subplot sampled rather than two trees on three subplots. Notwithstanding, these data have been presented.

The mean and standard deviations of elemental concentrations determined in foliar material collected from sugar maples in New England are presented in Table A-3 in Appendix A. Similarly, summary statistics for elemental concentrations in loblolly pine foliar material collected in Virginia are shown in Table A-4 (Appendix A).

Variance components were computed using the SAS procedure VARCOMP (SAS, 1985). For the loblolly data, variance components were determined using three-stage and four-stage sampling models Only a three-stage model was used for the sugar maple data because branch samples were not kept separate during sampling. The variance component estimates for the sugar maple three-stage model were calculated using the following equations

Source	Expected Mean Square
Plot	Var(Error) + 2 3529 Var(Subplot) + 5.6471 Var(Plot)
Subplot	Var(Error) + 2 Var(Subplot)
Error	Var(Error)

The variance component estimates for the loblolly pine three-stage model were determined using the following equations.

Source	Expected Mean Square
Plot	Var(Error) + 2 Var(Tree) + 12 Var(Plot)
Tree	Var(Error) + 2 Var(Tree)
Error	Var(Error)

The variance component estimates for the loblolly four-stage model were calculated using the following equations.

Source	Expected Mean Square
Plot	Var(Error) + 2 Var(Tree) + 4 Var(Subplot) + 12 Var(Plot)
Subplot	Var(Error) + 2 Var(Tree) + 4 Var(Subplot)
Tree	Var(Error) + 2 Var(Tree)
Error	Var(Error)

The percent variance attributable to each stage of sampling was calculated by dividing each individual variance component by the total variance. The percent variances for the sugar maples and loblolly pines are presented in Tables 7-2 and 7-3, respectively.

The second objective of the study was to determine the effects of sample compositing on the observed variability in elemental concentrations. The results of elemental analyses of composited loblolly pine samples are summarized in Table A-4.

7.5 DISCUSSION

The levels of macro- and micronutrients in sugar maple are similar to levels found by Leaf (1973) The concentration for many of the trace elements (e.g., As, Cd, Cr, Hg, Ni, Pb, Sr, and Ti) were at or below the detection limit of the analytical laboratory (see Tables A-3 and A-4). Differences in elemental concentrations between the New England plots and Virginia plots may not be due regional differences, but rather may be species-specific.

For those elements that were close to their detection limit the var(error) (i.e., branch-to-branch for loblolly) variance component terms were the major contributor to the overall variance. Precision is inversely related to concentration. Thus, the analytical variability may be the major contributing factor to the overall variance for many of the trace elements. Another source of variance in the var(error) term may be poor and variable recovery of elements from the foliar sample. This variability was noted in the pine needle standard reference material (SRM) analysis performed with each batch of samples for copper and potassium.

For sulfur measurements of loblolly foliar tissue, the largest variability was noted at the branch-to-branch level (94%) (Table 7-3). No direct comparison is available for sugar maple, because branch samples were composited. The var(error) term in the sugar maple three-stage model, which represents tree-to-tree variability, was 36% for sulfur (Table 7-2), whereas the equivalent error term for loblolly (var[Tree]) was only 1%.

In general, the trees-within-subplot variability was less than the between-plot variability for most elements. However, when the branch-to-branch (or within-tree) variability was high, the between-plot variability became smaller. To reduce the between-plot variability, the number of trees sampled per subplot can be increased.

The results of individual vs. composite sample analysis revealed that elemental values are very similar. The ability to collect composite samples will greatly reduce the cost of analysis of foliar tissue collected from multiple branches.

Procedures for archiving foliar tissue samples should be investigated. These procedures were not tested in this study but, as is the case for soils, foliar sample archives will provide a unique opportunity for later retrospective analyses of long-term trends. Archiving foliar tissue samples may also reduce the laboratory analytical effort required as part of routine monitoring, because not all analyses would have to be performed on every sample.

Table 7-2 PERCENT OF TOTAL VARIANCE FROM SUGAR MAPLE VARIANCE COMPONENTS

	C	N	S	SI	HG	ZN	P	FE	CU	MN	MG	NA	CO	AL
Variance Component														
Var(Plot)	56	45	47	77	17	0	38	48	4	21	30	29	17	69
Var(Subplot)	0	43	17	6	7	18	0	0	0	14	20	8	0	0
Var(Error)	44	12	36	17	76	82	62	52	96	65	50	63	83	31
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

	NI	K	TI	CR	PB	CD	SR	AS	MO	LI	BA	B	CA	V
Var(Plot)	30	54	84	77	49	25	78	10	35	35	24	46	81	24
Var(Subplot)	0	0	5	3	0	0	5	0	0	2	0	19	2	23
Var(Error)	70	46	11	19	51	75	17	90	65	64	76	34	17	53
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 7-3 PERCENT OF TOTAL VARIANCE FROM LOBLOLLY PINE VARIANCE COMPONENTS

	C	N	S	SI	HG	ZN	P	FE	CU	MN	MG	NA	CO	AL
Variance Component														
Var(Plot)	56	25	5	26	0	16	81	39	54	73	10	20	30	54
Var(Subplot)	4	17	0	3	7	39	0	8	20	5	0	3	12	0
Var(Tree)	15	45	1	43	1	18	17	45	0	18	49	10	3	42
Var(Error)	25	13	94	28	92	27	2	9	26	4	41	67	56	4
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Var(Plot)	57	29	5	26	0	24	83	40	64	74	8	21	32	55
Var(Tree)	18	58	1	45	7	49	15	51	7	22	43	12	12	41
Var(Error)	25	13	94	28	93	27	2	9	29	4	49	67	56	4
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

	NI	K	TI	CR	PB	CD	SR	AS	MO	LI	BA	B	CA	V
Var(Plot)	35	49	45	56	50	28	66	0	15	48	1	21	54	4
Var(Subplot)	21	1	0	3	1	0	0	12	7	0	6	0	0	0
Var(Tree)	17	0	1	0	0	0	0	19	0	15	0	49	36	17
Var(Error)	26	50	54	41	50	72	34	70	78	37	93	30	10	79
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Var(Plot)	39	49	45	58	50	28	66	1	17	49	2	21	57	3
Var(Tree)	34	0	0	0	0	0	0	29	1	12	4	45	32	17
Var(Error)	26	51	55	42	50	72	34	71	82	39	94	34	11	80
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

8 VEGETATION STRUCTURE

Steven P. Cline, David Cassell,
and Alisa L. Gallant

8.1 INTRODUCTION

Maintenance of biotic integrity is an assessment endpoint. Biotic diversity, a key component of integrity, is at risk from six major types of threats: (1) direct population reduction from hunting and fishing, (2) physical alteration of habitats, (3) chemical and solid waste pollution, (4) global atmospheric change, (5) introduction of alien species, and (6) cumulative or multiplicative effects of interactions among these major threats (U.S. Environmental Protection Agency, 1990). Physical alteration of habitats is an immediate concern and may exacerbate the potential impacts of future atmospheric change. For example, habitat alteration or destruction was identified as the greatest threat to diversity of birds, perhaps the best studied vertebrate taxon (U.S. Environmental Protection Agency, 1990). Consequently, the structure of land use/land cover types and animal habitats are leading candidate response indicators, along with area, pattern, and geographic extent (Fig. 8-1).

The primary objective of this study was to compare two field methods for measuring the vegetation structure of forests: ocular and pole. We concentrated upon the structure of understory vegetation, which comprises most of the plant species diversity in forests, is more sensitive to environmental gradients, and has a faster reaction time/turnover than overstory trees. Analyses included methodological differences in foliage occupancy, measurement variation, spatial variation, and time requirements.

8.2 METHODS

8.2.1 Vegetation Structure Measurement Methods

8.2.1.1 Ocular method

The ocular estimation method has been used routinely during forest inventory by the USFS Southeast FIA Unit (Cost, 1979; U.S. Forest Service, 1985b). The foliage occupancy of understory vegetation was estimated on subplots 1 and 2 of 20 plots in New England and 20 plots in Virginia using the ocular method. The ocular measurement procedure involved four main steps: (1) define the main vertical strata in the understory and estimate their heights, (2) estimate the total percent of space occupied by foliage in each vertical stratum, (3) determine the relative contribution (percent) of each physiognomic vegetation class (Table 8-1) to the total foliage occupancy in each stratum, and (4) list the four most abundant species of each physiognomic class in each stratum. Foliage occupancy by shrubs, vines, grasses, forbs, and trees < 2.54 cm dbh was estimated in the field. Normally, foliage occupancy by trees > 2.54 cm dbh is estimated from species-specific regression equations and added to the ocular estimates to develop the full stand profile; however, this data was not available for analysis for this report. In addition, the ocular data from the New England plots were not available for analysis.

Table 8-1 PHYSIOGNOMIC CLASSES FOR VEGETATION STRUCTURE

Code	Physiognomic Class
1	Yellow Pines
2	Other Softwoods
3	Hardwoods
4	Tropicals
5	Shrubs
6	Vines
7	Grasses and grasslike
8	Forbs
9	Mosses and lichens

Table 8-2 GROUND COVER SUBSTRATES FOR POLE METHOD

Code	Substrate
1	Mineral soil
2	Rock
3	Standing water
4	Stream
5	Dead wood > 10 cm diameter
6	Litter/duff
7	Live root or bole

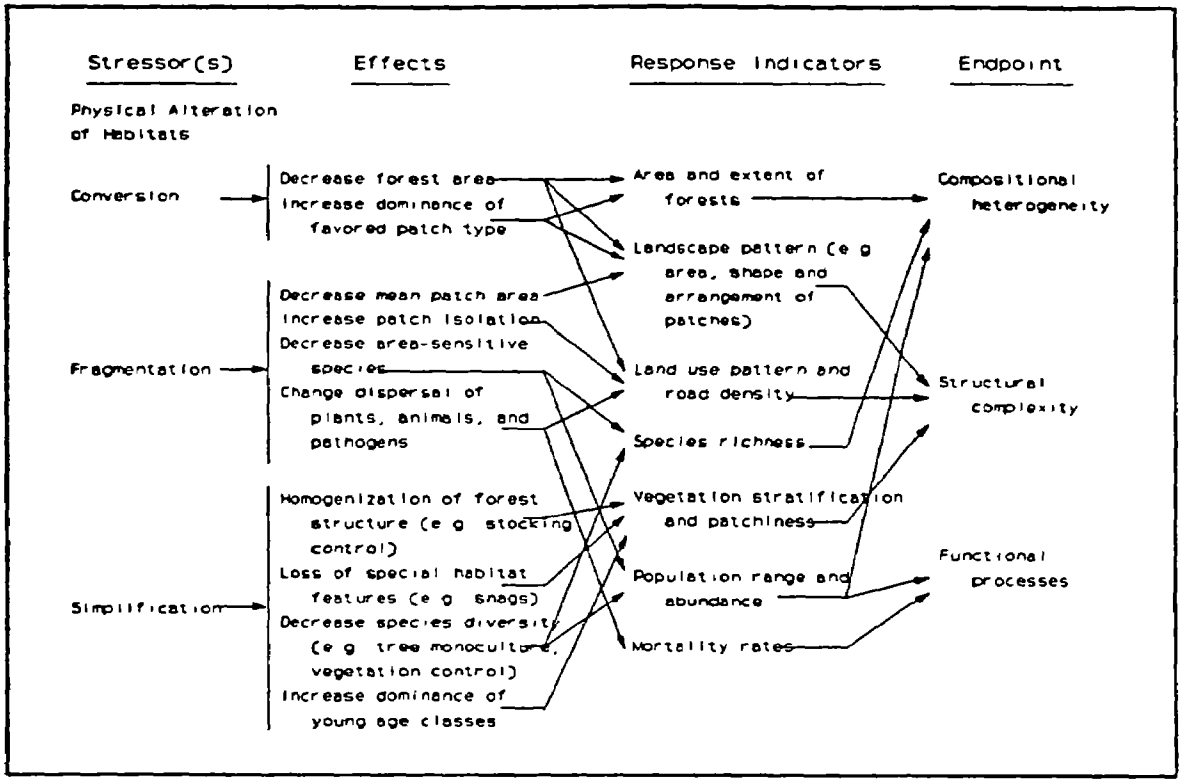

Figure 8-1. RELATIONSHIPS BETWEEN STRESSORS, RESPONSE INDICATORS, AND BIOTIC INTEGRITY ENDPOINT FOR THE VEGETATION STRUCTURE MEASUREMENTS

8.2.1.2 Pole method

The pole or vertical line intercept method was adapted from Short and Williamson (1986), who used a similar method to ground-truth the presence and position of wildlife habitat layers estimated from aerial photos. The presence and vertical distribution of foliage of understory vegetation was estimated on subplots 1 and 2 of 20 plots in New England and 20 plots in Virginia. Pole measurements were made at points spaced 12 ft (3.67 m) apart on a 16-point square grid centered on each subplot (Fig. 1-4). At each point a 30-ft (9.15 m), telescoping pole was raised and direct intersections ("hits") of living leaves and branches were recorded by physiognomic vegetation class (Table 8-1) and by height to the nearest foot (0.305 m). All sizes of vegetation were recorded, but hits originating from trees > 2.54 cm dbh were uniquely coded. The substrate upon which the pole rested was also recorded (Table 8-2). Hits of herbaceous vegetation, shrubs, or trees at the ground level were assigned to the first 1-ft interval.

8.2.1.3 Measurement variation

Reduction of measurement variation was emphasized, because it was one of the components of total variation subject to some control. Consequently, quality assurance (QA) procedures for the fieldwork called for within- and between-crew remeasurements to control and document the measurement variation associated with each of the vegetation structure methods. Even though a few between-crew remeasurements were made (four subplots [two each on two plots]), a field audit revealed that most of the within-crew remeasurements were not being made or were made incorrectly. For example, within-crew ocular remeasurements were not made in either Virginia or New England, and within-crew pole remeasurements in New England were compromised by a lack of independence between remeasurements. Consequently, for the pole method reliable remeasurement data collected during the training session were used to estimate measurement variation.

The data consisted of 126 pairs of original and remeasurements. Three types of remeasurements were made: within-crew (a crew remeasures itself, n=25), between-crew (field crews remeasure each other, n=25), and trainer-crew (trainer remeasures field crews, n=76). Training remeasurement data could not be used for the ocular method, because only a few remeasurements were recorded.

8.2.2 Statistical Analysis

8.2.2.1 Method comparisons

The data generated by each measurement method were paired by subplot and the differences in total foliage occupancy (%) were determined. The data were paired in two different ways for method comparisons. First, the pole and ocular data for each subplot were summarized and paired by the same vertical strata as defined by the ocular method. For the second way, the data were paired according to the 1-ft strata defined by the pole method. Student's t-test (normal distribution) and the Wilcoxon signed ranks test (distribution free) were used to test the null hypothesis that the mean difference in total foliage occupancy (%) between methods was equal to 0.

Total foliage occupancy was the sum of all physiognomic vegetation classes. To make the data sets from the two methods compatible, hits from vegetation >2.54 cm dbh were dropped from the pole data and data from above 30 ft were dropped from the ocular estimates. Two different methods were used to calculate total foliage occupancy from the pole data for comparison with the ocular data (Table 8-3). In the first method ("presence-absence method") the percent cover of vegetation in each stratum was calculated by determining the presence of a hit within any foot level of that stratum and dividing by the number of points per subplot (16). In the second method ("summation method") the percent cover of vegetation in each stratum was calculated by summing the hits within each foot level of that stratum and dividing by the product of the number of foot levels per stratum and the number of points per subplot (16). For the data paired by foot levels, the two methods of calculating total foliage occupancy produced equivalent estimates.

Table 8-3. ANALYSIS OF HYPOTHETICAL POLE MEASUREMENTS USING TWO CALCULATION METHODS METHOD 1 = PRESENCE/ABSENCE AND METHOD 2 = SUMMATION

Foot level	Stratum	Point numbers 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Vegetation cover
1	1	1	0	0	1	1	0	1	1	1	1	0	0	0	0	1	0	
2	1	0	0	0	0	0	0	1	0	1	1	1	0	1	0	1	0	
Method 1		1	0	0	1	1	0	1	1	1	1	1	0	1	0	1	0	10/16 = 63%
Method 2		1	0	0	1	1	0	2	1	2	2	1	0	1	0	2	0	14/32 = 44%
3	2	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	1	
4	2	0	1	1	0	0	0	0	1	0	1	0	1	1	0	0	0	
5	2	1	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0	
6	2	1	0	1	0	1	1	0	1	0	0	0	1	1	0	1	0	
Method 1		1	1	1	0	1	1	1	1	1	1	0	1	1	0	1	1	13/16 = 81%
Method 2		2	1	2	0	1	2	1	3	1	1	0	4	3	0	2	1	22/64 = 34%
7	3	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	1	
8	3	1	1	0	0	0	0	0	0	1	1	1	1	0	0	1	1	
9	3	0	0	1	1	1	0	1	0	1	0	0	0	0	0	1	1	
10	3	1	0	1	1	1	0	1	0	0	1	0	0	1	0	0	0	
11	3	0	1	0	0	0	0	0	1	0	1	1	0	1	0	1	0	
12	3	1	0	0	0	0	0	0	1	0	1	1	0	1	0	0	1	
13	3	1	0	1	0	1	0	1	0	0	0	0	1	1	1	0	0	
14	3	1	1	0	1	0	0	0	0	1	1	1	1	1	0	1	0	
15	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	
16	3	1	1	0	1	1	0	1	0	1	0	1	0	0	1	0	0	
Method 1		1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	15/16 = 94%
Method 2		7	5	3	4	4	0	4	4	5	6	6	4	6	2	5	5	70/160 = 44%

8.2.2.2 Measurement variation

Ocular method

Remeasurement tolerances set forth by the Southeastern FIA unit at the training session were ± 2 ft for heights of strata and ± 15% for foliage occupancy within strata. Between-crew remeasurements were analyzed by tallying the frequency with which they met these standards.

Pole method

For each pair of pole remeasurements at each foot level, the variance was calculated using the standard variance formula. When the remeasurement agreed with the original at a particular foot level, the variance estimate was zero, since the data at each foot level consisted of a pair of yes or no observations. When they differed, the variance estimate was $(1-0.5)^2 + (0-0.5)^2 = 0.5$. Each one of these estimates has one degree of freedom. For each foot level, these one-degree-of-freedom variance estimates were pooled using the standard formula for pooling variances. This was equivalent to taking a weighted average of the variances, using the degrees of freedom as the weights. This analysis captured the two main sources of measurement error at each point, namely recording of different numbers of hits and incorrectly assigning the recorded hits to foot levels.

A variance was calculated separately for within-crew, between-crew, and versus trainer, as was an overall pooled variance estimate using all 126 pairs of measurements. The within-crew and between-crew variance estimates were compared across foot levels using the Wilcoxon signed ranks test, due to the non-normality of the data.

8.2.2.3 Spatial variation

Spatial correlations among pole measurements were analyzed by the common procedure of computing and interpreting semivariograms (Ripley, 1981). The semivariograms showed if, and at what distance, spatial correlation of data levels off. For each pair of data of a given distance apart, the variance was calculated as half the square of their difference and then averaged for all pairs of that distance. The variance at zero distance represented measurement error, and was estimated by the pooled variance discussed in Section 8.2.2.2. A separate semivariogram was produced for each of the 30 foot levels of the pole measurements.

8.2.2.4 Sample allocation

The variance and time requirements of the pole measurements were analyzed to estimate the optimal sample sizes for subplots and measurements per subplot. The methodology described in Section 3 was used.

8.3 RESULTS

8.3.1 Method Comparisons

8.3.1.1 Percent foliage occupancy differences

Paired strata

The mean total foliage occupancy estimates (percentage) from the ocular method were significantly greater than estimates from the pole method. There was a mean difference of 3% between the ocular estimates and the pole estimates calculated by the "presence-absence method", a significant difference for both parametric (p-value=0.016, n=165) and nonparametric tests (p-value=0.020, n=165). Method differences appeared to be normally distributed with about two-thirds (67%) of the differences within ± 10% and nearly all (97%) within ± 30% (Fig 8-2)

In contrast, there was a much larger and more significant mean difference of 13.5% between the ocular estimates and the pole estimates calculated by the summation method (p-value<0.001, n=165) A nonparametric test was used because method differences appeared to lack normality due to more frequent positive differences (Fig. 8-3). Although the ocular method usually estimated greater foliage occupancy than the pole method, the methods often described similar distribution patterns of foliage occupancy. About equally often, however, the methods differed in both the amount and distribution of foliage occupancy.

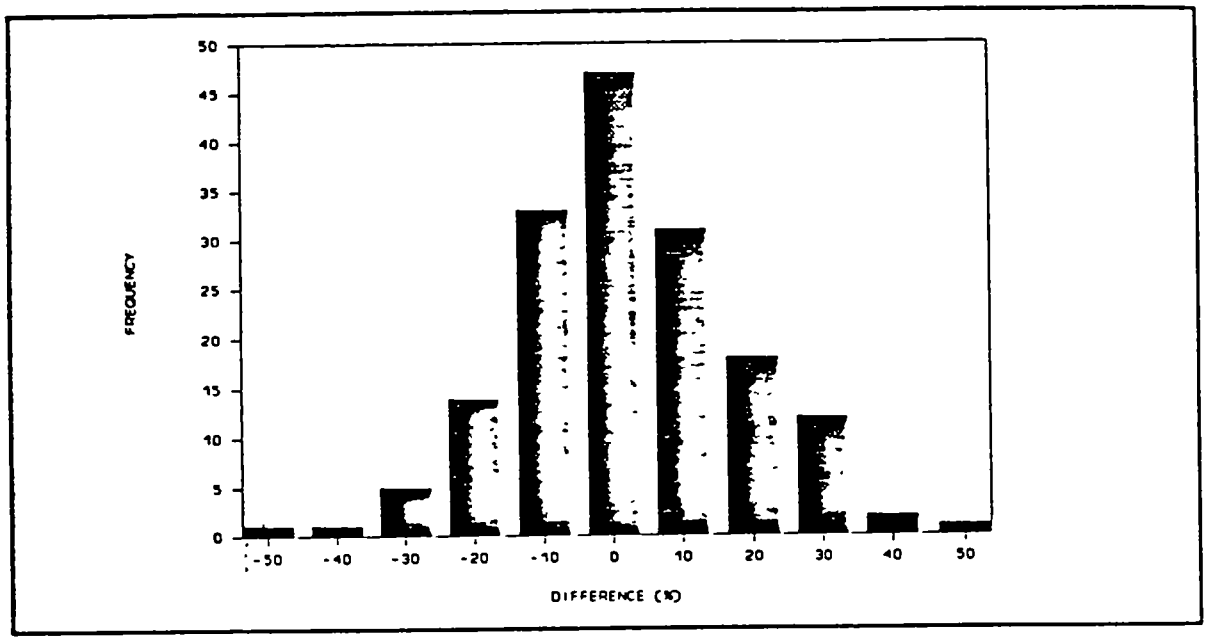

Figure 8-2 FREQUENCY OF DIFFERENCES IN TOTAL FOLIAGE OCCUPANCY BETWEEN THE OCULAR AND POLE MEASUREMENTS BY THE PRESENCE-ABSENCE METHOD

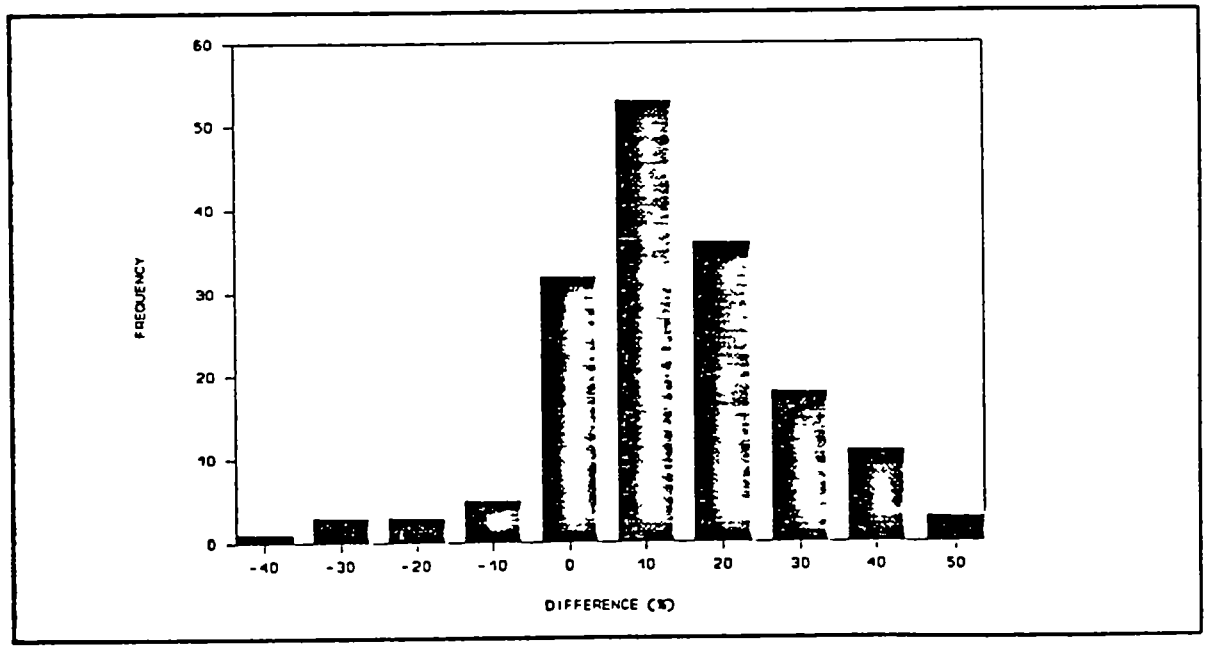

Figure 8-3. FREQUENCY OF DIFFERENCES IN TOTAL FOLIAGE OCCUPANCY BETWEEN THE OCULAR AND POLE MEASUREMENTS BY THE SUMMATION METHOD

Paired foot levels

When the data were paired by individual foot levels, the ocular estimates of total foliage occupancy significantly exceeded those of the pole estimates by an average of 12.5% (p-value < 0.001, n = 771). A nonparametric test was used because method differences appeared non-normal due to more frequent positive differences. This difference was very similar to the difference found between ocular and pole estimates when paired by strata and calculated by the summation method.

8.3.1.2 Measurement variation

Ocular method

In two of the four subplots remeasured in Virginia, the number of strata defined differed (plot 1955, subplot 2: four vs. two; and plot 2186, subplot 2: three vs. four). This was considered a high rate of error for this critical variable, since all of the remaining measurements (i.e., percent foliage occupancy estimates, lists of most abundant species by physiognomic class) were nested within the defined strata. These differences also presented problems for pairing strata for comparisons. When necessary, we used the convention of pairing in order the lowest two or three strata of each remeasurement. For the 12 pair of strata compared, 3 (25%) exceeded the ± 2 ft tolerance for strata height and 6 (50%) exceeded or equalled the ± 15% tolerance for foliage occupancy.

Pole method

The within-crew and between-crew variance estimates were compared across the 30 distinct foot levels (Table 8-4). These two variances were not significantly different (p-value > 0.05). The within- and between-crew variances were then pooled into an overall crew variance and compared to the versus-trainer variance. The versus-trainer variances were significantly larger than the overall crew variances (p-value < 0.01). On a subplot basis, the measurement variances would be only one-fourth as large because of division by 16, the number of points per subplot.

It is difficult to identify the specific reasons for greater versus-trainer variances than overall crew variability. A notable difference between the trainer and the crews was experience and training. The trainer was an experienced forest ecologist, but the crew members were professional tree climbers being trained to make vegetation measurements for the first time. This difference in experience likely had a general influence upon the manner in which the trainer and crews made the measurements. Perhaps the more important result was that the crews did not vary significantly among themselves.

Table 8-4 POLE METHOD MEASUREMENT VARIANCE FROM TRAINING SESSION REMEASUREMENTS*

Height	Pooled (n=126)	Within crew (n=25)	Between crews (n=25)	Versus trainer (n=76)
FT1	.07143	02000	04000	09868
FT2	02778	.00000	04000	03289
FT3	04365	00000	00000	07237
FT4	.03175	04000	02000	03289
FT5	.06746	.04000	06000	07895
FT6	.07143	.00000	08000	09211
FT7	05952	.08000	.06000	05263
FT8	.06349	06000	00000	08553
FT9	.05556	04000	04000	06579
FT10	.03968	02000	.08000	03289
FT11	04365	.02000	06000	04605
FT12	.05556	04000	08000	05263
FT13	.03175	02000	04000	03289
FT14	03968	.02000	02000	05263
FT15	.03175	04000	00000	03947
FT16	03571	.02000	04000	03947
FT17	05159	08000	02000	05263
FT18	.04365	06000	.04000	03947
FT19	.05952	06000	06000	05921
FT20	.02778	00000	02000	03947
FT21	.07143	.08000	.06000	07237
FT22	06349	10000	06000	05263
FT23	.05556	.08000	06000	04605
FT24	03968	.04000	02000	04605
FT25	.03968	02000	.02000	05263
FT26	.07540	.06000	08000	07895
FT27	07540	00000	16000	.07237
FT28	.04365	02000	08000	03947
FT29	.03968	.00000	.06000	04605
FT30	01190	02000	.00000	01316
> 30 FT	.07937	06000	.02000	10526

* See Section 8 2 2 2 for the method of calculation

8.3.2 Pole Method

8.3.2.1 Spatial variation

The semivariograms of the individual foot levels (e.g., 1, 11, and 21) consistently showed that spatial correlation leveled off by the 12-foot spacing between pole measurements, thus the measurements may be regarded as independent for plots in Virginia and New England (Figs. 8-4 and 8-5). This may have resulted because 12 ft was far enough to move measurements between most individual crowns of trees and tall shrubs and between clumps of herbaceous vegetation. In addition, if one considers the gap-phase dynamics of the forest stand as a relatively homogeneous stochastic process over an area, the distances between gaps would be random and would not appear consistently at specified distances.

The asymptotic variance shown on the semivariograms estimated the total variation associated with measurements at that foot level. This variance tended to decrease with height in the examples shown, and in general, averaging 0.422 at 1 ft, 0.159 at 11 ft, and 0.154 at 21 ft in Virginia and 0.249 at 1 ft, 0.151 at 11 ft, and 0.141 at 21 ft in New England. These numbers reflected structural features of forests, in that the vegetation below 5 or 6 ft varied widely from dense to sparse, while vegetation above 6 or 7 ft was less variable, being mostly sparse.

8.3.2.2 Sample allocation

Conservative estimates of sample sizes for subplots (m) and measurements per subplot (k) were 6 and 4, respectively (90th percentile, using cost model 1; see Section 3). A smaller median value of 3 subplots and 3 measurements per subplot, however, might suffice for regional estimates. Similarly, the total number of measurements per plot ($m \times k$) had a smaller median value of 9 compared to 15 and 20 for the 90th and 95th percentiles, respectively. These estimated optimal sample sizes may be underestimated since the plots were selected to be homogeneous and all subplots were rotated into the same forest condition. However, even if estimates were revised upward, sample size requirements for the pole measurements would likely be met using the 1991 sampling design of 28 measurements per plot.

8.3.2.3 Time requirements

Each subplot included 18 pole measurements (16-point square sampling grid plus 2 remeasurements per subplot). On average 34 and 33 min per subplot were required to complete the pole measurements in Virginia and New England, respectively (Table 8-5) Consequently, a single point required on average just under 2 min to measure. Minimum and maximum subplot times were 15 and 60 min, respectively, considering both regions.

8.4 DISCUSSION

8.4.1 Method Comparison

The ocular and pole methods both estimate the amount, arrangement, and composition of forest vegetation; however, the methods employ different conceptual, and, ultimately, procedural approaches to arrive at these estimates. For example, the ocular procedure uses qualitative guidelines to define strata In addition, foliage occupancy is estimated by visualizing square or rectangular boxes about the individual crowns of trees, shrubs, and tall herbs, including open space within the crown. Then individual crowns are summed to estimate the total foliage occupancy of each stratum. As indicated by the limited remeasurement results, estimates using these procedures can potentially vary widely among observers due to their experience and perceptions. Observer differences can be reduced by training, however, measurement tolerances remain relatively large.

In contrast, the pole method is more straightforward in that only hits of live vegetation by the pole need to be recorded. Consequently, the pole method requires little interpretation or calculation, except in cases of "close calls", which is simplified by following strict protocols for placing, leveling, and raising the pole. In addition, with the pole method the space within a crown is not included as occupied because the pole can, and often does, go through a crown with few or no hits being recorded Thus, the conceptual and resulting procedural differences are the main cause of the differences in results between the measurements Recognizing this, we developed the presence/absence method of calculating foliage occupancy from pole data in an attempt to make the method results more compatible

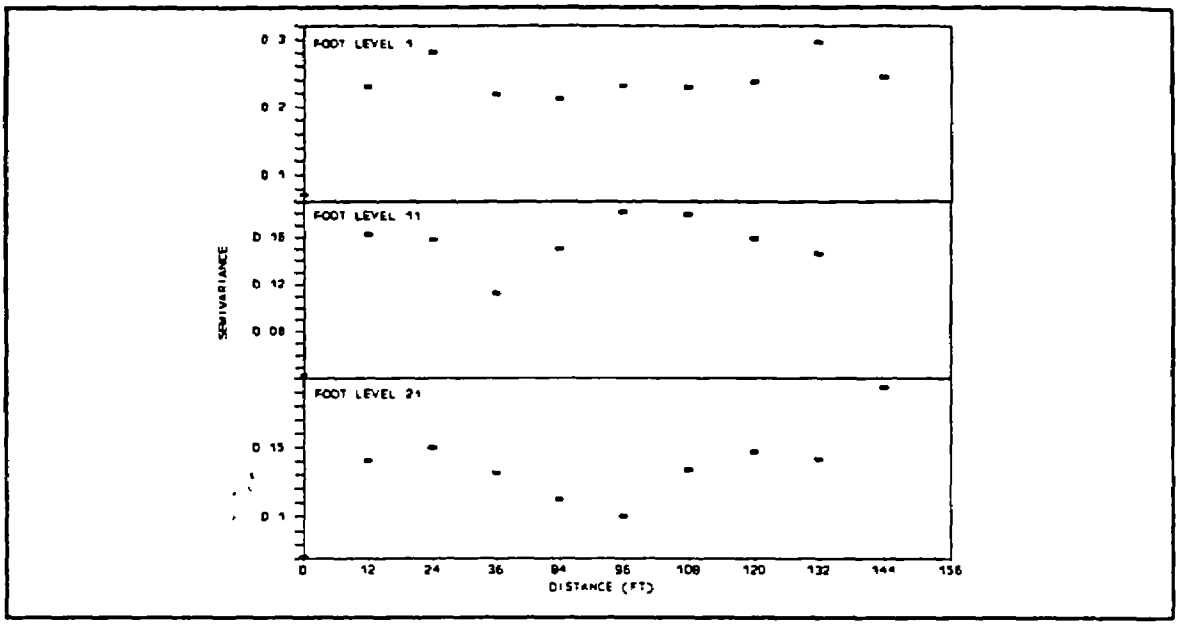

Figure 8-4. EXAMPLES OF SEMIVARIOGRAMS FOR THREE FOOT-LEVELS FROM POLE MEASUREMENTS BY THE SUMMATION METHOD IN VIRGINIA DATA FROM STEMS > 2 54 cm DIAMETER

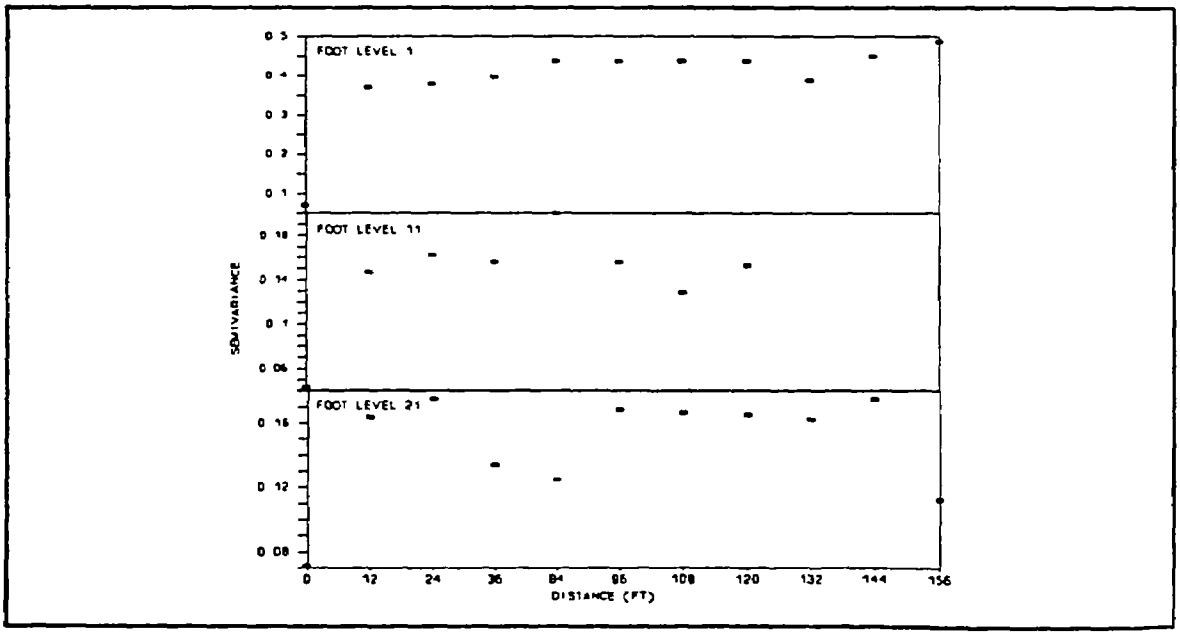

Figure 8-5 EXAMPLES OF SEMIVARIOGRAMS FOR THREE FOOT-LEVELS FROM POLE MEASUREMENTS BY THE SUMMATION METHOD IN NEW ENGLAND DATA FROM STEMS > 2 54 cm DIAMETER

Table 8-5. TIME REQUIRED TO COMPLETE POLE MEASUREMENTS*

Virginia				New England			
Plot	Subplot	Subplot time	Plot time	Plot	Subplot	Subplot time	Plot time
1839	1	–		0016	1	20	
1839	2	25	–	0016	2	30	50
1841	1	45		0117	1	40	
1841	2	25	70	0117	2	35	75
1843	1	35		0122	1	45	
1843	2	35	75	0122	2	35	80
1954	1	30		0155	1	35	
1954	2	30	60	0155	2	50	85
1955	1	35		0159	1	30	
1955	2	–	–	0159	2	35	65
1957	1	30		0160	1	30	
1957	2	30	60	0160	2	25	55
1958	1	–		0166	1	15	
1958	2	–	–	0166	2	25	40
1959	1	–		0173	1	30	
1959	2	–	–	0173	2	35	65
2072	1	35		0174	1	40	
2072	2	30	65	0174	2	45	85
2074	1	55		0181	1	33	
2074	2	35	90	0181	2	35	68
2075	1	25		0267	1	35	
2075	2	30	55	0267	2	–	–
2185	1	–		2270	1	40	
2185	2	–	–	2270	2	30	70
2186	1	30		0289	1	35	
2186	2	30	60	0289	2	25	60
2187	1	30		0321	1	33	
2187	2	35	65	0321	2	25	58
2188	1	53		0347	1	35	
2188	2	24	77	0347	2	40	75
2189	1	35		0420	1	–	
2189	2	35	70	0420	2	39	–
2190	1	30		0508	1	35	
2190	2	38	68	0508	2	25	60
2191	1	30		0692	1	25	
2191	2	20	50	0692	2	40	65
2192	1	40		0902	1	25	
2192	2	40	80	0902	2	20	45
2303	1	40		3270	1	30	
2303	2	32	72	3270	2	60	90
Average		34	68			33	66
Standard dev.		8	10			9	14
Range		20-55	50-90			15-60	40-90

* Each subplot included 18 pole measurements (16-point square sampling grid plus 2 remeasurements per subplot) Plot time was the sum of subplot times All times are in minutes

8.4.2 Measurement Variation

The total variation in measurements will greatly influence their usefulness as indicators of changes in forest condition. Regional, temporal, within-plot, within-subplot, and measurement variation are important components of total variation Measurement variation was emphasized in this study because although it can be relatively large for subjective measurements (Gumpertz et al., 1982), it can be controlled or reduced through QA procedures (Cline et al., 1989). What then is the relative contribution of measurement variation to the total variation of ocular and pole measurements of vegetation structure, and how can this variation be controlled and reduced?

This question cannot be addressed adequately for the ocular method due to a lack of remeasurement data, but a preliminary estimate can be calculated for the pole method. Measurement variation (Table 8-4) was less than 20% of total variation (Fig 8-6 and 8-7, average of asymptotic variances) in the first 5 or 6 ft levels, and usually 20 to 30% above 6 or 7 ft up to 30 ft. These ratios must be interpreted with caution, because we do not yet have a realistic estimate of total variation. Total variation will undoubtedly increase because no temporal variation is included here. Moreover, both regional and within-plot variation are underestimated here since the plots in each region are from a relatively small geographical area and the subplots were rotated into the same homogenous stand condition. In contrast, the measurement variances are probably robust, because the crews were unqualified (a worst-case scenario), the estimates were based upon a large sample size, and procedural improvements have been made. Consequently, there is reason to believe that the relative contribution of measurement error to total variation will decrease for the pole method, and easily meet Taylor's (1987) 10% guideline for an acceptable level of measurement error.

A major finding of this study was the need to hire qualified personnel to make the measurements Some of the problems that were encountered during the field study - little to no QA data and no plant species identification - would have been avoided if qualified personnel had carried out the measurements An experienced botanist familiar with the flora of the Southeast United States will make the vegetation structure measurements for the 1991 field study.

9 GROWTH EFFICIENCY

Kurt Riitters and Beverly Law

9.1 INTRODUCTION

Forest productivity is an important aspect of forest "health." The absorption of PAR (400 to 700 nm) by canopies is an important factor influencing tree growth and forest productivity (Kramer and Kozlowski, 1979; Russell et al., 1989). "Growth efficiency", or growth in relation to radiation transmittance or canopy density, is an integrative and sensitive measure of forest productivity (Waring and Schlesinger, 1985). Estimates of canopy density per unit area obtained via measurements of PAR absorption may also be related to species-specific measurements of visual symptoms (Section 5) to help interpret possible changes in overall canopy condition.

Recent technological advances have made it possible to rapidly measure radiation transmittance and leaf area index in the field (Pierce and Running, 1988; Gower and Norman, 1991), and permit serious consideration of these measurements for monitoring. Yet some problems of measurement variability must be solved to implement these measurements in a monitoring framework.

Cloudiness during the sampling period is one of the most important sources of variation in PAR measurements. Clouds absorb PAR (Fig. 9-1), and this may be confused with canopy absorption in some sampling designs. Thus, most of the reported measurements of PAR have been made on cloud-free days, and PAR transmittance is typically normalized by the ratio of under-canopy to ambient PAR (Fig. 9-2). But methods are needed for sampling irrespective of the sky condition, because not all applications can await cloud-free conditions. For example, large-scale regional surveys are typically conducted on tight schedules that allow a limited amount of time for sampling. In another example, measurements must sometimes be made at a certain time for comparisons with remotely sensed data Measurements of PAR made during this test of regional survey procedures identify some of the consequences of sampling different stand types under a variety of sky conditions.

The main objective of this study was to estimate components of sampling variation of transmitted PAR in two different forest types under different sky conditions. This information could then be used with information about the cost and feasibility of PAR measurements to develop better sampling designs for regional surveys (§3) and to define measurement quality objectives.

Also of concern was the potential that variable cloudiness would result in inaccurate, highly variable estimates of transmitted PAR. This section focuses on that potential, in particular on the serial correlation that was obtained among stations under cloudy sky conditions. This is important because, with serial correlation, the least-squares estimators of means will be unbiased and consistent, but variance estimates are likely to be biased (Kmenta, 1971), and this leads to improper hypothesis tests if the correlation is ignored.

9.2 METHODS

9.2.1 PAR Measurements

Seventeen northern hardwood stands in New England and 19 pine-oak stands in eastern Virginia were sampled. Within each stand, a plot consisting of four subplots was established (Fig. 9-3). At each subplot, under-canopy PAR measurements were made on a rectangular grid of 16 sampling stations Ambient PAR was measured at a sampling station in a nearby canopy opening or nonforested area

PAR was measured with a "Sunfleck Ceptometer" (Model SF-80, Decagon Devices, Inc., 1989). The SF-80 device is a hand-held integrating radiometer that contains 80 quantum sensors linked to a data processing and storage unit. In a continuous sampling mode, the SF-80 radiometer accumulates averages of 80 sensor values (micromoles per meter squared per second) until the operator requests one overall average for storage. For this study, each sample is the average of at least 30 intermediate averages accumulated during a ~30-s sampling interval.

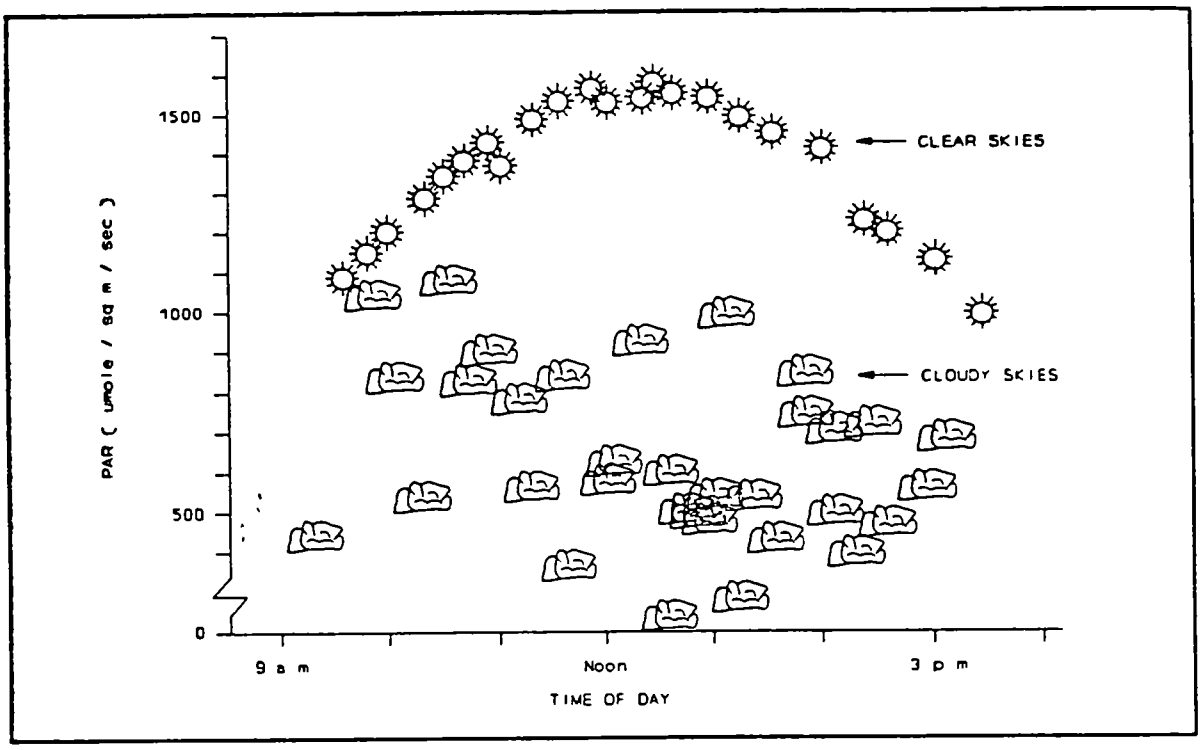

Figure 9-1. AMBIENT PAR IN RELATION TO TIME OF DAY AND SKY CONDITION EACH PLOTTED POINT IS THE AVERAGE OF 800 TO 2400 PAR SENSOR VALUES TAKEN OVER A 5 TO 10 min PERIOD AT THE DUKE FOREST, DURHAM, NC, ON TWO CLEAR AND TWO CLOUDY DAYS IN APRIL, 1990

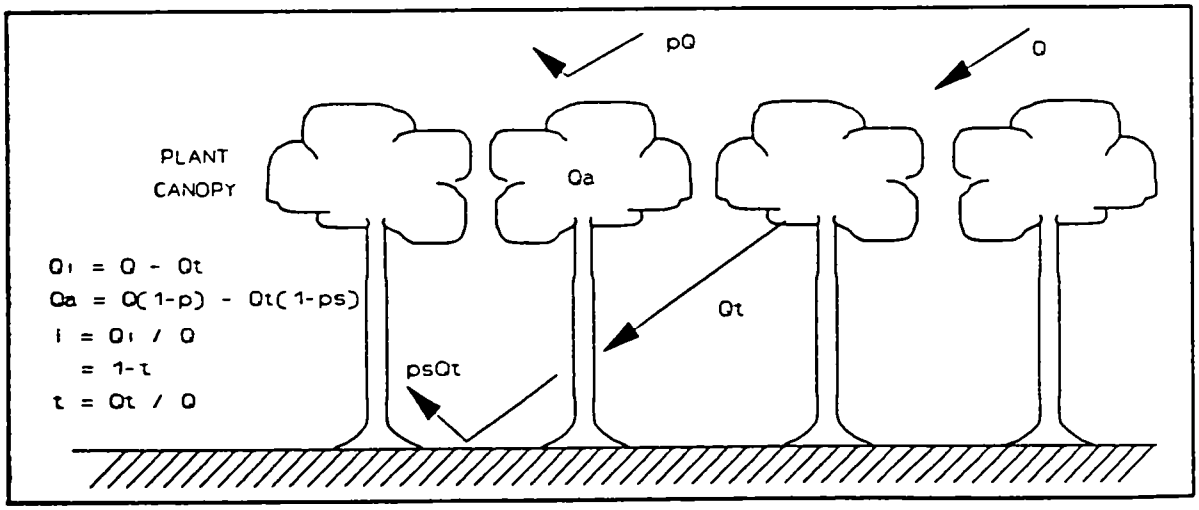

Figure 9-2. WHAT IS MEANT BY INTERCEPTED (Q_i) AND ABSORBED (Q_a) RADIATION Q IS THE INCIDENT RADIATION AND Pq THE RADIATION REFLECTED UPWARDS FROM THE VEGETATION Qt IS THE RADIATION TRANSMITTED THROUGH THE OVERSTORY AND psQt IS THAT PART OF THE TRANSMITTED RADIATION THAT IS REFLECTED UPWARDS BY THE SOIL AND GROUND FLORA THE INTERCEPTED FRACTION (i) IS THE COMPLEMENT OF THE TRANSMITTED FRACTION (t) ADAPTED FROM FIGURE 2 2 IN RUSSELL et al (1990)

Measurements were initiated at ~1000 h zone time at each plot and were continued for about 1 h until all sample stations were visited. The procedure started with 10 separate samples at the ambient station, where the SF-80 device was held level facing the sun. The 32 under-canopy stations on subplots 1 and 2 were then measured. At the under-canopy stations, the SF-80 device was swept in a level circle around the station at arm's length and waist height, effectively sampling about 10 m^2. The SF-80 measuring device was temporarily halted when the sweep was obstructed by tree stems or brush and restarted without losing the accumulated data after moving around the obstruction. Ten more samples were then collected at the ambient station, followed by 32 samples at under-canopy stations on subplots 3 and 4, and another 10 samples at the ambient station. In this way, a total of 30 ambient and 64 under-canopy measurements were made at each plot.

9.2.2 Statistical Analysis

The mean and the CV of the 30 ambient measurements were used to classify the sky conditions encountered at each plot (Table 9-1) If the CV was ≤20%, the sky condition was "clear" if, in addition, the mean was ≥900 $\mu mol/m^2/s$, and it was "overcast" if the mean was <900 $\mu mol/m^2/s$. The sky condition was always "variably cloudy" if the CV was >20%. The cutoff value for the mean is about 60% of the maximum plot ambient mean encountered (Table 9-1), and the clear sky condition includes a few days with light, high haze. The cutoff value for the CV was determined after a visual inspection of the ambient data.

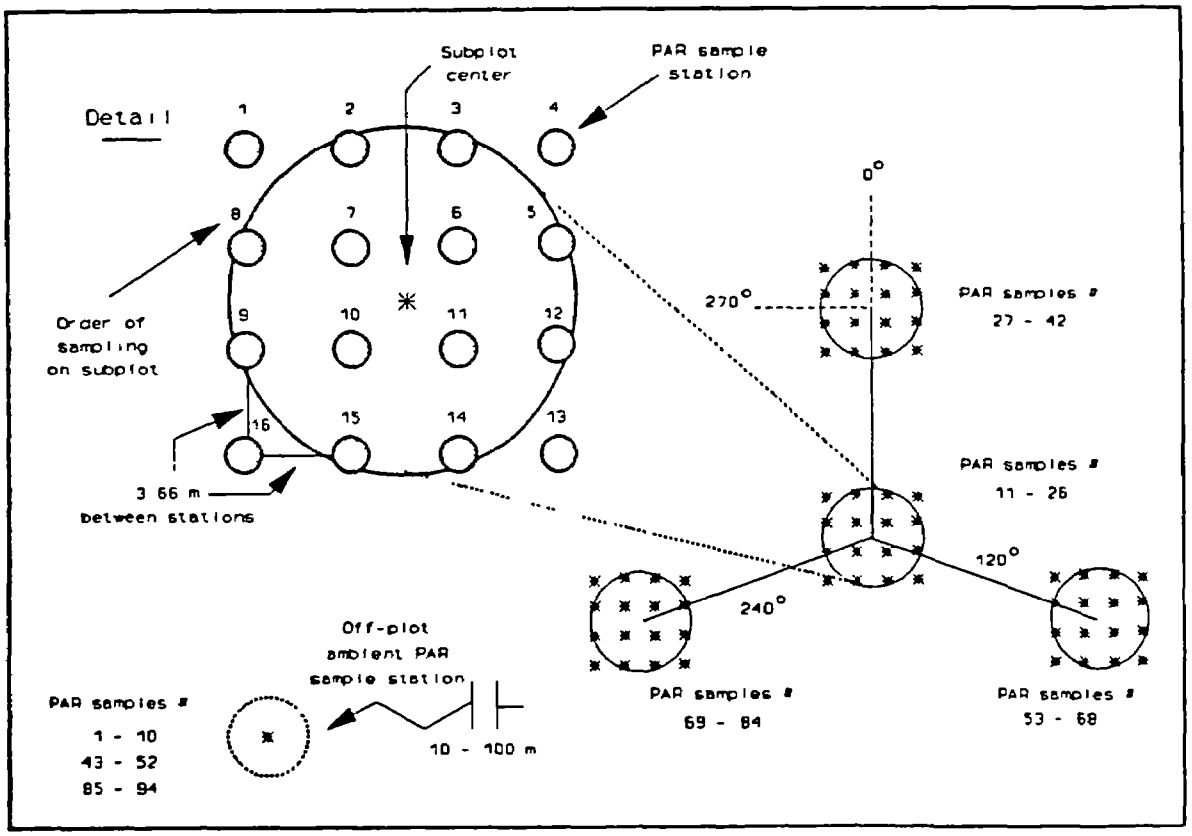

Figure 9-3 DETAILS OF PAR SAMPLING DESIGN THE LARGE CIRCLES ARE THE 0 017-ha SUBPLOTS UPON WHICH THE SQUARE GRIDS (3 66 m) OF SAMPLING STATIONS ARE SUPERIMPOSED SUBPLOTS ARE LOCATED 36 6 m FROM SUBPLOT 1 CENTER AT AZIMUTHS OF 0, 120, AND 240 DEGREES.

Table 9-1. AMBIENT PAR AND SKY CONDITIONS BY PLOT

Forest region	Plot no.	Ambient PAR Mean (μmol/m²/s)	Ambient PAR CV (%)	Time[a]	Sky code[b]
New England	16	1299	5 2	0950	CL
	122	1597	4 9	1020	CL
	155	416	24 6	1020	VC
	160	23	19 1	1000	OV
	173	1268	26 7	1050	VC
	174	1181	12 7	1005	CL
	181	88	73 1	1055	VC
	267	994	7.7	0925	CL
	270	1417	3 2	1025	CL
	289	1113	30 2	1020	VC
	321	71	34 0	1025	VC
	347	1372	5 3	1020	CL
	420	1376	8.2	1030	CL
	508	394	18 5	1040	OV
	692	19	2 8	1130	OV
	902	891	64 2	1040	VC
	3270	133	46 8	1050	VC
Virginia	1839	1395	2 9	1025	CL
	1841	501	29 0	1105	VC
	1843	895	23 4	1110	VC
	1954	239	22 5	1030	VC
	1955	590	45.7	1020	VC
	1957	1108	16 7	1030	CL
	1958	349	19.3	1105	OV
	1959	973	24 5	1030	VC
	2072	1309	11 3	1035	CL
	2074	361	17 0	1055	OV
	2185	94	3 5	1025	OV
	2186	347	7.3	1230	OV
	2187	1385	1.7	1055	CL
	2188	269	68 5	0950	VC
	2189	375	63 2	1225	VC
	2190	1531	3 5	1055	CL
	2191	1202	7.8	1030	CL
	2192	1488	11 9	1105	CL
	2303	239	30 4	1140	VC

[a] Zone time (nearest 5 min) at the midpoint of the sampling period

[b] Sky codes are based on the mean (μmol/m²/s) and CV (%) of ambient PAR: CL = "clear", OV = "overcast", and VC = "variably cloudy".

The percentage of transmitted PAR (PTPAR) was estimated for each under-canopy sampling station as follows. For stations on subplots 1 and 2, the measured PAR values were divided by the average of the 20 ambient PAR values measured during the first and second visits to the ambient station. For stations on subplots 3 and 4, the divisor was the average of the 20 ambient PAR values measured during the second and third visits to the ambient station. A logarithmic transformation of PTPAR, ln(PTPAR + 1), was applied to normalize the frequency distributions of PTPAR. Mean values of ln(PTPAR + 1) by subplot (n = 16) and by plot (n = 64) are shown in Table 9-2.

To estimate components of variance, linear models for nested designs (e.g., John, 1971) were used in the ANOVA (Table 9-3). A three-factor model with effects of plot, subplot within plot, and station within subplot was estimated by forest type. To explore the extremes of variances, a reduced, two-factor model was also estimated by plot. Both linear models provide estimates of the station and subplot variance components. Two contrasts of mean ln(PTPAR + 1) among plots of different sky conditions ("clear" vs. "cloudy", and "overcast" vs "variably cloudy") were estimated for each forest type by using the three-factor ANOVA and sets of orthogonal contrast coefficients. Estimates of plot median PTPAR, and confidence intervals based on variance estimates from the two-factor ANOVA, were obtained by back-transformations without a variance correction.

To explore the possibility of serial correlation, Box-Jenkins models (Box and Jenkins, 1970) were fit to the series of 64 values of ln(PTPAR + 1) for each plot. These analyses assumed stationary series and equal time intervals between series values. Each series was first tested for the presence of serial correlation by the Q-statistic (Ljung and Box, 1978) with a significance level of $p = 0.10$. For series with significant serial correlation, the autocorrelation functions were inspected to suggest appropriate models. A parsimonious model was developed using the Q-statistic to assess model adequacy. The fitted Box-Jenkins models were then used to estimate an adjusted series of ln(PTPAR + 1) for each plot that exhibited serial correlation. The ANOVAs were then repeated with the adjusted series in place of the original series for these plots.

Although the canopy was very uniform in each sampled stand, it is possible that the values of ln(PTPAR + 1) were spatially correlated. Spatial correlation would violate one assumption needed to apply the usual sample size equations in Section 3. Spatial correlation could also be incorrectly identified as serial correlation when the sampling design confounds the space and time dimensions. In this study, each time-series of 64 values contains partially confounded sets of spatial series at lags of one, two, and three stations in an east-west direction, and so this possibility was explored.

Table 9-2. UNADJUSTED MEANS OF ln(PTPAR + 1) BY PLOT AND SUBPLOT

Forest region	Plot no	Plot mean	Mean for subplot 1	2	3	4
New England	16	0 0630	0 0924	0 0162	0 0508	0 0928
	122	0 0154	0 0103	0 0116	0 0222	0 0178
	155	0 2344	0 0462	0 0674	0 5515	0 2729
	160	0 3723	0 4875	0 2174	0 4222	0 3625
	173	0 0721	0 0358	0.1363	0 0268	0.0897
	174	0 0074	0 0046	0 0130	0 0048	0 0074
	181	0 0754	0 1594	0 0612	0 0247	0 0562
	267	0 0277	0 0183	0 0354	0 0286	0 0286
	270	0 0874	0 0325	0 0872	0 1391	0 0911
	289	0 1549	0 0324	0 0790	0 1125	0 3958
	321	0 1944	0 1364	0 2981	0 0879	0 2554
	347	0 0262	0 0340	0 0208	0 0223	0 0276
	420	0 0597	0 0749	0 0920	0 0246	0 0472
	508	0 0431	0 0377	0 0251	0 0512	0 0584
	692	0 4463	0 5462	0.7343	0 1783	0 3263
	902	0 0296	0 0254	0 0319	0 0272	0 0340
	3270	0 1585	0 2523	0 0899	0 1050	0 1869
Virginia	1839	0 0477	0 0270	0 0502	0 0514	0 0623
	1841	0 0239	0 0437	0 0221	0 0069	0 0230
	1843	0 0648	0 0402	0 0830	0 0963	0 0395
	1954	0 0250	0 0213	0 0286	0.0288	0 0210
	1955	0 3273	0 1501	0 4205	0 1970	0 5414
	1957	0 2527	0 2669	0 1968	0 3174	0 2296
	1958	0 2462	0 1874	0 3346	0 3842	0 0784
	1959	0 0153	0 0157	0 0128	0 0091	0 0236
	2072	0 0405	0 0189	0 0298	0 0837	0 0294
	2074	0 1131	0 1434	0 1719	0 0625	0 0748
	2185	0 1662	0 1814	0 1057	0 1962	0 1813
	2186	0 1472	0 1889	0 1047	0 0960	0 1992
	2187	0 0379	0.0488	0 0347	0 0253	0 0428
	2188	0 0260	0 0424	0 0296	0 0208	0 0113
	2189	0 0158	0 0361	0 0214	0 0024	0 0032
	2190	0 0676	0 0680	0 0666	0 0645	0.0714
	2191	0 1380	0 1748	0 1912	0 1130	0 0731
	2192	0 0213	0 0194	0 0161	0 0267	0 0228
	2303	0 0278	0 0258	0 0245	0 0300	0 0308

The absence of serial correlation does not imply an absence of spatial correlation, but serial correlation would (in this design) appear as east-west anisotropic spatial correlation. Therefore, the plots without serial correlation provided the best tests of spatial correlation For these plots, the semivariance of ln(PTPAR + 1) was plotted over distance between stations for all station pairs (e g., Robertson, 1987). These semivariograms showed virtually no evidence of spatial correlation at scales from ~3.7 to ~60 m. Furthermore, the variances estimated by the weighted means of the semivariance statistic were approximately equal to the between-station variances estimated by the two-factor ANOVAs. If these plots are representative, it may be concluded that spatial correlation was not incorrectly identified as serial correlation in the time series analyses.

9.3 RESULTS

The average ambient PAR and sky conditions are shown for each plot in Table 9-1. Average ambient PAR ranged from only 19 to almost 1600 μmol/m^2/s The lower values in the hardwood stands are questionable because the field crews noted that it was difficult to find suitable canopy openings and to orient the radiometer towards the sun on very cloudy days. The higher values are typical of late-morning values obtainable on cloud-free days in the summer.

The time series analysis revealed that serial correlation was never significant under clear sky conditions (Table 9-4). Under cloudy sky conditions, however, serial correlation was significant in 19 of 22 cases. An autoregressive, degree one (AR1) model was appropriate for 18 of these 19 cases. A parsimonious model could not be identified for one plot (number 2189), but the AR1 model did reduce serial correlation. The sharp contrast between the results obtained under clear sky conditions and results obtained under cloudy conditions suggests that clouds produced the serial correlation. This is likely because clouds intercept PAR, and therefore any variation in the depth or density of clouds that is associated with their passage overhead will produce a correlated series of actual ambient PAR, and, thus, of PTPAR under a homogeneous canopy.

Serial correlation affected the estimates of variance components. Comparisons of ANOVAs before and after autoregression adjustments (Table 9-4) suggest order-of-magnitude increases in the between-subplot and between-station variance components as a result of serial correlation. Because the adjustments reduced the between-subplot variance proportionally more than the between-station variance, the percentage of the total plot variance attributable to stations usually increased after adjustment. Thus, in this nested design, the adjustments should tend to increase the precision of plot-level and subplot-level means of ln(PTPAR).

The adjustments for serial correlation also made the between-station variance components for cloudy sky conditions comparable to those obtained for clear sky conditions (Table 9-4). But the percentage of variance attributable to stations was still lower on cloudy days because the between-subplot variances remained much higher under cloudy sky conditions. If it is assumed that the stands were otherwise similar, it seems that cloud variability not accounted for by the AR1 models increased the variability of estimated PTPAR at the subplot level, which resulted in higher between-subplot variances relative to clear sky conditions.

The three-factor ANOVAs before and after time-series adjustments (Table 9-5) show the effects of serial correlation on the precision of comparisons among plots. The increased precision of contrasts among plots after adjustment is due to the reduction in between-subplot variance. The importance of this reduction can be gauged, for example, by the approximate doubling of F - ratios for the contrasts of sky conditions after adjustment.

Figure 9-4 shows the estimated median PTPAR for each plot and illustrates the time-series adjustments on a per-plot basis. There was little change in the plot medians, but the confidence intervals were narrower. Because the estimates were obtained by back-transformation of plot means and standard errors of ln(PTPAR + 1), the intervals were based on relative error and were wider at higher values of median PTPAR. The intervals for different plots were also different because they were based on plot-specific variances estimated from the two-factor ANOVAs rather than on a common variance estimated from the three-factor ANOVAs.

Not much should be made of the apparently higher transmittance under cloudy sky conditions in the hardwood stands. This is so despite the significant contrast of clear and cloudy sky conditions (Table 9-5) and the visual impression of higher transmittance under cloudy sky conditions (Fig. 9-4). The reason for caution is that the evidence comes mostly from stands for which the ambient PAR measurements were unrealistically low (Table 9-1). Ambient PAR is isotropic under cloudy sky conditions (Smith and Clark, 1990), and small canopy openings will yield inaccurate and low averages, this would tend to increase the estimated mean PTPAR. Very large canopy openings were always available near the pine stands, and in those cases the contrast of clear and cloudy sky conditions was neither significant (Table 9-5) nor suggested visually (Fig. 9-4).

9.4 DISCUSSION

Under clear sky conditions, there was little variation in the percentage of transmitted PAR between stations or between subplots in these uniform stands. The sampling design yielded very precise estimates of plot mean ln(PTPAR + 1) and plot median PTPAR was estimated with a relative standard error of 0.1 to 2.7%. There was no evidence of serial correlation under clear sky conditions, and the usual variance estimates were therefore appropriate. Spatial correlation, although not detected here, could require stratification or other analyses to derive appropriate estimates of median PTPAR and its variance under less uniform canopies.

The serial correlation of PAR measurements under cloudy sky conditions reduced the precision of estimated plot median percentages of transmitted PAR. The relative standard errors obtained were 0.2 to 12.2% before adjustment; these values were up to four times larger than those obtained under clear sky conditions. The relative standard errors were still large after adjustment (0.1 to 10.4%) in comparison to clear sky conditions. The differences were not important for hypothesis tests in this study because the overall precision was rather high. But the differences could be much more important when fewer samples are taken, or in stands where transmitted PAR is more variable.

Table 9-3 LINEAR MODELS AND EXPECTED VALUES OF MEAN SQUARES FOR THE ANOVAS

	Three-factor model		Two-factor model	
Source of variance	Expected value of the mean square	Corresponding variance component	Expected value of the mean square	Corresponding variance component
Plot	$\sigma_T^2 + 16\sigma_S^2 + 64\sigma_P^2$	σ_P^2	Not in model	Not estimated
Subplot	$\sigma_T^2 + 16\sigma_S^2$	σ_{S1}^2	$\sigma_T^2 + 16\sigma_S^2$	σ_{S2}^2
Station	σ_T^2	σ_{T1}^2	σ_T^2	σ_{T2}^2
Linear model[a]	$\ln(PTPAR+1)_{i,k} = \mu + P_i + S_j + T_k$ P_i = plot S_j = subplot within plot T_k = station within subplot		$\ln(PTPAR+1)_{l,m} = \mu + S_l + T_m$ S_l = subplot T_m = station within subplot	

[a] PTPAR is the estimated percent of ambient PAR transmitted through the canopy

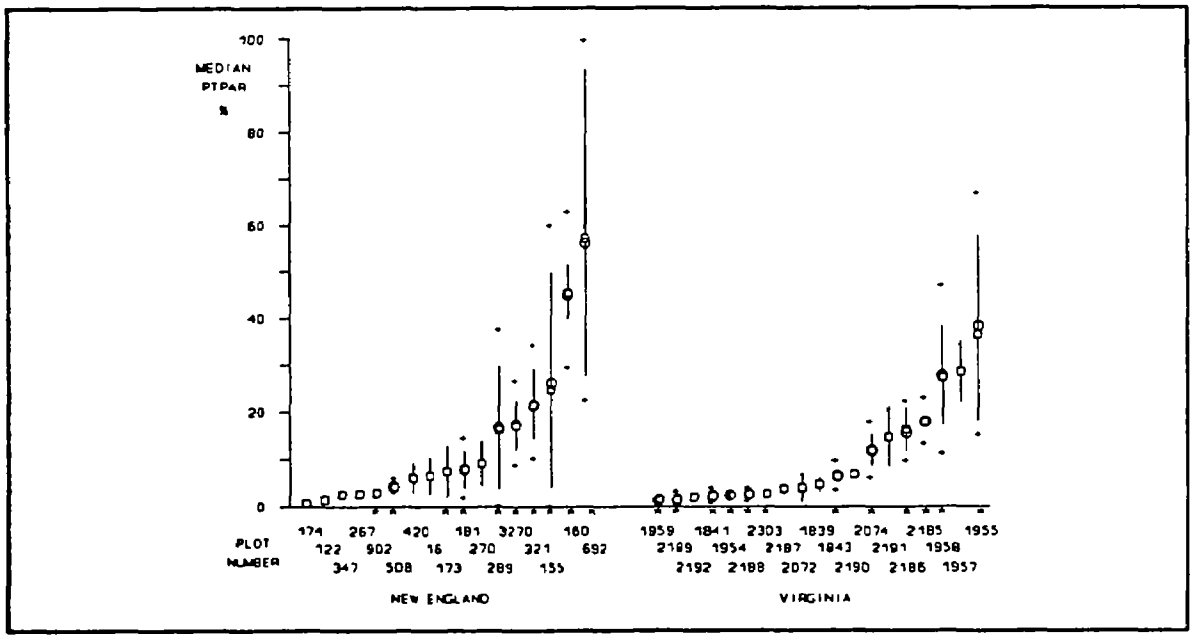

Figure 9-4 PLOT MEDIAN PERCENT TRANSMITTED PAR MEDIANS ARE SHOWN BEFORE (□) AND AFTER (○) THE ADJUSTMENT FOR SERIAL CORRELATION SOLID LINES INDICATE CONFIDENCE INTERVALS OF ± 2 PERCENTAGE STANDARD ERRORS AFTER ADJUSTMENT, COMPARE TO WIDTHS BEFORE ADJUSTMENT (+) FOR THOSE PLOTS WITH SERIAL AUTOCORRELATION. PLOTS MEASURED ON CLOUDY DAYS ARE INDICATED BY ASTERISKS ON THE ABSCISSA

Table 9-4 TWO-FACTOR ANOVA OF PAR BY PLOT BEFORE AND AFTER TIME SERIES ANALYSIS[a]

					Before time series analysis				Time series analysis			After time series analysis			
Sky	Forest region	Plot	Contrast coefficient C_1	C_2	Mean square subplot	$\hat{\sigma}^2_{\varepsilon}$	Mean square station ($=\hat{\sigma}^2_{T2}$)	Station[b] term	Model	ϕ	SE(ϕ)	Mean square subplot	$\hat{\sigma}^2_{\varepsilon}$	Mean square station ($=\hat{\sigma}^2_{T2}$)	Station[b] term
								%							%
Overcast	New England	160	7	-7	0 21265	0 01259	0 01129	47 3	AR1	0 43	0 12	0 02606	0 00147	0 00261	64 1
		508	7	-7	0 00348	0 00018	0 00057	76 0	AR1	0 63	0 10	0 00138	0 00007	0 00023	75 8
		692	7	-7	0 95566	0 05929	0 00706	10 6	AR1	0 89	0 06	0 69001	0 04255	0 00926	17 9
		Average			0 39060	0 02402	0 00631	44 6				0 23915	0 01470	0 00403	52 6
	Virginia	1958	7	-8	0 31179	0 01912	0 00592	23 6	AR1	0 68	0 09	0 10970	0 00659	0 00425	39 2
		2074	7	-8	0 04478	0 00249	0 00488	66 2	AR1	0 55	0 11	0 01375	0 00077	0 00142	64 9
		2185	7	-8	0 02678	0 00154	0 00209	57.5	AR1	0 41	0 12	0 00039	0 00020	0 00039	66 4
		2186	7	-8	0 04730	0 00289	0 00101	25 9	AR1	0 81	0 08	0 02611	0 00157	0 00092	36 8
		Average			0 10766	0 00651	0 00348	43 3				0 03749	0 00228	0 00175	51 8
Variably cloudy	New England	155	7	3	0 88178	0 05376	0 02167	28 7	AR1	0 85	0 08	0 53518	0 03247	0 01573	32 6
		173	7	3	0 04165	0 00154	0 01700	91 7	WN	–	–	0 04165	0 00154	0 01700	91 7
		181	7	3	0 05435	0 00320	0 00322	50 2	AR1	0 66	0 09	0 02188	0 00127	0 00152	54 5
		289	7	3	0 42985	0 02596	0 01449	35 8	AR1	0 70	0 09	0 19986	0 01201	0 00760	38 7
		321	7	3	0 15564	0 00853	0 01924	69.3	AR1	0 69	0 09	0 06048	0 00316	0 00998	76 0
		902	7	3	0 00025	0 00000	0 00080	100 0	WN	–	–	0 00025	0 00000	0 00080	100 0
		3270	7	3	0 09154	0 00522	0 00806	60 7	AR1	0 59	0 10	0 03179	0 00181	0 00282	60 9
		Average			0 23644	0 01403	0 01207	62 3				0 12730	0 00747	0 00792	64 9
	Virginia	1841	7	4	0 00365	0 00022	0 00012	35 8	AR1	0 69	0 09	0 00160	0 00010	0 00006	40 2
		1843	7	4	0 01369	0 00078	0 00122	61 0	AR1	0 41	0 12	0 00154	0 00008	0 00024	74 8
		1954	7	4	0 00030	0 00002	0 00002	55 2	AR1	0 53	0 11	0 00007	0 00000	0 00001	63 5
		1955	7	4	0 54893	0 03324	0 01714	34 0	AR1	0 92	0 07	0.33434	0 01976	0 01820	47 9
		1959	7	4	0 00061	0 00003	0 00010	75 0	AR1	0 36	0 12	0 00006	0 00000	0 00001	83 5
		2188	7	4	0 00281	0 00017	0 00008	32 7	AR1	0 82	0 08	0 00178	0 00011	0 00005	33 7
		2189	7	4	0 00417	0 00025	0 00014	35 6	AR1?	0 65	0 10	0 00163	0 00010	0 00006	39 8
		2303	7	4	0 00015	0 00000	0 00013	98 8	WN	–	–	0 00015	0 00000	0 00013	98 8
		Average			0 07179	0 00434	0 00237	53 5				0 04265	0 00252	0 00235	60 3
Clear	New England	16	-10	0	0 02182	0 00097	0 00634	86 8	WN	–	–	0 02182	0 00097	0 00634	86 8
		122	-10	0	0 00049	0 00002	0 00019	91 2	WN	–	–	0 00049	0 00002	0 00019	91 2
		174	-10	0	0 00024	0 00001	0 00006	82 5	WN	–	–	0 00024	0 00001	0 00006	82 5
		267	-10	0	0 00079	0 00000	0 00137	100 0	WN	–	–	0 00079	0 00000	0 00137	100 0
		270	-10	0	0 03039	0 00139	0 00808	85 3	WN	–	–	0 03039	0 00139	0 00808	85 3
		347	-10	0	0 00058	0 00000	0 00056	99 8	WN	–	–	0 00058	0 00000	0 00056	99 8
		420	-10	0	0 01421	0 00038	0 00808	95 5	WN	–	–	0.01421	0 00038	0 00808	95 5
		Average			0 00979	0 00040	0 00353	91 6				0 00979	0 00040	0 00353	91 6
	Virginia	1839	-12	0	0 00352	0 00013	0 00139	91 3	WN	–	–	0 00352	0 00013	0 00139	91 3
		1957	-12	0	0 04290	0 00153	0 01838	92 3	WN	–	–	0 04290	0 00153	0 01838	92 3
		2072	-12	0	0 01370	0 00068	0 00287	80 9	WN	–	–	0 01370	0 00068	0 00287	80 9
		2187	-12	0	0 00166	0 00004	0 00104	96 4	WN	–	–	0 00166	0 00004	0 00104	96 4
		2190	-12	0	0 00013	0 00000	0 00403	100 0	WN	–	–	0 00013	0 00000	0 00403	100 0
		2191	-12	0	0 04812	0 00252	0 00782	75 6	WN	–	–	0 04812	0 00252	0 00782	75 6
		2192	-12	0	0 00033	0 00001	0.00020	96 1	WN	–	–	0 00033	0 00001	0 00020	96 1
		Average			0 01577	0 00070	0 00510	90 4				0 01577	0 00070	0 00510	90 4

[a] The time series models are WN (white noise), implying that no time-series adjustments were made, or AR1 (first-degree autoregression) with autoregressive parameter ϕ. The contrast coefficients are used in the ANOVA reported in Table 9-5

[b] $100 * (\hat{\sigma}^2_{T2} / \hat{\sigma}^2_{\varepsilon} + \hat{\sigma}^2_{T2})$

Table 9-5 THREE-FACTOR ANOVA OF PAR BY FOREST TYPE BEFORE AND AFTER TIME SERIES ANALYSIS[a]

			Before time series analysis						After time series analysis					
							Variance component[b]						Variance component[b]	
Forest region	Source	df	Sum of squares	Mean square	F	p(>F)	Estimate	%	Sum of squares	Mean square	F	p(>F)	Estimate	%
New England	Plot[c]	16	16 55652	1 03478	6 08	< 0 01	0 01351	43 3	16 73718	1 04607	10 60	< 0 01	0 01480	56 8
	C_1	(1)	4 95613	4 95613	29 10	< 0 01	–	–	4 90450	4 90450	49 72	< 0 01	–	–
	C_2	(1)	3.26700	3 26700	19 18	< 0.01	–	–	3 48548	3 48548	35.33	< 0 01	–	–
	Subplot[d]	51	8 68612	0 17032	22 61	< 0 01	0 01017	32 6	5 03118	0 09865	18 19	< 0 01	0 00583	22 4
	Station[e]	1020	7 68242	0 00753	–	–	0 00753	24 1	5 53261	0 00542	–	–	0 00542	20 8
	Total	1087	32 92506					100.0	27.30097					100 0
Virginia	Plot	18	10 17930	0 56552	9 63	< 0 01	0 00792	52 9	9 73833	0 54102	17 00	< 0 01	0 00796	61 3
	C_1	(1)	0 05038	0 05038	0.86	0 36	–	–	0.04289	0 04289	1 35	0.25	–	–
	C_2	(1)	1 79104	1 79104	30 51	< 0 01	–	–	1 87095	1 87095	58 79	< 0 01	–	–
	Subplot	57	3 34596	0 05870	16.26	< 0 01	0 00344	23 0	1.81388	0 03182	9.83	< 0 01	0 00179	13 8
	Station	1140	4 11497	0 00361	–	–	0 00361	24 1	3.68893	0 00324	–	–	0 00324	24 9
	Total	1215	17 64023					100 0	15 24114					100 0

[a] C_1 is a contrast of clear and cloudy sky conditions, and C_2 is a contrast of overcast and variably cloudy sky conditions C_1 and C_2 are orthogonal contrasts of plots in each forest type See Table 9-4 for contrast coefficients

[b] Variance components for plot, subplot, and station estimate σ_p^2, σ_{s1}^2, and σ_{T1}^2, respectively

[c] Plot percent $= 100\ \hat{\sigma}_p^2 / (\hat{\sigma}_p^2 + \hat{\sigma}_{s1}^2 + \hat{\sigma}_{T1}^2)$

[d] Subplot percent $= 100\ \hat{\sigma}_{s1}^2 / (\hat{\sigma}_p^2 + \hat{\sigma}_{s1}^2 + \hat{\sigma}_{T1}^2)$

[e] Station percent $= 100\ \hat{\sigma}_{T1}^2 / (\hat{\sigma}_p^2 + \hat{\sigma}_{s1}^2 + \hat{\sigma}_{T1}^2)$

The estimates of variance components obtained in this study can be used to select numbers of samples, stations, and subplots in future studies of the same general design (§3). The higher between-subplot variance will require more subplots on cloudy days to achieve the same precision of plot comparisons. The measurement of more subplots also implies additional measurements at the ambient station to maintain the same sampling design.

The serial correlation obtained under cloudy sky conditions was caused by the separation in time of the ambient PAR measurements from the series of under-canopy PAR measurements. With this design, any serial correlation in the actual ambient PAR owing to cloud passage during the under-canopy sampling period will cause serial correlation in the under-canopy measurements. Although serial correlation does not change the validity of the usual mean-value estimators, time series adjustments will always be needed to satisfy the assumptions of independence and to estimate appropriate standard errors for hypothesis testing. There is no guarantee that serial correlation can be identified after the fact, particularly in heterogeneous canopies, because spatial and temporal variances may be confounded For this reason, it may be worthwhile to make two consecutive measurements at every sampling station so that spatial and temporal variance can be cleanly separated

The reduced efficiency of this design on cloudy days was not fully corrected by an AR1 model of serial correlation. It may be that shifts in actual ambient PAR between subplots inflated the between-subplot variance. This variation would not be affected much by an AR1 model, but it should be detectable as nonstationarity of the time series and therefore amenable to analysis by other Box-Jenkins models. But here, the result was that more subplots and ambient measurements were needed to achieve the same precision of plot mean transmittance on cloudy days.

Cloudy sky conditions do not invalidate the sample design, but they do make it less efficient than it could be. These analyses emphasize the importance of obtaining comparable measurements of ambient PAR with which to estimate transmittance on cloudy days. Under clear sky conditions, the use of

ambient measurements made before and after the under-canopy measurements is acceptable because changes in ambient PAR are relatively small, slow, and predictable. But cloudy sky conditions (including overcast) can cause unpredictable, large, and fast changes in ambient PAR. The utility of the AR1 model suggests that cloud variability is important at a scale of minutes, but it is probably also important at other scales. Cloudy sky conditions also require larger canopy openings to obtain accurate estimates of ambient PAR.

Better estimates of station-by-station transmittance will probably not be obtained by simply increasing the frequency of visits to the ambient station, so long as there is a time lag between ambient and under-canopy measurements. Even continuous measurement of ambient PAR cannot guarantee comparability of measurements if the measurement devices are separated in space, because clouds are nonuniform in space as well as in time. Solutions to this sampling and data aggregation problem must consider the spatial and temporal scales at which inferences are to be made, relative to the scales at which cloud and canopy conditions are likely to change. One possibility is sequential sampling to achieve a target precision in both ambient and under-canopy situations. Another possibility is continuous measurement of ambient PAR and the use of a time-synchronized, running-average estimator of the ratio of under-canopy PAR to ambient PAR. The latter option was selected for testing in 1991.

9.5 MEASUREMENT QUALITY OBJECTIVES

This study was accompanied by a QA program to develop standard operating procedures and a methods manual (Dwire et al., 1990), to train, test, and field audit data collectors, and to perform QC remeasurements (Burkman and Mickler, 1990). Another aspect of the QA program that is addressed in this section is the definition of measurement quality objectives (MQOs) to guide future PAR studies.

Measurement quality is described by precision, accuracy, representativeness, repeatability, and completeness of a data set that is collected for a specific purpose. For deciding among alternate field data collection procedures, the most important data attributes are accuracy, repeatability, and precision. Precision is a function of the sampling design relative to the degree and structure of population variability, and is treated in detail in the discussion of variance components and sample design in Section 3. Objectives for accuracy and repeatability of PAR measurements require duplicate measurements in a variety of situations. If one measurement gives a "true" value, then the accuracy of a procedure can be assessed. Without a known (or assumed) true value, only repeatability can be assessed.

During the course of this study, duplicate measurements were made by trainers and crews during training, testing, QC visits, and audits In all cases, the same sampling design and measurement procedures were utilized. The duplicate measurements from the training plot, three test plots, and five field audit plots were used to suggest MQOs. (The training and test plots are within the Pocahontas State Forest, VA, in mixed loblolly pine-oak stands. The audit plots are numbers 267, 1958, 1959, 2190, and 2192.) Three of these 9 plots had 2 duplicate measurements, giving a total of 12 instances where both a trainer and a crewperson made measurements. A second set of remeasurement data were collected by the crewpersons on four plots (173, 267, 1955, and 2186) during QC visits. On one of these plots, two remeasurements were made by the crew, giving a total of six combinations of measurements.

Repeatability was assessed using bivariate plots of the duplicate estimates of plot average PTPAR and subplot average PTPAR (these estimates were not made using the logarithmic transformation) The correspondence of the two estimates is evidence of the repeatability of the procedure. In Figure 9-5, the crew estimates are plotted in relation to the trainer estimates from the first set of remeasurements, and there appears to be reasonably good correspondence. In Figure 9-6, the two crew estimates from the second set of remeasurements are plotted in relation to each other, and there appears to be much less correspondence.

It is reasonable to conclude that the repeatability of plot and subplot PTPAR was less in the operational situation than in the training, testing, and auditing situations. Some of the discrepancy is probably due to day-to-day variation in cloud conditions with the second set of remeasurement data It may also be speculated that the crews did not obtain a high level of repeatability because they

"rushed" the relatively simple PAR measurements. Although 2 h were allotted for PAR measurements, on average less than 1 h was utilized.

Assuming that the trainers obtained "true" values of PTPAR, it is possible to examine the accuracy of crew measurements by looking at the absolute value of the differences in estimates on a plot and subplot basis. Figure 9-7 shows the frequency distribution of these differences obtained for the first set of remeasurement data, and in most cases both the "error" in subplot and plot averages was 3% (absolute) or less.

These values were used to define MQOs as shown in Figure 9-8 and described by these equations.

Subplot MQO

$$Y_s = 2\% + 0.2 * (\text{True } \% - 10\%) \quad (4)$$

Plot MQO

$$Y_p = 1\% + 0.1 * (\text{True } \% - 5\%) \quad (5)$$

where Y_s and Y_p refer to the allowable errors (i.e., absolute differences between "true" and obtained estimates of PTPAR) for subplots and plots, respectively. Most of the values in Figure 9-8 that lie above these lines were obtained during early training and testing, and the later audit sample values fell mostly below the MQO lines, suggesting that accuracy improved during the course of the study.

Strictly, there was no independent test of whether the crews met these suggested MQOs, because there is no independent set of trainer and crew remeasurements. But if the data from the second set of (crew-only) remeasurements are used, and if the first measurement is arbitrarily defined to be the "true" value, then it appears that the MQOs were not generally met in operational settings (Fig. 9-9). The same reasons given for lack of repeatability would explain the apparent lack of accuracy.

9.6 LOGISTICS

The SF-80 device has an internal clock, and every observation is time-stamped. The analysis of these recorded times is summarized by region in Table 9-6.

Crews usually started sampling within one-half hour of the appointed time (11 a.m.). The New England crew started as early as 10 a.m. and as late as noon. The Virginia crews never started before about 11 a.m. but started as late as 1 p m

The average time required for subplot sampling (64 observations plus travel between stations within subplots) was 0.52 h in New England and 0.39 h in Virginia. The maximum time required was 0.75 h and the minimum was 0.23 h. Ambient samples (30 observations total) required about 0.08 h in both regions.

Travel time to and from the ambient station (four trips total) was relatively variable because the ambient station was not a fixed distance away from the plot and because crews sometimes had to search for an appropriate location. On average, about 0.25 h was required, but times as low as 0.09 h and as high as 0.80 h were recorded. Travel time between subplots 1 and 2, and between 3 and 4, averaged about 0.08 h with a maximum of 0.34 h and a minimum of 0.02 h.

This analysis does not account the time for "break," "thinking," or "helping someone else" during the sampling procedures. Some of the higher values (especially in the "travel" category) are probably due to these activities, and the overall averages are probably somewhat inflated. Yet overall, the crews required less than 1 h on average to complete the measurement procedures, and never exceeded the 2 h allotment of time. The actual on-station sampling time is less affected by extraneous activities; on average, about one-half hour was required to make and store 94 observations of PAR.

Table 9-6 TIME REQUIRED FOR PAR SAMPLING

	Mean (h)	Maximum (h)	Minimum (h)	C V (%)
New England				
Start time	10.99	11 87	9.98	4
Sampling time				
-Subplots	0 52	0 75	0 36	23
-Ambient	0 08	0 09	0 06	12
Travel time				
-To/from ambient	0.23	0 80	0 09	73
-Between subplots	0 08	0 17	0 04	41
Total time	0 90	1.60	0 60	26
Virginia				
Start time	11 50	13 17	10 57	6
Sampling time				
-Subplots	0 39	0 69	0 23	30
-Ambient	0 08	0 09	0 06	15
Travel time				
-To/from ambient	0 28	0 79	0 11	60
-Between subplots	0 08	0 34	0 02	88
Total time	0 82	1 77	0 47	36

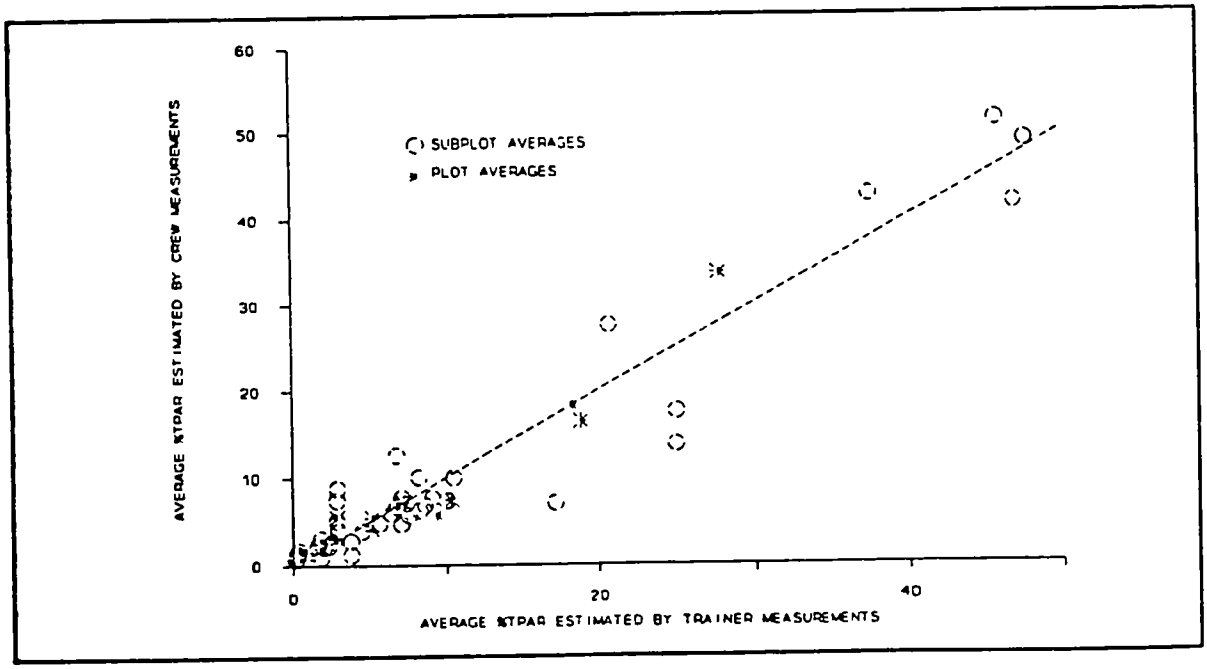

Figure 9-5. REPEATABILITY OF PTPAR IN TRAINING, TESTING, AND FIELD AUDITING EACH MEAN IS BASED ON 16 (SUBPLOT) OR 64 (PLOT) STATION MEASUREMENTS THE 1 1 RATIO LINE IS DRAWN FOR COMPARISON

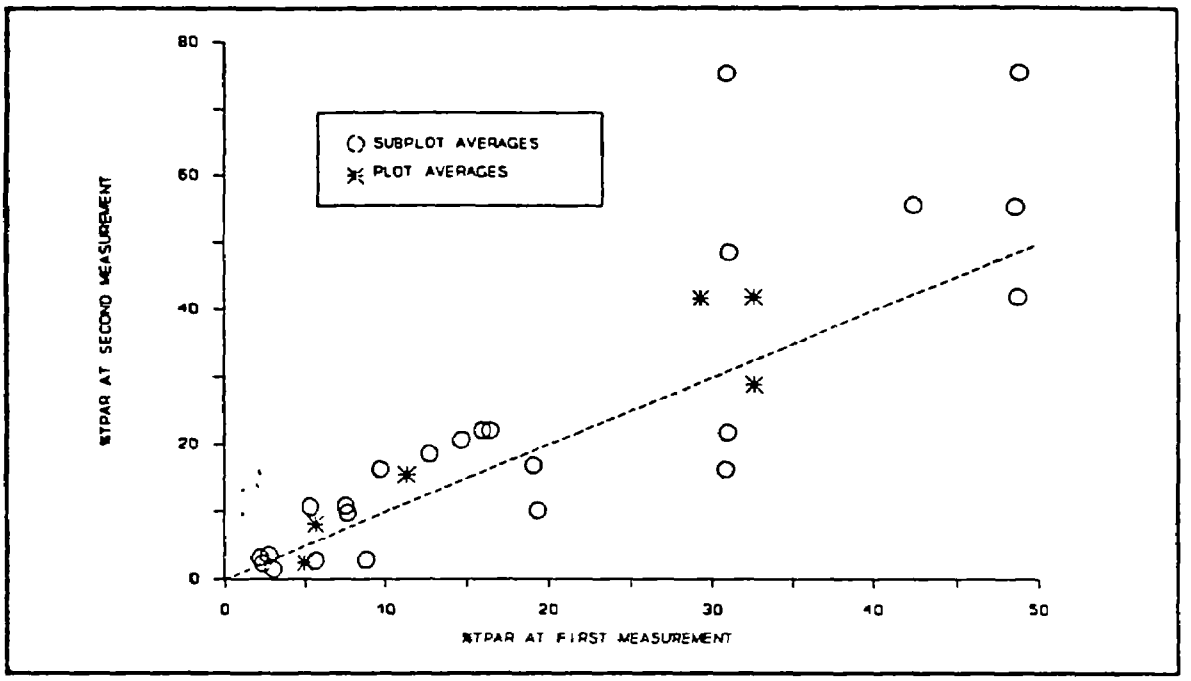

Figure 9-6 REPEATABILITY OF PTPAR IN CREW REMEASUREMENTS EACH MEAN IS BASED ON 16 (SUBPLOT) OR 64 (PLOT) STATION MEASUREMENTS THE 1 1 RATIO LINE IS DRAWN FOR COMPARISON (COMPARE TO FIGURE 9-5)

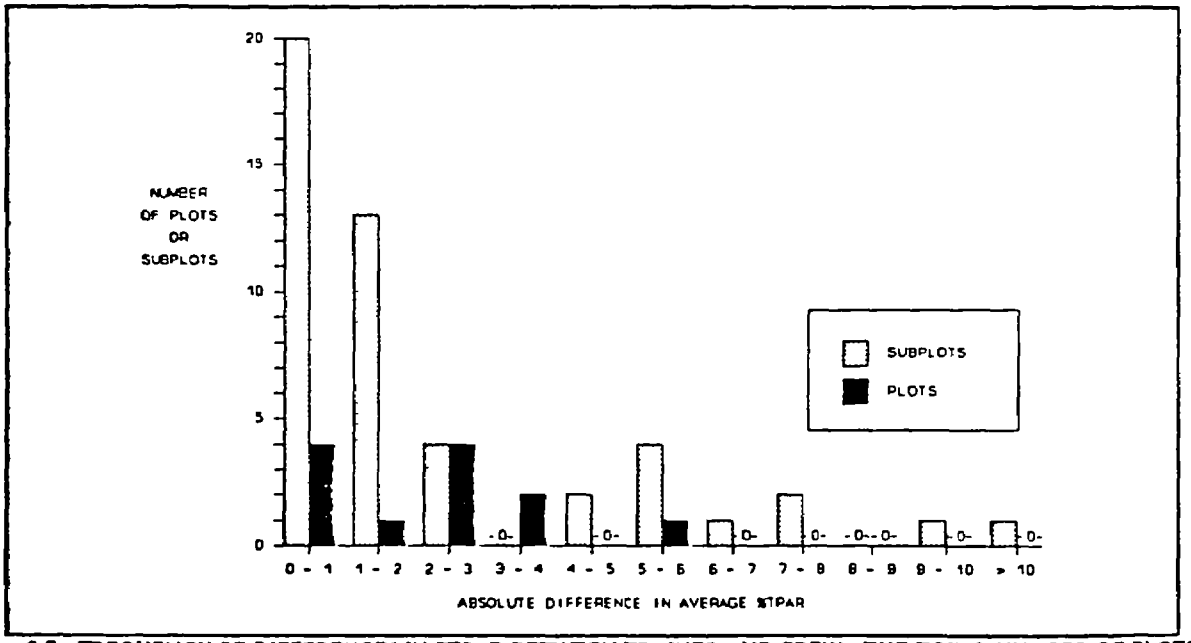

Figure 9-7. FREQUENCY OF DIFFERENCES IN PTPAR BETWEEN TRAINER AND CREW THE TOTAL NUMBER OF PLOTS IS 12 AND THE TOTAL NUMBER OF SUBPLOTS IS 48 SEE ALSO FIGURE 9-5

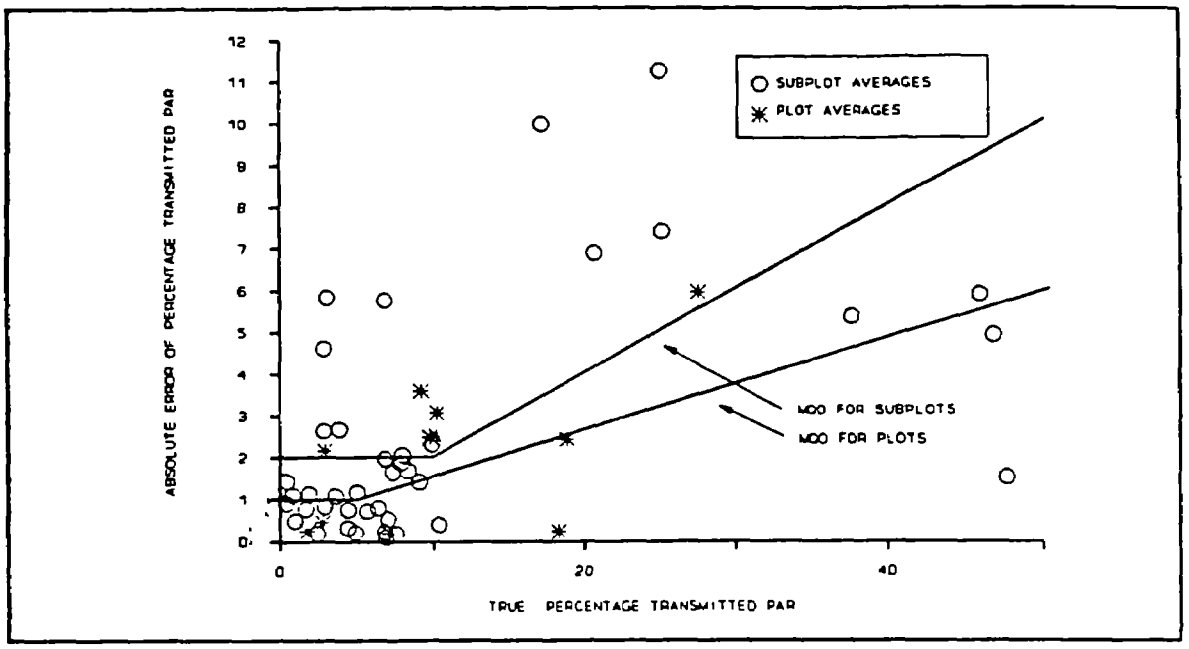

Figure 9-8 MEASUREMENT QUALITY OBJECTIVES FOR SUBPLOT AND PLOT MEAN PTPAR THE SUBPLOT MQO IS A 2% ABSOLUTE ERROR FOR PTPAR LESS THAN 10%, AND AN ADDITIONAL 20% RELATIVE ERROR FOR PTPAR GREATER THAN 10%. THE PLOT MQO IS A 1% ABSOLUTE ERROR FOR PTPAR LESS THAN 5%, AND AN ADDITIONAL 10% RELATIVE ERROR FOR PTPAR GREATER THAN 5% ALSO SHOWN ARE ERRORS IN SUBPLOT AND PLOT MEAN PTPAR ESTIMATES OBTAINED DURING TRAINING, TESTING, AND FIELD AUDITING

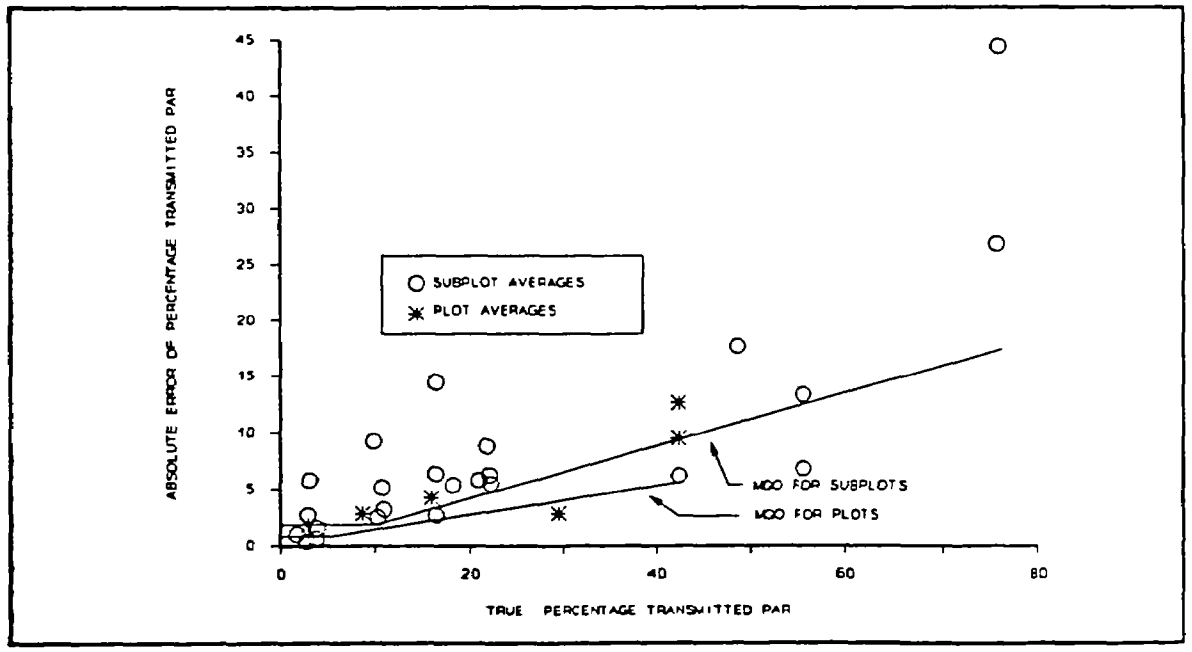

Figure 9-9. FIELD EXPERIENCES WITH MQOS BASED ON CREW REMEASUREMENTS ERROR CALCULATIONS ASSUME THE FIRST CREW MEASUREMENT IS "TRUE" THE MQOS ARE AS IN FIGURE 9-8

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APPENDIX A

SUPPLEMENTAL TABLES

Table A-1 DESCRIPTIVE DATA BY SUBPLOT AT EACH LOCATION

Plot no.	Subplot	Slope[a] percent	Aspect[b] degrees	Terrain position[c]	Micro-relief[d]	Landform[e]	Forest type[f]	Disturbance[g]
16	1	18	112	mid-slope	planar	headslope	red maple-northern hardwood	
	2	12	142	"	"	"	"	
	3	20	107	"	"	"	"	
	4	22	121	"	"	sideslope	"	
117	1	13	63	"	"	"	sugar maple-beech-yellow birch	
	2	12	50	"	"	"	"	
	3	23	47	"	"	"	"	
	4	18	72	"	"	"	"	
122	1	6	278	upper slope	"	ridgetop	"	
	2	25	348	"	convex	sideslope	"	
	3	5	80	"	planar	ridgetop	"	
	4	7	250	"	"	sideslope	"	
155	1	6	191	lower slope	"	"	"	
	2	8	192	mid-slope	"	"	"	
	3	0	0	flatland	"	none	"	insects
	4	0	0	"	"	"	"	
159	1	8	43	mid-slope	"	sideslope	"	
	2	5	20	lower slope	"	"	"	
	3	6	58	mid-slope	"	"	"	
	4	10	50	upper slope	"	"	"	
160	1	10	205	mid-slope	concave	headslope	"	
	2	6	216	upper slope	convex	sideslope	"	
	3	6	243	"	complex	headslope	"	
	4	7	238	mid-slope	concave	"	"	
166	1	15	177	lower slope	planar	headslope	sugar maple-beech-yellow birch	
	2	18	172	mid-slope	"	sideslope	"	
	3	10	175	lower slope	concave	headslope	"	
	4	16	130	mid-slope	complex	"	"	
173	1	10	222	lower slope	planar	"	red maple-northern hardwood	
	2	5	285	"	"	"	"	
	3	5	190	"	"	"	"	
	4	35	300	mid-slope	"	sideslope	"	
174	1	52	290	"	"	"	sugar maple-beech-yellow birch	
	2	35	261	"	"	"	"	
	3	86	305	upper slope	"	"	"	
	4	50	295	mid-slope	"	"	"	
181	1	15	197	"	"	"	"	
	2	17	195	"	"	"	"	
	3	6	190	"	"	ridgetop	"	site prep
	4	5	152	"	"	sideslope	"	
267	1	14	149	"	"	headslope	red maple-northern hardwood	
	2	15	65	"	"	sideslope	"	
	3	5	159	lower slope	"	headslope	"	
	4	20	260	mid-slope	"	sideslope	"	

Table A-1 (CONTINUED)

Plot no.	Subplot	Slope[a] percent	Aspect[b] degrees	Terrain position[c]	Micro-relief[d]	Landform[e]	Forest type[f]	Disturbance[g]
270	1	7	284	lower slope	concave	•	•	weather
	2	15	303	•	planar	•	•	
	3	10	285	mid-slope	•	•	•	
	4	22	310	lower slope	•	headslope	•	weather
289	1	13	102	mid-slope	planar	sideslope	red maple-northern hardwood	
	2	7	76	•	•	•	sugar maple-beech-yellow birch	
	3	9	88	•	•	•	•	
	4	15	87	upper slope	•	•	•	
321	1	24	174	mid-slope	•	•	•	
	2	20	160	upper slope	•	•	•	
	3	20	163	mid-slope	•	•	•	
	4	20	168	•	•	•	•	
347	1	16	291	•	concave	headslope	•	
	2	38	295	upper slope	planar	•	•	
	3	15	290	mid-slope	•	•	•	
	4	18	285	•	•	•	•	
420	1	5	352	lower slope	•	sideslope	red maple-northern hardwood	
	2	0	0	bottomland	•	none	sugar maple-beech-yellow birch	
	3	5	22	lower slope	•	sideslope	•	
	4	0	0	flatland	•	none	•	
508	1	5	250	lower slope	•	sideslope	•	
	2	8	230	upper slope	•	•	•	
	3	9	250	•	•	•	•	
	4	0	0	flatland	•	•	•	
692	1	5	22	lower slope	•	•	red maple-northern hardwood	
	2	0	0	flatland	•	none	•	
	3	5	64	lower slope	•	sideslope	•	
	4	17	15	mid-slope	•	•	•	
3270	1	12	55	mid-slope	convex	sideslope	sugar maple-beech-yellow birch	
	2	15	84	•	planar	•	•	
	3	7	30	•	•	•	•	
	4	24	87	•	•	•	•	
1839	1	0	0	flatland	•	none	loblolly	
	2	0	0	•	•	•	•	
	3	0	0	•	•	•	•	
	4	0	0	•	•	•	•	
1841	1	0	0	•	•	•	•	
	2	0	0	•	•	•	•	
	3	0	0	•	•	•	•	
	4	0	0	•	•	•	•	
1843	1	0	0	•	•	•	•	
	2	0	0	•	•	•	•	
	3	0	0	•	•	•	•	
	4	0	0	•	•	•	•	

Table A-1 (CONTINUED)

Plot no.	Subplot	Slope[a] percent	Aspect[b] degrees	Terrain position[c]	Micro-relief[d]	Landform[e]	Forest type[f]	Disturbance[g]
1954	1	0	0	•	•	•	•	
	2	0	0	•	•	•	•	
	3	0	0	•	•	•	•	
	4	0	0	•	•	•	•	
1955	1	0	0	bottomland	concave	draw	•	weather
	2	6	210	•	•	•	•	•
	3	0	0	•	•	•	•	•
	4	9	65	upper slope	convex	headslope	•	•
1957	1	5	115	mid-slope	convex	sideslope	loblolly	
	2	5	120	•	•	•	•	
	3	5	115	•	•	•	•	
	4	5	120	•	•	noseslope	•	fire
1958	1	0	0	flatland	planar	none	•	weather
	2	0	0	•	•	•	•	•
	3	0	0	•	•	•	•	•
	4	0	0	•	•	•	•	•
1959	1	0	0	•	•	•	•	
	2	0	0	•	•	•	loblolly-hardwood	
	3	0	0	•	•	•	loblolly	
	4	0	0	•	•	•	loblolly-hardwood	
2072	1	0	0	•	•	•	loblolly	
	2	0	0	•	•	•	•	
	3	0	0	•	•	•	•	
	4	0	0	•	•	•	•	
2074	1	0	0	•	•	•	•	fire
	2	0	0	•	•	•	•	
	3	0	0	•	•	•	•	
	4	0	0	•	•	•	•	
2075	1	0	0	•	•	•	•	
	2	0	0	•	•	•	loblolly-hardwood	
	3	0	0	•	•	•	loblolly	
	4	0	0	•	•	•	loblolly-hardwood	
2185	1	6	325	upper slope	convex	sideslope	loblolly	
	2	0	0	bench	complex	headslope	•	
	3	0	0	•	•	•	•	
	4	5	330	upper slope	convex	sideslope	•	
2186	1	0	0	flatland	planar	none	•	
	2	0	0	•	•	•	•	
	3	0	0	•	•	•	•	
	4	8	164	mid-slope	concave	sideslope	•	
2187	1	5	322	•	planar	•	•	
	2	8	310	•	•	•	•	
	3	6	25	•	•	•	•	
	4	7	320	•	•	•	•	

Table A-1 (CONTINUED)

Plot no.	Subplot	Slope[a] percent	Aspect[b] degrees	Terrain position[c]	Micro-relief[d]	Landform[e]	Forest type[f]	Disturbance[g]
2188	1	0	0	flatland	"	none	"	
	2	0	0	"	"	"	loblolly-hardwood	
	3	0	0	"	"	"	"	
	4	0	0	"	"	"	loblolly	
2189	1	0	0	"	"	"	"	
	2	10	310	mid-slope	complex	sideslope	"	
	3	5	170	flatland	planar	none	"	
	4	5	255	"	"	"	"	fire
2190	1	8	329	top of slope	"	headslope	"	
	2	9	320	lower slope	concave	draw	"	
	3	9	245	mid-slope	"	sideslope	"	
	4	10	222	"	"	"	"	
2191	1	5	306	mid-slope	planar	sideslope	loblolly	
	2	5	313	"	"	"	"	
	3	0	0	flatland	"	none	"	
	4	5	300	mid-slope	"	sideslope	"	
2192	1	5	21	lower slope	concave	"	"	
	2	5	357	mid-slope	"	"	"	
	3	10	299	"	planar	"	"	
	4	10	19	"	"	"	"	
2303	1	5	45	"	complex	"	"	
	2	5	44	"	"	"	"	
	3	5	305	flatland	"	"	"	
	4	5	203	mid-slope	"	"	"	

[a] Percentage slope at subplot center (Zedaker and Nicholas, 1988)
[b] Direction of exposure for land surfaces that have slope >5% (Zedaker and Nicholas, 1988)
[c] The location of the subplot along the slope profile (Zedaker and Nicholas, 1988)
[d] The shape of a slope or slope position on which the subplot is located (Zedaker and Nicholas, 1988)
[e] The position of the subplot with respect to surrounding topography (Zedaker and Nicholas, 1988)
[f] Subjective judgement based on plurality of species in dominant and co-dominant crown classes See Table 3 for descriptions (From Duire et al , 1990).
[g] Evidence of named type of disturbance on the subplot

Table A-2 OVERSTORY NUMBERS OF TREES, BASAL AREA, AND AVERAGE DIAMETER BY SPECIES

Plot no.	Species	No of trees	Basal area	Avg dbh[a]
		ha^{-1}	m^2/ha	cm
16	eastern white pine	267	13 95	25 8
	red maple	163	7.32	23 9
	paper birch	59	2.77	24 4
	white ash	30	0 69	17.2
	black cherry	89	3 08	21 0
	northern red oak	44	0 48	11 7
117	eastern hemlock	44	2 06	24 3
	red maple	44	3 42	31 3
	sugar maple	178	9 67	26 3
	yellow birch	119	4 80	22 7
	paper birch	74	2 56	21 0
	American beech	30	5.18	47 2
	eastern hophornbeam	30	0 25	10 3
	American basswood	15	0 25	14 7
122	red spruce	44	1 33	19 5
	eastern hemlock	415	13 45	20 3
	red maple	119	4 14	21 1
	sugar maple	222	4.72	16 4
	yellow birch	30	0 46	14 1
	paper birch	44	1 79	22 6
	American beech	282	6 08	16 6
	white ash	15	0 48	20 3
	bigtooth aspen	133	5 92	23 8
155	balsam fir	89	1 12	12 6
	red spruce	15	0 12	10 2
	red maple	119	6 32	26 0
	sugar maple	222	4 21	15 5
	yellow birch	59	3.82	28 6
	black cherry	89	3 97	23 8
159	balsam fir	148	1 76	12 3
	eastern hemlock	44	3 83	33.1
	red maple	222	6.98	20 0
	sugar maple	148	2 40	14 4
	yellow birch	267	7.27	18 6
	American beech	15	0 26	15 0
	white ash	148	7.88	26.0
160	balsam fir	30	0 36	12 5
	red spruce	30	2 08	29 9
	eastern hemlock	252	8 55	20 8
	red maple	326	17 45	26 1
	sugar maple	104	3 50	20 7
	yellow birch	59	4 15	29 9
	American beech	15	0 15	11.2
	eastern hophornbeam	30	0 77	18 1
	black cherry	44	4 19	34 6
166	balsam fir	30	1 29	23 5
	red spruce	133	2 46	15 3
	red maple	15	1 19	32 0
	sugar maple	119	5 50	24 3
	yellow birch	89	9 41	36 7
	American beech	341	6 32	15 4
	white ash	44	1 54	21 0
173	eastern white pine	74	1 46	15 8
	eastern hemlock	415	10 81	18 2
	red maple	89	3 60	22 7
	sugar maple	44	0 65	13 7
	yellow birch	44	1 72	22 2
	sweet birch	44	0 71	14 2
	paper birch	59	1 09	15 3
	American beech	119	1 70	13 5
	white ash	44	1 22	18 7
	black cherry	30	2 19	30 6
	northern red oak	59	7 39	39 8
174	eastern hemlock	311	9 61	19 8
	sugar maple	252	10 05	22 5
	yellow birch	15	1 37	34 3
	paper birch	30	3 36	38 0
	American beech	119	6 70	26 8
	eastern hophornbeam	15	0 15	11 2
	northern red oak	44	16 29	68 3
181	balsam fir	15	0 11	9 7
	red spruce	44	0 44	11 2
	red maple	15	0 12	10 2
	sugar maple	311	9 07	19 3
	yellow birch	119	8 55	30 3
	sweet birch	15	0 08	8 4
	American beech	15	0 09	8 9
	common choke cherry	178	1 15	9 1
267	balsam fir	59	1 22	16 2
	white spruce	15	1 03	29 7
	red spruce	59	1 18	15 9
	striped maple	178	1 28	9 6
	red maple	356	11 84	20 6
	sugar maple	30	0 27	10 8
	yellow birch	119	3 67	19 8
	paper birch	30	2 68	33 9
	white ash	15	0 10	9 1

Table A-2 (CONTINUED)

Plot no.	Species	No. of trees	Basal area	Avg dbh
		ha^{-1}	m^2/ha	cm
270	eastern white pine	30	2 60	33 4
	eastern hemlock	267	8 38	20 0
	red maple	104	2 54	17 6
	sugar maple	59	0 61	11 5
	yellow birch	30	0.51	14 8
	sweet birch	178	7 18	22 7
	paper birch	30	0 54	15 2
	American beech	44	2 85	28 6
	white oak	44	2 65	27 5
	northern red oak	119	7.21	27 8
289	balsam fir	104	1.86	15 1
	red spruce	30	1.15	22 2
	striped maple	15	0 18	12 4
	red maple	534	5 57	11 5
	yellow birch	15	0 11	9 9
	paper birch	59	1 85	19 9
	American beech	59	1 06	15 1
	bigtooth aspen	252	7.58	19 6
	quaking aspen	15	0 48	20 3
321	red spruce	44	2 56	27 1
	red maple	44	6 98	44 7
	sugar maple	415	7 95	15 6
	American beech	237	10 72	24 0
	eastern hophornbeam	15	0 83	26 7
347	balsam fir	148	5.20	21 1
	red spruce	252	4 65	15 3
	striped maple	30	0 64	16 5
	red maple	44	1 62	21 6
	sugar maple	89	3 87	23 5
	yellow birch	148	11 56	31 5
	sweet birch	15	0 09	8 6
	paper birch	44	0 94	16 4
	cherry	59	1 54	18 2
	American mountain-ash	74	0 74	11 2
420	balsam fir	44	1 26	19 0
	red spruce	222	6.52	19 3
	eastern hemlock	15	2 71	48 3
	striped maple	74	0.72	11.1
	red maple	267	11 15	23 1
	yellow birch	15	1 06	30 2
	American beech	30	0 97	20 4
	eastern hophornbeam	44	0 68	14 0
508	balsam fir	89	1.07	12 4
	white spruce	59	4.26	30 3
	red maple	311	11 14	21 3
	sugar maple	237	7 44	20 0
	American beech	148	3 90	18 3
	eastern hophornbeam	30	0 29	11 1
	quaking aspen	282	3 20	12 0
692	balsam fir	400	4 80	12 4
	red spruce	178	6 19	21 0
	eastern white pine	89	3 07	21 0
	northern white-cedar	44	1 51	20 8
	red maple	163	4 42	18 6
	bigtooth aspen	15	2 38	45 2
3270	balsam fir	133	1 21	10 8
	red spruce	104	2 60	17 8
	striped maple	30	0 15	8 0
	red maple	104	4 00	22 2
	sugar maple	104	3 93	22 0
	yellow birch	193	7 05	21 6
	paper birch	297	5 07	14 8
	American beech	15	0 10	9 4
	common choke cherry	208	1 97	11 0
	American mountain-ash	30	2 04	29 6
1839	loblolly pine	489	21 84	23 8
	red maple	237	2 83	12 3
	sweetgum	44	0 47	11 6
	lowland blackgum	59	0 74	12 6
	white oak	30	0 54	15 2
	willow oak	89	9 13	36 1
1841	loblolly pine	341	25 87	31 1
	red maple	30	3 05	36 2
	sweetgum	682	8 59	12 7
	elm	148	2 33	14 1
1843	loblolly pine	400	16 30	22 8
	red maple	193	2 85	13 7
	American holly	15	0 14	10 9
	sweetgum	44	0 54	12 4
	sweetbay	74	0 47	9 0
	lowland blackgum	74	0 42	8 5
	white oak	267	4 60	14 8
	water oak	74	0 94	12 7

Table A-2 (CONTINUED)

Plot no.	Species	No of trees	Basal area	Avg dbh
		ha^{-1}	m^2/ha	cm
1954	loblolly pine	474	37 77	31 8
	red maple	282	3 96	13 4
	persimmon	15	0 11	9 9
	sweetgum	208	3 59	14 8
	lowland blackgum	15	0 16	11 7
	elm	44	1 13	18 0
1955	loblolly pine	311	19 93	28 5
	Virginia pine	15	0 61	22 9
	red maple	178	2 20	12 5
	black walnut	15	0 99	29 2
	sweetgum	30	0 97	20 5
	lowland blackgum	15	0 12	10 2
1957	loblolly pine	193	15 36	31 9
	red maple	74	2 40	20 3
	flowering dogwood	74	0 64	10 5
	persimmon	15	0 09	8 6
	American holly	44	0 32	9.5
	sweetgum	311	4 88	14 1
	lowland blackgum	15	0 11	9 9
	sourwood	15	0 29	15 7
	white oak	30	1 26	23 3
1958	loblolly pine	311	12 17	22 3
	red maple	104	0 98	11 0
1959	loblolly pine	534	16 24	19 7
	red maple	178	6 26	21 2
	American beech	104	2 77	18 4
	American holly	89	1 34	13 8
	sweetgum	104	2 37	17 0
	sourwood	44	0 47	11 6
	white oak	15	2 10	42 4
	water oak	74	3 84	25 7
	post oak	15	0 74	25 1
2072	loblolly pine	474	21 58	24 1
	Virginia pine	15	0 13	10.7
	red maple	119	1 08	10 8
	hickory	74	0 99	13 1
	flowering dogwood	15	0 08	8 1
	American beech	15	0 21	13 5
	American holly	15	0 08	8 4
	sweetgum	133	1 50	12 0
	yellow-poplar	89	0 85	11 0
	white oak	208	2 40	12.1
	scarlet oak	15	0 29	15 7
	southern red oak	44	0 41	10 8
	post oak	15	0 09	8 6
	black oak	30	0 38	12 8
2074	loblolly pine	549	17 98	20 4
	red maple	15	0 08	8 1
	American holly	44	0 45	11 3
	sweetgum	59	0 72	12 4
	yellow-poplar	15	0 19	12 7
	sourwood	89	1 52	14 8
	white oak	15	0 35	17 3
	scarlet oak	15	0 10	9 1
	southern red oak	415	4 59	11 9
	water oak	15	0 23	14 0
	willow oak	30	0 19	9 0
2075	loblolly pine	489	22 67	24 3
	red maple	15	0 14	10 9
	bluebeech	15	0 09	8 6
	hickory	59	1 66	18 9
	American holly	15	0 09	8 9
	sweetgum	30	3 61	39 4
	southern red oak	15	0 17	11 9
	water oak	15	0 23	14 0
	willow oak	59	6 41	37 1
	post oak	15	0 10	9 1
	black oak	74	4 08	26 5
2185	eastern redcedar	44	0 24	8 3
	loblolly pine	297	21 75	30 6
	Virginia pine	652	16 17	17 8
	sweetgum	15	0 23	14 0
	lowland blackgum	30	0 30	11 3
	black cherry	15	0 07	7 9
2186	loblolly pine	801	31 00	22 2
	Virginia pine	252	5 42	16 5
	red maple	44	0 30	9 3
	sweetgum	44	0 48	11 7
	yellow-poplar	30	1 39	24 4
2187	loblolly pine	356	11 23	20 0
	Virginia pine	400	8 35	16 3
	yellow birch	104	0 98	11 0
	American holly	15	0 07	7.6
	sweetgum	74	1 83	17 7
	yellow-poplar	208	4 84	17 2
	upland blackgum	15	0 15	11 2
	southern red oak	163	1 47	10 7
	black oak	59	1 20	16 0

Table A-2 (CONTINUED)

Plot no.	Species	No of trees	Basal area	Avg dbh
		ha^{-1}	m^2/ha	cm
2188	loblolly pine	534	12 94	17.6
	red maple	104	0 61	8 7
	sweetgum	208	2 98	13 5
	lowland blackgum	74	0 60	10 1
	white oak	30	1 04	21 2
	southern red oak	15	0 65	23 6
	water oak	15	0 07	7 9
	willow oak	74	8 04	37 1
	black oak	15	0 25	14 7
2189	eastern redcedar	15	0 09	8 6
	shortleaf pine	89	6 54	30 6
	loblolly pine	593	13 34	16 9
	red maple	15	0 24	14 5
	hickory	30	0 15	8 1
	yellow-poplar	104	1 22	12 3
	bigtooth aspen	148	2 68	15 2
	white oak	193	2 67	13 3
	scarlet oak	44	0 59	12 9
	black oak	15	0 24	14 5
2190	loblolly pine	148	8 90	27 6
	red maple	15	0 58	22 4
	bluebeech	119	1 76	13 7
	hickory	15	0 10	9 1
	flowering dogwood	15	0 11	9 7
	American holly	30	0 18	8 9
	sweetgum	148	4 12	18 8
	yellow-poplar	208	4 26	16 2
	lowland blackgum	44	0 48	11 8
	white oak	59	0 45	9 8
	southern red oak	133	2 62	15 8
	northern red oak	15	0 41	18 8
	elm	15	0 17	12 2
2191	shortleaf pine	30	0.62	16 3
	loblolly pine	1067	22 67	16 4
	hickory	15	0.13	10 7
	sweetgum	163	1 93	12 3
	lowland blackgum	15	0 11	9 7
	sourwood	15	0 07	7 6
	white oak	15	1 35	34 0
	black oak	15	0 12	10 2
2192	eastern redcedar	15	0 17	11 9
	loblolly pine	830	32 74	22 4
	red maple	30	0 16	8 3
	sweetgum	297	3 00	11 3
	yellow-poplar	341	6 19	15 2
	sourwood	30	0 22	9 7
	southern red oak	15	0 13	10 4
2303	loblolly pine	237	16 30	29 6
	Virginia pine	89	5 25	27 4
	flowering dogwood	15	0 08	8 4
	sweetgum	148	2 26	13 9
	yellow-poplar	163	1 81	11 9
	southern red oak	59	0 36	8 8
	black oak	15	0 07	7 6
	sassafras	30	0 27	10 7

[a] Diameter of the tree of average basal area

Table A-3. MEANS AND STANDARD DEVIATIONS OF ELEMENTAL CONCENTRATIONS IN SUGAR MAPLE FOLIAR TISSUE

Plot	Subplot	Mean	SD
Aluminum			
122	1	51	6
	2	45	9
	3	56	4
159	1	65	12
	3	73	1
	4	56	4
174	1	70	14
	2	72	8
	3	66	9
267	1	59	6
	2	63	9
	3	53	24
270	3	41	10
321	1	26	8
	2	26	7
	4	35	0
Carbon			
122	1	46 8	1 04
	2	47 3	0 58
	3	46 5	0 24
159	1	46 0	0 28
	3	46 6	0 15
	4	46 4	0 64
174	1	46 2	0 66
	2	46 0	0 20
	3	46 0	0 43
267	1	45 8	0 48
	2	45 6	0 25
	3	46 4	0 37
270	3	47 5	0 45
321	1	46 8	0 64
	2	47.5	0 43
	4	47 1	0 38
Nitrogen			
122	1	1.57	0 074
	2	1 47	0 078
	3	1 69	0 163
159	1	1 33	0 237
	3	1 60	0 212
	4	1 45	0 081
174	1	2 10	0 004
	2	1 88	0 000
	3	1 29	0.035
267	1	1.51	0 106
	2	1 79	0 067
	3	1 99	0 159
270	3	1 42	0 114
321	1	2 09	0 050
	2	2 21	0 110
	4	2 17	0 007

Plot	Subplot	Mean	SD
Silicon			
122	1	1898	283
	2	1915	375
	3	1805	134
159	1	2828	126
	3	2504	503
	4	4459	955
174	1	2598	735
	2	2588	318
	3	1830	697
267	1	3057	1332
	2	3025	757
	3	2831	717
270	3	444	35
321	1	381	56
	2	347	83
	4	341	25
Mercury			
122	1	n d	n d
	2	n d	n d
	3	n d	n d
159	1	n d	n d
	3	n d	n d
	4	4	7
174	1	5	8
	2	n d	n d
	3	6	5
267	1	n d	n d
	2	n d	n d
	3	33	43
270	3	n d	n d
321	1	n d	n d
	2	n d	n d
	4	n d	n d
Zinc			
122	1	23	1 4
	2	21	1 4
	3	36	8 5
159	1	21	4 9
	3	29	3 5
	4	28	7 1
174	1	32	4 9
	2	31	4 9
	3	33	3 5
267	1	30	1 4
	2	36	16 3
	3	25	2 1
270	3	24	2 6
321	1	24	11 3
	2	30	2 8
	4	24	1 4

Table A-3 (CONTINUED)

Plot	Subplot	Mean	SD	Plot	Subplot	Mean	SD
Phosphorus				Manganese			
122	1	1392	458	122	1	1134	150
	2	1074	113		2	898	315
	3	1375	84		3	1379	242
159	1	820	76	159	1	526	62
	3	899	78		3	531	115
	4	888	66		4	636	26
174	1	1380	245	174	1	813	198
	2	1104	88		2	491	75
	3	1227	91		3	1158	84
267	1	1586	330	267	1	812	66
	2	1938	781		2	1468	1039
	3	1322	94		3	317	41
270	3	1142	285	270	3	1401	681
321	1	1311	396	321	1	1691	687
	2	1172	52		2	1526	369
	4	1101	8		4	930	25
Iron				Magnesium			
122	1	49	1	122	1	995	21
	2	52	8		2	905	6
	3	61	4		3	1381	365
159	1	53	4	159	1	1491	194
	3	70	6		3	1275	250
	4	54	1		4	1064	199
174	1	85	13	174	1	1752	383
	2	74	6		2	1434	231
	3	77	15		3	1927	36
267	1	49	6	267	1	1331	477
	2	65	7		2	1742	180
	3	54	3		3	1984	26
270	3	74	2	270	3	1244	132
321	1	73	33	321	1	1428	415
	2	69	9		2	1251	429
	4	80	12		4	1535	251
Copper				Sodium			
122	1	8	2.1	122	1	70	47
	2	5	0 0		2	282	14
	3	10	4.2		3	184	25
159	1	8	1 4	159	1	164	65
	3	8	0 7		3	328	64
	4	6	0 0		4	167	139
174	1	8	1 4	174	1	200	49
	2	9	0 7		2	228	164
	3	8	2 1		3	204	173
267	1	8	2 1	267	1	265	113
	2	9	2 8		2	154	6
	3	12	0 7		3	141	68
270	3	7	2 4	270	3	69	63
321	1	10	2 1	321	1	7	159
	2	10	6 4		2	66	44
	4	8	0 0		4	48	55

Table A-3 (CONTINUED)

Plot	Subplot	Mean	SD	Plot	Subplot	Mean	SD
Cobalt				Titanium			
122	1	1	1 4	122	1	14 5	3 5355
	2	3	2 8		2	n d	n d
	3	4	3.5		3	n d	n d
159	1	2	0 7	159	1	19 5	0 7071
	3	4	0 7		3	18	4 2426
	4	2	0 7		4	20 5	0 7071
174	1	4	0 0	174	1	26 5	0 7071
	2	3	0 7		2	23 5	10 6066
	3	4	0.7		3	28	2 8284
267	1	2	0 0	267	1	21 5	2 1213
	2	3	0 7		2	26 5	2 1213
	3	n d	n d		3	15	4 2426
270	3	4	0 5	270	3	n d	n d
321	1	4	2.8	321	1	n d	n d
	2	4	0.7		2	n d	n d
	4	4	1 4		4	n d	n d
Nickel				Chromium			
122	1	3	0 7	122	1	11	4 2
	2	5	2 8		2	8	1 4
	3	5	2 8		3	10	0 7
159	1	3	0.7	159	1	11	1 4
	3	3	0 0		3	16	0 7
	4	3	0 7		4	14	1 4
174	1	5	0.0	174	1	16	2 8
	2	4	0 0		2	15	0 0
	3	7	0 0		3	14	0 0
267	1	3	0.0	267	1	14	0 7
	2	4	1.4		2	16	3 5
	3	2	1 4		3	12	0 7
270	3	5	1.7	270	3	2	0 5
321	1	7	4 2	321	1	6	3 5
	2	6	0 7		2	8	6 4
	4	5	1 4		4	3	0 7
Potassium				Lead			
122	1	7705	757	122	1	28	3
	2	8490	515		2	27	7
	3	9606	872		3	22	6
159	1	8445	243	159	1	21	0
	3	8887	328		3	31	14
	4	9441	2351		4	32	15
174	1	8362	2193	174	1	41	0
	2	7372	112		2	41	0
	3	5948	1241		3	31	14
267	1	10303	2199	267	1	21	0
	2	10245	270		2	31	14
	3	10703	2244		3	31	14
270	3	5751	909	270	3	14	5
321	1	9060	677	321	1	11	1
	2	7983	1387		2	18	15
	4	8266	1379		4	11	3

Table A-3 (CONTINUED)

Plot	Subplot	Mean	SD
Cadmium			
122	1	2	0 7
	2	n d	n d
	3	n d	n d.
159	1	n d	n d
	3	2	0 7
	4	2	0 7
174	1	1	0 0
	2	2	0 7
	3	2	0 7
267	1	n d	n d
	2	n d	n d
	3	n d	n d
270	3	n d	n d
321	1	n d	n d
	2	n d	n d
	4	n d	n d
Strontium			
122	1	39	14 1
	2	32	3 5
	3	41	6 4
159	1	40	5 7
	3	38	8 5
	4	30	4 2
174	1	90	9 9
	2	82	2 8
	3	78	2.8
267	1	36	12 7
	2	44	9 2
	3	40	5 7
270	3	62	7 3
321	1	49	17 7
	2	39	8 5
	4	66	0 7
Arsenic			
122	1	21	3 5
	2	n d	n d
	3	n d	n d
159	1	27	1 4
	3	21	2 1
	4	36	2 8
174	1	n.d	n d
	2	27	15 6
	3	n d	n d
267	1	n d	n d
	2	32	9 2
	3	n d.	n d
270	3	n d	n d
321	1	18	7.8
	2	n.d	n d
	4	19	8.5

Plot	Subplot	Mean	SD
Molybdenum			
122	1	n d	n d
	2	n.d.	n d
	3	1	1 4
159	1	4	1 4
	3	6	0 7
	4	5	0 7
174	1	6	2 1
	2	12	6 4
	3	8	4 9
267	1	5	2 8
	2	6	1 4
	3	11	10 6
270	3	3	2 6
321	1	4	0 7
	2	3	1 4
	4	5	1 4
Lithium			
122	1	103	41
	2	78	26
	3	122	30
159	1	138	54
	3	167	21
	4	92	26
174	1	178	66
	2	184	30
	3	142	0
267	1	132	64
	2	169	60
	3	145	16
270	3	88	15
321	1	91	52
	2	60	14
	4	125	47
Barium			
122	1	155 0	73 54
	2	117 5	44 55
	3	166 5	26 16
159	1	131.0	36 77
	3	131 0	35 36
	4	142 5	10 61
174	1	119 5	17 68
	2	91.5	9 19
	3	97 5	4 95
267	1	170 0	49 50
	2	276 5	140 71
	3	88 5	12 02
270	3	162 3	52 83
321	1	236 5	119 50
	2	233.5	129 40
	4	220 5	2 12

Table A-3 (CONTINUED)

Plot	Subplot	Mean	SD	Plot	Subplot	Mean	SD
Boron				Sulfur			
122	1	49	0	122	1	0 23	0 021
	2	42	2		2	0 19	0 032
	3	49	8		3	0 23	0 039
159	1	51	9	159	1	0.25	0 021
	3	57	1		3	0 22	0 042
	4	59	3		4	0 23	0 011
174	1	61	1	174	1	0 23	0 004
	2	71	13		2	0 22	0 011
	3	37	6		3	0 18	0 014
267	1	36	1	267	1	0 24	0 014
	2	40	4		2	0 27	0 007
	3	50	16		3	0 27	0 039
270	3	41	15	270	3	0 16	0 031
321	1	31	9	321	1	0 22	0 011
	2	26	1		2	0 17	0 042
	4	20	4		4	0 14	0 018
Calcium				Vanadium			
122	1	6044	2416	122	1	n d	n d
	2	4758	2249		2	n d	n d
	3	6313	1436		3	n d	n d
159	1	11801	2051	159	1	13	2
	3	11204	742		3	15	3
	4	8808	1860		4	18	2
174	1	14683	1308	174	1	16	0
	2	14623	1221		2	13	4
	3	13125	727		3	12	1
267	1	10810	3400	267	1	11	1
	2	13634	2439		2	16	1
	3	14186	1773		3	n d.	n d
270	3	5414	245	270	3	n d	n d
321	1	5643	2258	321	1	n d	n d
	2	4871	1459		2	n d	n d
	4	7614	373		4	13	5

Table A-4. MEANS AND STANDARD DEVIATIONS FOR ELEMENTAL ANALYSES OF LOBLOLLY PINE FOLIAR SAMPLES*

Plot	Subplot	$Mean_I$	SD_I	$Mean_C$	SD_C	SD_{WI}
Aluminum						
1843	1	218	39	244	97	16
	2	309	18	266	49	55
	3	240	60	273	102	34
1954	1	563	91	565	114	31
	3	437	25	457	5	22
	4	451	74	444	49	11
1955	1	563	186	556	151	39
	2	412	170	388	155	5
	4	322	58	320	71	22
1959	1	163	17	157	6	14
	2	273	9	266	2	15
	3	288	2	279	12	51
2072	1	618	62	627	78	17
	2	514	247	530	298	113
	3	565	122	563	106	12
2187	1	593	243	603	222	23
	3	609	158	612	170	25
	4	505	28	490	33	20
2189	1	467	22	474	16	38
	2	567	30	563	4	15
	3	718	266	717	253	55
Carbon						
1843	1	51 6	0 16	52 0	0 11	0 33
	2	51.3	0 72	51 3	0 70	0 69
	3	51 5	0 28	52 2	0 22	0 69
1954	1	50 6	0 70	50 9	0 84	0 44
	3	51 1	0 49	50 9	0 01	0 08
	4	50 9	0 45	51 0	0 16	0 16
1955	1	50 9	0 36	50 7	0 48	0 53
	2	50 9	0 72	50 9	0 45	0 06
	4	50 7	0 60	50 4	0 35	0 63
1959	1	49 3	0 26	49 3	0 60	0 20
	2	49 5	0 79	48 6	0 14	0 18
	3	49 2	0 01	49 4	0 18	0 78
2072	1	51 0	0 12	51 3	0 46	0 57
	2	49 4	0 55	49 5	0 20	0 30
	3	50 9	0 45	51 1	0 12	0 78
2187	1	51.1	0 26	50 8	0 02	0 04
	3	50 7	0 48	50 7	0 47	0 27
	4	51 1	0 49	52 6	2 50	0 29
2189	1	51 5	0 01	51 6	0 21	0 40
	2	51 6	0 16	51 7	0 16	0 49
	3	51 2	0 87	51.3	1 19	0 57

Plot	Subplot	$Mean_I$	SD_I	$Mean_C$	SD_C	SD_{WI}
Nitrogen						
1843	1	0 97	0 042	0 97	0 050	0 022
	2	1 02	0 039	1 00	0.042	0 034
	3	0 98	0 083	0 99	0 088	0 046
1954	1	1 31	0 186	1 30	0 145	0 084
	3	1 31	0 050	1 31	0 021	0 013
	4	1.13	0 072	1 13	0 057	0 045
1955	1	1 17	0 050	1 12	0 035	0 040
	2	0 82	0 152	0 81	0 180	0 060
	4	1 10	0 101	1 16	0 106	0 052
1959	1	1 18	0 175	1 21	0 053	0 046
	2	1 26	0 348	1 28	0 375	0 173
	3	1 08	0 012	1 05	0 042	0 081
2072	1	1 00	0 078	1 03	0 092	0 026
	2	1 13	0 131	1 11	0 113	0 045
	3	0 86	0 067	0 86	0 021	0 025
2187	1	1 08	0 037	1 07	0 156	0 085
	3	0 93	0 080	0 93	0 127	0 065
	4	1 02	0 069	1 03	0 007	0 006
2189	1	0 95	0 021	0 95	0 007	0 022
	2	1 08	0 057	1 06	0 071	0 021
	3	0 97	0 113	0 96	0 141	0 022
Silicon						
1843	1	380	90	463	168	34
	2	556	9	529	98	45
	3	427	39	463	144	40
1954	1	915	12	871	15	48
	3	1207	138	1210	40	142
	4	903	214	960	167	32
1955	1	1747	788	1389	264	398
	2	980	19	776	202	108
	4	696	241	756	214	232
1959	1	608	5	517	77	41
	2	1042	764	1106	667	215
	3	973	250	945	622	806
2072	1	1888	23	2023	54	85
	2	1210	765	1372	529	528
	3	1293	561	1272	457	214
2187	1	990	85	1313	67	106
	3	1130	240	1169	269	63
	4	1015	786	1395	846	385
2189	1	878	158	921	7	81
	2	823	219	882	227	191
	3	1122	65	1102	54	178

Table A-4 (CONTINUED)

Plot	Subplot	$Mean_t$	SD_t	$Mean_c$	SD_c	SD_{wt}
Mercury						
1843	1	n d	n d	n d	n d.	n d.
	2	n d	n d	n d.	n d	n d
	3	n d	n d	n d	n d	n d.
1954	1	n d	n d	n d	n d	n d
	3	n d	n d	n d	n d	n d
	4	22	39	n d	n d.	n d
1955	1	5	7	-2	2	5
	2	n d	n d	n d	n d	n d
	4	6	5	n d	n d	n d
1959	1	n d	n d	n d	n d	n d
	2	n d	n d	13	20	n d
	3	n d	n d	n d	n d	n d.
2072	1	n d.	n d	n d	n d	n d
	2	n d	n d	7	10	n d
	3	n d	n d	n d	n d.	n d
2187	1	n d	n d	n d	n d	n d
	3	n d	n d	n d	n d	n d
	4	8	15	n d	n d	20
2189	1	n d	n d	n d	n d.	n d
	2	n d	n d	n d	n d	n d
	3	n d	n d	n d	n d	n d
Zinc						
1843	1	30	4 2	26	0 7	5 7
	2	30	2 5	26	2 1	3.2
	3	24	6 7	22	8 5	4 6
1954	1	27	4 9	29	7 8	2 9
	3	30	12 0	32	14 1	2 5
	4	30	4 9	28	5 7	1 0
1955	1	35	14 8	35	14 1	6 7
	2	27	6 4	26	6 4	3 6
	4	54	6 4	49	2 1	5 4
1959	1	32	0 7	32	3 5	5 1
	2	47	8 8	46	4 9	5.2
	3	61	2 8	56	7 1	19 1
2072	1	34	2 1	36	1 4	2 5
	2	35	2 5	33	1 4	1 8
	3	29	0 7	27	1 4	3 6
2187	1	37	4 9	36	2.1	1 4
	3	31	0 0	31	0.7	1 4
	4	29	1 1	29	0.1	2 1
2189	1	27	4 6	27	0 7	6 3
	2	34	5 7	33	3 5	2 9
	3	37	6 4	36	4 9	2.2

Plot	Subplot	$Mean_t$	SD_t	$Mean_c$	SD_c	SD_{wt}
Phosphorus						
1843	1	483	16	560	116	4
	2	577	124	467	13	26
	3	591	53	587	74	57
1954	1	1772	659	1758	704	106
	3	1927	99	2018	59	90
	4	1807	27	1805	24	61
1955	1	1137	145	1151	134	79
	2	711	42	723	63	26
	4	891	165	886	168	63
1959	1	950	50	953	47	92
	2	1084	391	1086	379	109
	3	985	69	938	113	131
2072	1	724	36	728	36	25
	2	905	168	866	144	64
	3	742	159	737	132	63
2187	1	1143	4	1143	7	83
	3	929	89	934	75	50
	4	901	126	872	143	71
2189	1	672	16	681	8	6
	2	799	94	786	86	13
	3	667	57	662	46	9
Iron						
1843	1	69	17	61	18	7
	2	67	6	72	8	8
	3	67	5	72	6	10
1954	1	69	20	68	16	2
	3	62	8	63	8	5
	4	77	7	76	6	4
1955	1	99	2	96	1	7
	2	106	45	106	42	3
	4	60	18	60	13	4
1959	1	42	3	43	2	4
	2	49	4	50	8	4
	3	43	6	45	3	6
2072	1	54	8	58	11	3
	2	43	12	45	13	7
	3	68	13	63	15	10
2187	1	59	4	58	4	7
	3	59	4	62	8	1
	4	62	11	62	9	8
2189	1	62	2	62	4	3
	2	65	5	66	10	4
	3	56	4	57	6	3

Table A-4 (CONTINUED)

Plot	Subplot	$Mean_t$	SD_t	$Mean_c$	SD_c	SD_{wt}
Copper						
1843	1	12	2 8	9	2 1	3 5
	2	7	0 4	9	0 7	1 8
	3	6	0 7	6	1 4	2 5
1954	1	7	1 8	7	0 7	1 5
	3	7	2 1	7	2 8	1 6
	4	8	1 4	7	1 4	3 0
1955	1	7	0 0	6	0 0	2 2
	2	6	0 7	5	0 0	3 6
	4	17	7 8	11	0 7	12 2
1959	1	30	4 2	32	7 8	7 3
	2	39	4 2	33	12 0	20 5
	3	67	1 1	61	7 8	22 6
2072	1	8	1 8	10	0 0	2 1
	2	12	1 8	13	5 7	2 5
	3	21	6 4	11	2 1	18 8
2187	1	11	7 1	7	1 4	8 0
	3	8	1 1	10	0 7	0 5
	4	7	1 8	7	0 4	2 5
2189	1	10	3 2	7	0 0	7 0
	2	10	1 1	8	1 4	1 8
	3	9	2 5	6	1 4	1.1
Manganese						
1843	1	69	31	62	24	14
	2	68	24	67	18	9
	3	61	22	62	26	10
1954	1	174	9	175	19	6
	3	249	53	264	59	40
	4	313	130	306	118	52
1955	1	311	167	314	169	91
	2	323	264	317	257	34
	4	55	27	54	25	7
1959	1	46	8	46	5	11
	2	76	19	67	8	9
	3	151	5	137	10	121
2072	1	976	133	940	91	59
	2	611	351	614	368	69
	3	683	14	717	59	107
2187	1	753	152	757	157	66
	3	467	93	465	96	19
	4	416	40	410	46	43
2189	1	595	160	597	139	59
	2	708	203	691	220	63
	3	734	253	722	264	113

Plot	Subplot	$Mean_t$	SD_t	$Mean_c$	SD_c	SD_{wt}
Magnesium						
1843	1	625	251	524	118	58
	2	658	29	689	30	100
	3	536	87	541	125	33
1954	1	499	72	489	96	16
	3	511	38	535	22	62
	4	477	92	473	78	14
1955	1	619	254	635	272	235
	2	630	97	618	91	45
	4	648	64	637	34	98
1959	1	561	61	559	35	77
	2	602	164	596	171	93
	3	695	17	662	51	224
2072	1	672	99	670	95	40
	2	593	52	576	56	72
	3	765	128	779	93	68
2187	1	606	100	610	103	13
	3	707	56	703	57	45
	4	648	106	648	89	76
2189	1	509	142	505	127	14
	2	643	49	641	38	28
	3	669	178	655	173	86
Sodium						
1843	1	137	84	68	161	47
	2	117	76	75	71	55
	3	200	49	207	23	115
1954	1	256	51	283	14	66
	3	263	50	214	5	41
	4	244	40	157	66	60
1955	1	315	86	276	57	110
	2	205	8	279	211	90
	4	190	51	128	13	104
1959	1	131	13	64	33	85
	2	175	51	577	693	98
	3	178	17	181	51	19
2072	1	215	53	309	29	71
	2	237	76	188	62	112
	3	398	233	236	37	168
2187	1	103	43	190	63	44
	3	175	5	244	32	93
	4	173	42	163	48	129
2189	1	175	10	116	14	40
	2	136	24	202	112	75
	3	159	18	265	137	56

Table A-4 (CONTINUED)

Plot	Subplot	$Mean_t$	SD_t	$Mean_c$	SD_c	SD_{wt}
Cobalt						
1843	1	2	1.1	3	0 0	1 5
	2	4	0 7	3	0 0	1 6
	3	3	0 4	3	1 4	1.1
1954	1	2	1 1	n d.	n d	0 5
	3	1	0 0	1	1 4	0 7
	4	1	1 4	2	0 7	1 0
1955	1	2	0 4	3	0 7	0 5
	2	2	0 4	2	0 0	0 5
	4	1	0 0	1	1 4	1.0
1959	1	1	0 0	2	0 7	0 0
	2	2	0 4	2	0 7	0 5
	3	2	0 7	1	0 0	0 0
2072	1	2	0 4	3	1 4	0 5
	2	1	0 4	1	2 1	1 5
	3	2	0 4	1	0 0	1.1
2187	1	2	1 1	1	0 7	0 5
	3	2	0 4	2	0 7	0 5
	4	1	0 4	1	0 3	0 5
2189	1	1	1 1	2	0 7	0 5
	2	1	0 4	2	0 7	1 1
	3	1	0 0	1	0 0	0 7
Nickel						
1843	1	3	1 1	4	0 7	0 5
	2	3	0 7	3	0 0	0 7
	3	4	0 0	4	0 7	0 7
1954	1	5	1 4	4	2 1	0 7
	3	4	1 4	4	1 4	2.2
	4	3	0 7	3	0 0	0 7
1955	1	5	0 7	5	1 4	0 7
	2	3	0 0	3	0 0	0 7
	4	3	1 1	3	1 4	1 1
1959	1	4	0 7	4	0 0	0 7
	2	4	0 0	4	0 0	1 0
	3	4	0 7	5	0 7	1 0
2072	1	6	1 1	7	2 8	1 1
	2	8	2 5	8	3 5	0 5
	3	4	0 7	3	0 0	0 7
2187	1	2	0 7	3	0 7	0 7
	3	3	0 0	3	0 0	0 7
	4	2	0 4	2	1 1	0.5
2189	1	3	1 1	3	0 7	0 5
	2	4	0 7	5	0 7	0 7
	3	3	0 4	4	0 7	0 5

Plot	Subplot	$Mean_t$	SD_t	$Mean_c$	SD_c	SD_{wt}
Potassium						
1843	1	3553	1401	3288	1185	211
	2	3616	977	3613	1084	689
	3	4003	339	4209	637	911
1954	1	6010	328	6021	162	460
	3	6750	1220	5936	93	1825
	4	6152	239	5961	400	102
1955	1	5705	248	5382	244	387
	2	4260	1060	4469	1356	48
	4	5368	1148	5457	427	775
1959	1	6589	952	6495	926	405
	2	8179	751	8171	911	834
	3	6673	952	7033	260	1897
2072	1	4575	845	5217	713	409
	2	3855	172	5422	2344	3965
	3	4580	307	4361	100	732
2187	1	4597	650	5110	383	340
	3	4752	17	4940	15	892
	4	5146	515	5028	358	238
2189	1	4407	344	4107	617	155
	2	5248	472	5621	1024	199
	3	4293	687	4629	67	665
Titanium						
1843	1	n d	n d	n d	n d	n d
	2	n d	n d	n d	n d	n d
	3	n d	n d	n d	n d	n d
1954	1	16	7 8	n d	n d	7 3
	3	12	4 6	n d	n d	5 2
	4	n d	n d	15	7 1	n d
1955	1	19	1 1	20	3 5	2 5
	2	19	2 1	18	2 1	2 5
	4	15	0 4	16	4 9	1 1
1959	1	10	2 1	10	1.4	2 5
	2	15	3 2	17	9 2	4 6
	3	13	2 1	10	1 4	3 5
2072	1	11	2 5	15	4 2	1 1 0
	2	10	6 0	n d	n d	2 5
	3	14	3 5	n d	n d	5 0
2187	1	15	3 2	14	2 1	3 4
	3	14	1 1	14	4 9	1 1
	4	12	0 7	14	0 7	3 6
2189	1	n d	n d	n d	n d	n d
	2	n d	n d	n d	n d	n d
	3	10	2 1	11	9 2	8 1

Table A-4 (CONTINUED)

Plot	Subplot	$Mean_i$	SD_i	$Mean_c$	SD_c	SD_{wi}
Chromium						
1843	1	6	1 4	3	1 4	5 1
	2	3	0 7	5	4 2	1 0
	3	5	3 2	6	3 5	4 0
1954	1	12	1 4	8	0 0	2 8
	3	10	0 4	4	0 7	1 8
	4	10	1 1	11	1 4	2 1
1955	1	13	1 8	15	0 7	0 5
	2	13	0 4	13	2 1	2 1
	4	12	0 0	12	1 4	0 7
1959	1	13	2 5	8	3.5	1 5
	2	14	2 8	14	0 7	0 7
	3	14	1 8	12	0 0	0 5
2072	1	15	2 1	17	2 8	3.5
	2	17	2 8	14	1 4	6 7
	3	15	2 5	18	3 5	7 6
2187	1	12	0 7	14	0 7	5 1
	3	13	0 4	14	4 9	1 1
	4	7	4 2	14	1 8	6 5
2189	1	18	0 4	13	9 2	2 5
	2	18	0 4	11	5 7	1 1
	3	17	1.1	17	1.4	3 2
Lead						
1843	1	11	1	11	3	4
	2	11	5	16	5	2
	3	8	1	9	1	7
1954	1	27	3	21	2	5
	3	27	1	18	1	5
	4	26	7	26	4	7
1955	1	23	1	23	1	0
	2	22	2	22	2	1
	4	18	7	23	0	10
1959	1	22	1	30	9	18
	2	24	1	31	16	2
	3	29	2	23	2	8
2072	1	22	0	22	0	0
	2	20	3	22	0	4
	3	22	1	22	0	1
2187	1	31	1	29	1	11
	3	30	2	30	0	2
	4	29	1	30	1	4
2189	1	22	0	22	0	0
	2	32	14	22	0	0
	3	22	0	32	13	1

Plot	Subplot	$Mean_i$	SD_i	$Mean_c$	SD_c	SD_{wi}
Cadmium						
1843	1	1	0.7	1	0 7	1 0
	2	n d	n d.	n d	n d	n d
	3	1	0.7	n d.	n d	1 0
1954	1	2	1.1	1	0 7	1 8
	3	n d	n d	1	0 0	n d
	4	1	0 4	2	1 4	0 5
1955	1	n d	n d	1	0 0	n d
	2	n d	n d	1	0 0	n d
	4	n d	n d	1	0 7	1 1
1959	1	1	0 7	n d	n d	2 5
	2	n d	n d	n d	n d	n d
	3	1	0 0	n d	n d	1 6
2072	1	6	1 8	6	6 4	8 2
	2	11	6 4	8	9 2	7 1
	3	8	3 2	n d	n d	6 5
2187	1	n d	n d	n d	n d	n d
	3	n d	n d	n d	n d	n d
	4	n d	n d	n d	n d	n d
2189	1	2	3.2	n d	n d	5 5
	2	7	8 5	11	15 6	12 5
	3	12	7 4	6	8 5	17 0
Strontium						
1843	1	5	2 1	4	2 1	0 7
	2	6	1 1	7	1 4	1 5
	3	5	1 1	5	1 4	1 1
1954	1	n d	n d	n d	n d	n d
	3	3	0 7	3	2 1	0 0
	4	n d	n d	n d	n d	n d
1955	1	4	3 9	4	3 5	2 5
	2	4	0 0	3	1 4	0 0
	4	n d	n d	n d	n d	n d
1959	1	2	1 1	3	0 7	1 1
	2	3	1 1	n d	n d	2 1
	3	2	0 4	2	0 0	1 1
2072	1	11	1 8	11	1 4	2 1
	2	11	2 5	8	8 5	4 6
	3	12	2 5	14	0 0	1 5
2187	1	4	0 4	4	0 7	0 5
	3	6	2 8	7	2 1	0 0
	4	5	0 7	5	0 8	1 4
2189	1	14	4 6	13	5 7	0 5
	2	14	3 5	15	9 9	8 6
	3	17	5 7	12	0 0	12 0

Table A-4 (CONTINUED)

Plot	Subplot	$Mean_t$	SD_t	$Mean_c$	SD_c	SD_{wt}
Arsenic						
1843	1	17	8.5	24	17 7	3 5
	2	n d.	n d.	n d	n d	n d
	3	n d	n d.	n d	n d	n d
1954	1	n d.	n d.	n d	n d	n d
	3	n d.	n d	n d	n d	n d
	4	n d.	n d.	n d	n d	n d
1955	1	n d	n d	n d	n d	n d
	2	22	6 4	n d	n d	3.8
	4	n d	n d	n d	n d	n d
1959	1	n d.	n d	n d	n d	n d
	2	n d	n d	n d	n d	n d
	3	n d	n d	16	2 8	n d
2072	1	n d.	n d	n d	n d	n d
	2	n d.	n d	n d	n d	n d
	3	n d	n d	n d	n d	n d
2187	1	n d	n d	n d	n d	n d
	3	16	6 7	19	9 9	11 9
	4	n d.	n d	19	5 7	n d.
2189	1	n d.	n d.	n d	n d	n d
	2	n d.	n d	n d	n d	n d
	3	n d.	n d	n d	n d	n d
Molybdenum						
1843	1	n d	n d	n d	n d	n d
	2	n d.	n d	n d	n d	n d
	3	n d.	n d	2	1 4	n d
1954	1	n.d.	n d.	n d	n d	n d
	3	n d	n d.	n d	n d	n d
	4	n d	n d	1	2 8	n d
1955	1	4	1 8	1	1 4	3 0
	2	2	2 8	n d	n d	3 5
	4	4	4 9	n d	n d	2.2
1959	1	3	1.1	4	4 9	3.2
	2	7	2 1	2	2 1	7.6
	3	n d.	n d	n d	n d	n d
2072	1	n d	n d.	5	7 1	n d
	2	2	0 7	6	6 4	2 2
	3	4	3 5	2	1 4	3 0
2187	1	3	0 0	5	2 8	1 6
	3	3	2 1	5	4 9	3 0
	4	5	1 4	5	4 4	2 5
2189	1	2	1 4	n d	n d	1 0
	2	5	0 7	1	1 4	4 3
	3	2	1 8	n d	n d	2 1

Plot	Subplot	$Mean_t$	SD_t	$Mean_c$	SD_c	SD_{wt}
Lithium						
1843	1	23	4	19	8	3
	2	23	13	27	8	1
	3	20	1	27	1	7
1954	1	28	1	36	9	3
	3	37	6	38	9	1
	4	28	6	30	6	3
1955	1	27	8	31	23	7
	2	21	4	28	11	2
	4	19	7	17	4	3
1959	1	18	2	20	4	4
	2	23	4	23	5	10
	3	25	9	27	6	5
2072	1	21	4	23	5	7
	2	25	16	23	17	5
	3	33	4	35	13	15
2187	1	46	2	44	4	7
	3	41	9	38	16	5
	4	39	0	26	27	11
2189	1	44	8	34	5	12
	2	39	2	38	5	11
	3	36	6	30	8	7
Barium						
1843	1	19 3	13 79	14 5	7 78	3 04
	2	24 0	3 54	27 5	0 71	7 91
	3	15 8	3 89	19 5	6 36	6 50
1954	1	4 5	0 71	5 0	1 41	1 00
	3	8 5	2 83	7 5	3 54	0 71
	4	5 0	0 71	5 5	2 12	1 58
1955	1	23 8	25 10	22 5	23 33	14 53
	2	18 5	4 24	14 0	5 66	1 58
	4	5 8	1 77	5 5	2 12	1 50
1959	1	8 0	0 71	8 5	0 71	2 55
	2	202 5	248 19	9 0	1 41	365 35
	3	19 3	10 96	9 5	0 71	17 01
2072	1	67 3	18 03	69 0	19.80	15 08
	2	25 5	23 34	27 0	24 04	3 61
	3	112 5	26 87	110 5	21 92	8 28
2187	1	19 8	2 48	21 5	7 78	3 91
	3	31 5	16 26	33 0	16 97	2 00
	4	23 8	15 91	12 3	2 40	21 15
2189	1	58 3	31 47	54 0	25 46	6 58
	2	34 0	9 90	32 0	12 73	5 10
	3	43 8	3 89	44 0	1 41	13 83

Table A-4 (CONTINUED)

Plot	Subplot	Mean$_i$	SD$_i$	Mean$_c$	SD$_c$	SD$_{wi}$
Boron						
1843	1	12	5	10	4	2
	2	13	3	14	1	8
	3	14	3	15	1	5
1954	1	14	8	14	6	1
	3	11	1	10	2	1
	4	9	2	10	1	2
1955	1	10	2	12	3	1
	2	14	1	14	1	1
	4	12	3	19	2	2
1959	1	21	11	22	4	4
	2	12	1	13	1	3
	3	13	0	12	2	1
2072	1	12	1	12	3	2
	2	15	0	14	0	2
	3	12	2	18	6	2
2187	1	12	1	10	0	2
	3	15	5	15	4	4
	4	11	2	11	1	2
2189	1	19	11	19	10	4
	2	23	1	21	1	4
	3	20	9	18	8	7
Calcium						
1843	1	956	635	829	528	147
	2	1037	375	1076	250	102
	3	946	240	994	337	115
1954	1	1466	359	1437	243	15
	3	1948	528	2058	535	162
	4	1248	268	1217	197	120
1955	1	2058	1245	2086	1312	774
	2	1517	583	1474	548	93
	4	1129	170	1150	164	41
1959	1	789	13	810	91	192
	2	1106	48	1057	21	128
	3	1085	128	1090	120	242
2072	1	2003	147	2016	153	101
	2	1630	1009	1667	1049	275
	3	1765	195	1798	151	94
2187	1	2386	103	2390	127	193
	3	2134	670	2110	604	54
	4	2354	38	2342	17	226
2189	1	2388	496	2353	499	106
	2	2275	297	2240	355	147
	3	2620	612	2607	701	427

Plot	Subplot	Mean$_i$	SD$_i$	Mean$_c$	SD$_c$	SD$_{wi}$
Vanadium						
1843	1	n d	n d	n d.	n d	n d
	2	n d.	n d	n d.	n d	n d
	3	n d	n d.	n d	n d	n d
1954	1	n d.	n.d	n d.	n d	n d
	3	n d	n d	n d.	n d	n d
	4	n d	n d	n d.	n d	n d
1955	1	n d	n d	n d	n d	n d
	2	10 5	2 1213	n d	n d	2 23607
	4	n d	n d	n d	n d	n d
1959	1	n d	n d	n d.	n d	n d
	2	12 5	2 8284	n d	n d	4 52769
	3	n d.	n d	n d	n d	n d
2072	1	n d.	n d	n d	n d	n d
	2	n d.	n d	n d	n d	n d
	3	n d	n d	n d	n d	n d
2187	1	n d	n d	17	2 8284	n d
	3	n d	n d	n d	n d	n d
	4	n d	n d	n d	n d	n d
2189	1	n d	n d	n d	n d	n d
	2	n d	n d	n d	n d	n d
	3	n d	n d	n d	n d	n d
Sulfur						
1843	1	0 066	0 019	0 055	0 014	0 021
	2	n d	n d.	0 073	0 011	n d
	3	0 063	0 004	0 058	0 011	0 007
1954	1	0 116	0 016	0 128	0 004	0 003
	3	0 130	0 000	0 123	0 018	0 005
	4	0 125	0 018	0 128	0 011	0 018
1955	1	0 165	0 004	0.163	0 004	0 008
	2	0.129	0.005	0 155	0 007	0 045
	4	0 148	0 032	0 143	0 018	0 041
1959	1	0 104	0 002	0 118	0 004	0 025
	2	0.113	0 011	0 113	0 004	0 005
	3	0 103	0 004	0 105	0.000	0 018
2072	1	0 089	0 005	0 095	0 014	0 006
	2	0 093	0 011	0 093	0 004	0 000
	3	0 093	0 014	0 090	0 014	0 011
2187	1	0.103	0.004	0.103	0 004	0 010
	3	0 095	0.004	0 098	0 004	0 004
	4	0 099	0 005	0 099	0 005	0 009
2189	1	0 080	0 007	0.078	0 011	0 005
	2	0 086	0 002	0 083	0 004	0 006
	3	0.079	0 005	0 085	0 007	0 003

* Mean$_i$ and SD$_i$ are the mean and standard deviation of the individual foliage samples, Mean$_c$ and SD$_c$ are the mean and standard deviation of the composited foliage samples, and SD$_{wi}$ is the within-tree (between-branch) standard deviation