Assessing large-scale surveyor variability in the historic forest data of the original U.S. Public Land Survey

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Abstract: The U.S. General Land Office Public Land Survey (PLS) records are a valuable resource for studying pre-European settlement vegetation. However, these data were taken for legal, not ecological, purposes. In turn, the instructions the surveyors followed affected the data collected. For this reason, it has been suggested that the PLS data may not truly represent the surveyed landscapes. This study examined the PLS data of northern Wisconsin, U.S.A., to determine the extent of variability among surveyors. We statistically tested for differences among surveyors in recorded tree species, size, location, and distance from the survey point. While we cannot rule out effects from other influences (e.g., environmental factors), we found evidence suggesting some level of surveyor bias for four of five variables, including tree species and size. The PLS data remain one of the best records of pre-European settlement vegetation available. However, based on our findings, we recommend that projects using PLS records examine these data carefully. This assessment should include not only the choice of variables to be studied but also the spatial extent at which the data will be examined.

Résumé : Les données d'arpentage des terres publiques de la Direction générale des terres des États-Unis sont une ressource précieuse pour l'étude de la végétation qui existait avant la colonisation par les Européens. Cependant, ces données ont été prises à des fins légales et non écologiques. Par conséquent, la procédure suivie par les arpenteurs-géomètres a affecté les données qui ont été collectées. C'est pourquoi certains ont émis l'opinion que les données d'arpentage pourraient ne pas être représentatives des paysages qui ont été arpentés. Cette étude se penche sur les données d'arpentage dans le nord du Wisconsin, aux États-Unis, pour évaluer le degré de variabilité entre les arpenteurs-géomètres. Nous avons testé s'il y avait une différence statistiquement significative entre les arpenteurs-géomètres quant aux espèces d'arbres rapportées, à leur dimension, à leur localisation et à leur distance du point de référence. Bien que nous ne puissions éliminer les effets dus à d'autres sources, comme les facteurs environnementaux, nous avons découvert des indices laissant supposer un certain degré de biais chez les arpenteurs-géomètres pour quatre des cinq variables incluant la dimension et l'espèce d'arbre. Les données d'arpentage demeurent parmi les meilleures données disponibles sur la végétation qui était présente avant la colonisation par les Européens. Cependant, sur la base de nos résultats, nous recommandons que les projets qui utilisent ce type de données les examinent attentivement. Cette évaluation devrait inclure non seulement le choix des variables à étudier mais aussi l'échelle spatiale à laquelle les données seront examinées.

[Traduit par la Rédaction]

Introduction

Ecosystem management and the need to characterize natural variability in ecosystems have made records of the U.S. pre-European settlement vegetation valuable (e.g., Swetnam et al. 1999; Cissel et al. 1999). Reconstructions of presettlement vegetation have been useful in understanding the relationship of vegetation to factors such as soils (Whitney 1982, 1986; Delcourt and Delcourt 1996), climate (Finley 1951), and fire history (Lorimer 1977; Kline and Cottam 1979; Grimm 1984), as well as for understanding how landscape patterns have changed over time (Stearns 1949; Mladenoff and Howell 1980; Iverson 1988; Whitney 1994; White and Mladenoff 1994; Schwartz 1994; Abrams and Ruffner 1995; Cole and Taylor 1995). Maps of the pre-European settlement vegetation have also been used to help identify priorities and locations for restoring forest ecosystems (Galatowitsch 1990).

Although such reconstructions are useful, it is important to note that human activities have influenced North American vegetation for millennia. The degree of this influence has been variable both in space and time. Therefore, reconstructions of presettlement vegetation should be interpreted within their regional context. In addition, climate change, which can result in ecosystem shifts, can occur within a time scale of centuries (Davis 1986). Nevertheless, records of the presettlement vegetation provide one of the few reliable data

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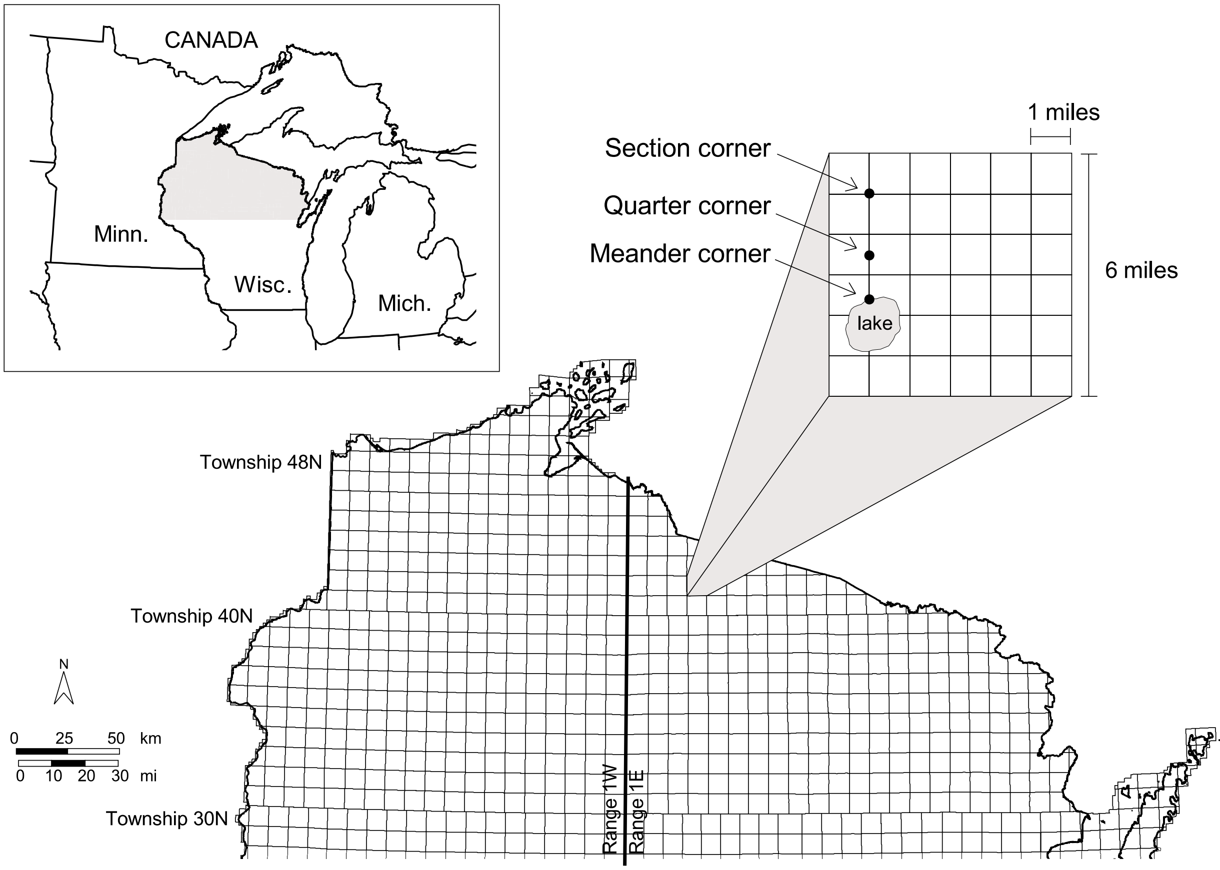
Fig. 1. Township boundaries of Wisconsin. The township referred to as Township 42 north, Range 4 east has been expanded to show the 36 one-square-mile sections that compose a township. Examples of section, quarter, and meander corners are also shown. (From Manies and Mladenoff 2000, reproduced with kind permission from Kluwer Academic Publishers, Landsc. Ecol., Vol. 15, p. 743, Fig. 1, © 2000 Kluwer Academic Publishers.)



sources of the vegetation of 100–150 years ago, especially if the region has undergone extensive alteration or removal of native vegetation since that time (Curtis 1959). The systematic records of the U.S. General Land Office (GLO) Public Land Survey (PLS) are particularly useful for this purpose.

The PLS data, sometimes also referred to as GLO or GLOS data, was recorded in the United States from eastern Ohio to the west coast between the late 18th and early 20th centuries (Stewart 1935). In this survey land was divided into townships of 36 one-square-mile sections (1 mile = 1.6 km; Fig. 1). The PLS surveyors marked the boundaries between townships (exterior points) and sections (interior points) by placing posts or stones in the ground at the intersection of section lines (section corners), the midpoints between section corners (quarter corners), and those locations where section lines crossed a navigable river, bayou, or lake (meander corners; Fig. 1). At each of these corners the surveyors also blazed two to four trees, one per compass quadrant (NE, NW, SE, and SW), which are called bearing or witness trees. The surveyors recorded in their notebooks the species, diameter, and location (distance and bearing from the corner) of each tree (Stewart 1935).

It is these witness tree data that have been used to reconstruct the pre-European settlement vegetation. These data, however, were taken for legal, not ecological purposes. In fact, the surveyors had specific instructions to aid them in their choice of witness trees, influencing the types and sizes of trees chosen. Because surveyor instructions sometimes stated that "only the soundest and thriftiest of the trees…" were to be used (Stewart 1935), surveyors may have avoided short-lived species if others were available (Grimm 1984). Surveyors also may have preferred species with thin bark that were easy to blaze and inscribe (Bourdo 1956). One version of the surveyor instructions also stated "... sound trees from 6 to 8 inches [15 to 20 cm] in diameter, of the most hardy species, favorably located, are to be preferred for marking" (Stewart 1935). Therefore, surveyors likely tended to avoid very small trees, which have high mortality and for which blazing is more likely to cause death. At times, they may have also tended to avoid large trees that were more likely to be cut for lumber (Hushen et al. 1966). Both formal instructions and variability in how these instructions were carried out may have affected the data recorded.

Our current ability to spatially analyze data at broader spatial extents, using geographic information systems (GIS), gives us an opportunity to quantify and assess surveyor variability. In this study we systematically analyzed variability among surveyors for a large sample of the PLS data located in northern Wisconsin, U.S.A. Examining a large region allows statistical comparisons of data among different individual surveyors.

Bourdo (1956) was the first to examine bias in the PLS data. Using the mean post-to-tree distance for each dominant species, he looked for bias in surveyors' choice of species and diameters. Bourdo also detailed methods to examine surveyor quadrant choice using chi-square analysis. Many have used Bourdo's techniques to estimate bias in their data (Van Deelen et al. 1996; Siccama 1971; Hushen et al. 1966; McIntosh 1962). Delcourt and Delcourt (1974) expanded upon Bourdo's work, suggesting the use of analysis of variance (ANOVA) when testing for distance biases. They preferred this method over chi-square analysis, because ANOVA does not assume that each dominant species is represented in the forest by equal numbers of trees. Grimm (1984) stated that all such statistical techniques may be invalid, because they assume trees are randomly distributed throughout the forest. He argued that because the PLS data do not meet this assumption, results using these methods are questionable. However, we believe that Bourdo's and Delcourt and Delcourt's statistical techniques are appropriate even if there is a modest departure from the assumption of randomness. While a simulation study would be required to test such an assumption, the fact that we are using such a large data set, over a wide area, leads us to believe any effects of nonrandomness would be minimal.

In this study we expand upon the work of Bourdo (1956) and others, using additional statistical techniques to quantify and characterize variability in the PLS data from the northern forested region of Wisconsin. We hypothesize that differences might exist between surveyors in (*i*) preferred species, (*ii*) the sizes of selected trees, and (*iii*) the distances traveled to each tree. We also examine the location of witness trees in regards to their corners (i.e., quadrant and bearing within a quadrant). It has been hypothesized that if bias is found for such locations there is more reason to believe that other biases may exist (C. Lorimer, personal communication). We also assess the importance of surveyor variability when examining data at different spatial scales.

The purpose of this study was not to determine which surveyor best represented the true vegetation, an unanswerable question, but instead to evaluate the extent of differences or variability among surveyors while attempting to control for environmental differences. Most of our reported analyses focus on comparing each surveyor individually with each other individual surveyor. Based on the number of surveyor pairs analyzed, one would expect a certain number of these pairs to be significant by chance alone. If more significant differences are found between pairs of surveyors than the expected number then the hypothesis that surveyor variability exists is supported, indicating that greater attention should be paid to bias effects when using the data.

Study area

The study area consists of townships surveyed during the 1850s and 1860s across northern Wisconsin (Fig. 1). This region was glaciated during the Wisconsin phase, and soils vary from coarse outwash sands to loamy moraines and till plains to clays in former lake plains. The climate is continental with mild summers (mean July temperature 18°C) and relatively long, cold winters with heavy annual snowfall (200–400 cm, mean January temperature –10°C). Mean annual precipitation is 85 cm (Curtis 1959).

This region was dominated by extensive old-growth forests of eastern hemlock (*Tsuga canadensis* (L.) Carrière), sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis* Britton) on mesic soils, with extensive white pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.) found on sandy soils. Forested wetlands are common, dominated by white (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.) BSP), balsam fir (*Abies balsamea* (L.) Mill.), and tamarack (*Larix laricina* (Du Roi) K. Koch; Curtis 1959; Finley 1951). Disturbance in this region is dominated by small-scale events (e.g., tree fall). Mortality due to fire and wind is also found, although, with return intervals >1000 years, they play a minor role (Frelich and Lorimer 1991). Nearly complete logging from the mid-1800s to the early 1900s has heavily altered the region. Today, the forests are young. Pine and hemlock are much rarer, with early successional species such as trembling aspen (*Populus tremuloides* Michx.) common (Mladenoff and Pastor 1993; Mladenoff and Stearns 1993). Such extensive and complete change of the landscape makes data derived from the PLS records particularly valuable.

Methods

Data format

The PLS data (both interior and exterior points) were transcribed from microfilm copies of the original surveyor notebooks into a computer format using LANDREC, a program developed to enter data from PLS survey records (Manies 1997). The output of this program allows direct importation of the data into software such as data base management systems, statistical packages, and GIS. Only quarter, section, and meander corner data were used in the analysis, although other information is available as output. All statistical analyses were run using SAS (SAS Institute Inc. 1990) unless otherwise stated.

Since our main objective was to determine if differences exist among surveyors, we attempted to control for other factors. Differences among environments were minimized by removing those data that were not in what we determined to be "general mesic" environments. General mesic environments were defined as loamy soil, upland areas that were predominately forested by eastern hemlock, sugar maple, and yellow birch (as opposed to sandy soil areas where pine and oak predominate). Found within these general mesic environments are smaller patches of lowland forests, which are dominated by northern white-cedar (*Thuja occidentalis* L.), spruce, and tamarack. We determined which points were in general mesic areas by combining a PLS data map with a map of U.S. Forest Service Land Type Associations (LTAs; ECOMAP 1993) using GIS. The LTAs are based on climate, bedrock geology, glacial landform, soils, and current vegetation. Corners within LTAs classified as general mesic ecosystems were used in the analysis (Fig. 2). We also noted that hemlock reaches the western limit of its range within the study region (Goder 1955). To remove any differences in species availability among surveyors we deleted from the data base points outside the range of hemlock.

The resulting data base has records from 68 townships, or parts thereof, and covers over 300 mi^2 (776 km^2; Fig. 3). These data were recorded between 1847 and 1865 using the same general surveying procedures (Stewart 1935). Sixteen surveyors recorded a total of 8564 witness trees, representing 33 different species. We analyzed only those surveyors recording more than 260 trees (3% of the total general mesic data base). We also removed individual tree species with fewer than 86 occurrences (~1% of the total general mesic data base). The final data base consists of 10 surveyors, 13 species, and 8169 trees (Table 1). If each surveyor is compared with each other individual surveyor, there are 45 possible pairs. Based on $\alpha = 0.05$, we would expect on average 2.25 (= 45 × 0.05) pairs to be found significant even if there is no bias among the surveyors. Therefore, a minimum of three significantly different surveyor pairs is required to exceed the number of differences expected from chance alone. If for some tests not all surveyors are included, the expected number of pairs found to be significant will be N × 0.05, where N is the number of surveyor pairs being considered.

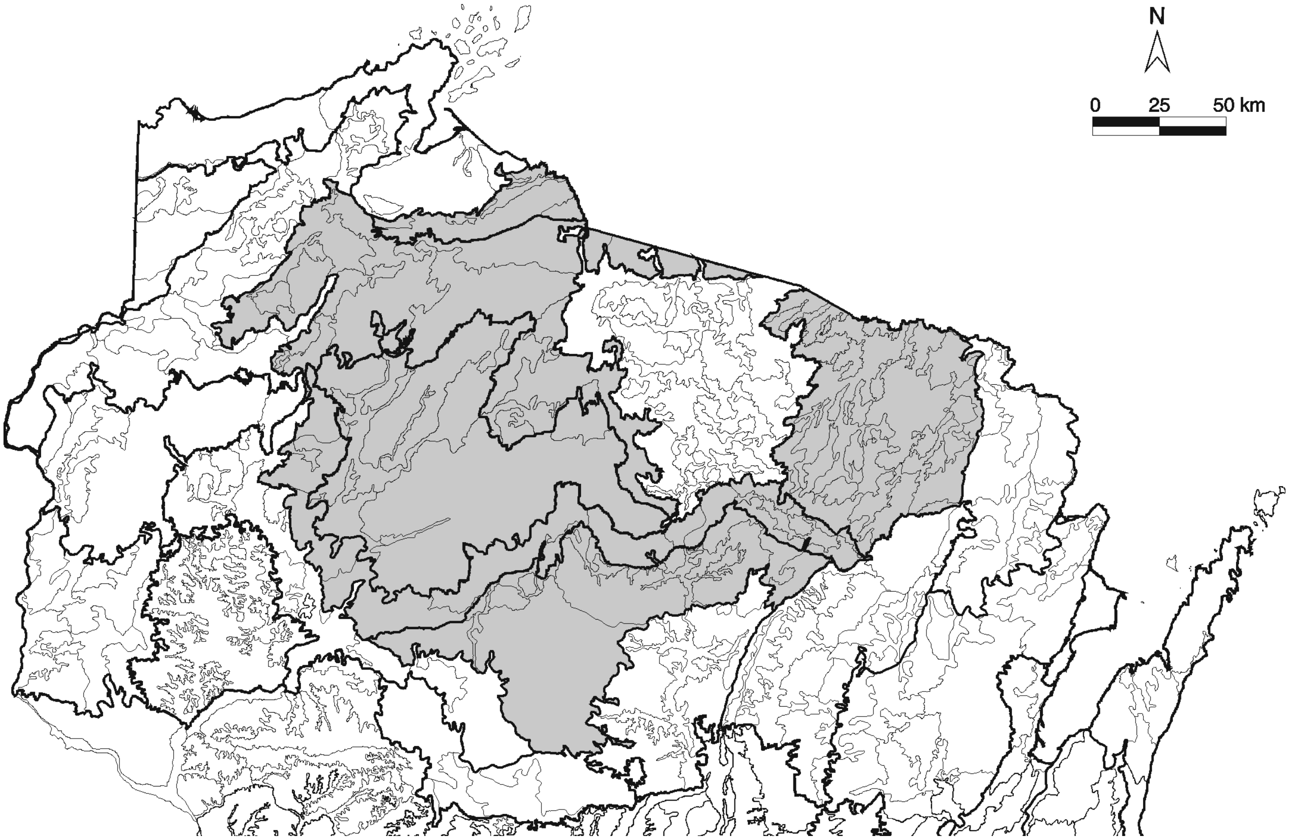


Fig. 2. Subsections (thick boundaries) and land type associations (LTAs; thin boundaries) of northern Wisconsin. LTAs that were classified as general mesic ecosystems are shaded. Data are based on the U.S. Forest Service hierarchical land classification system (ECOMAP 1993).

We note that these 45 tests are not independent. For example, if surveyor Nos. 1 and 2 are not different for a given test, and similarly surveyor Nos. 1 and 3 are not different, this implies that surveyor Nos. 2 and 3 cannot be very different. Therefore, we cannot perform formal inferences on the number of pairs found significant. Nevertheless, we use this number as a strong qualitative indicator of overall differences. Those species that occupy >5% of the final data base ("core species") are hemlock, birch, tamarack, sugar maple, cedar, spruce, and fir. We feel most confident in our results for these seven species.

In our study we assume that the forests within our data base are sufficiently homogeneous such that the observed differences can be attributed to surveyor variability and not to discrepancies in forest structure. We feel this assumption is justified for two reasons. First, we controlled environmental variability as much as possible by only using points in LTAs that were classified as a general mesic environment. Second, forests in the region we studied are dominated by small-scale disturbances (e.g., individual tree-falls), which occur over decades to a few centuries, creating relatively homogeneous landscapes, especially when examined at a broader spatial extent. We also investigated the PLS data over a large area specifically to minimize the effect of small-scale variations.

Surveyor variability for species

We assessed differences among the surveyors in species selection of witness trees using two types of chi-square analysis. Surveyors were compared with all other surveyors as a group as well as to each individual surveyor.

Surveyor variability for diameter

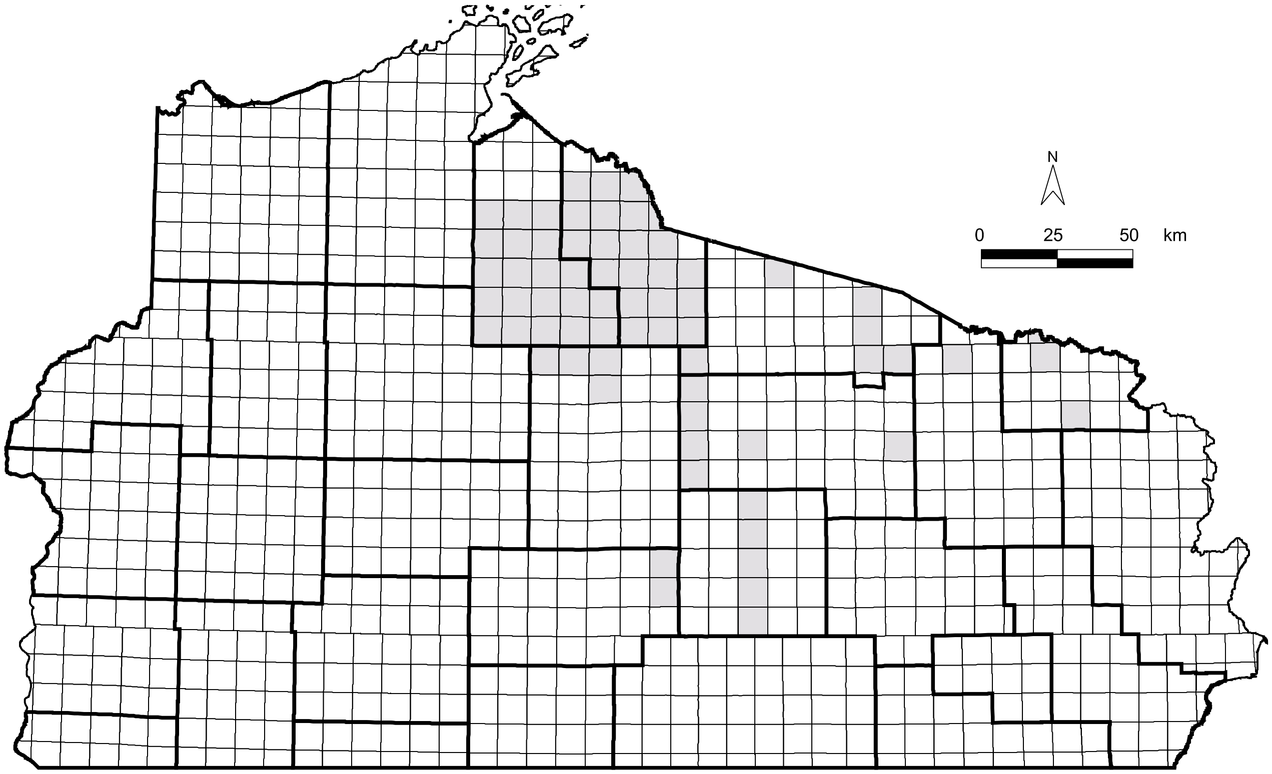
Analysis of variance (ANOVA) with the general linear model (GLM) and least squared differences (LSD) test were used for examining the differences among surveyors for the mean tree diameters of each species. (LSD tests were performed in all cases, even if the GLM p value, which tests the null hypothesis of no differences among surveyors, was greater than 0.05. Results in such cases are interpreted cautiously.) To remove the effect of skewed diameter distributions, the data were transformed using the log of each diameter plus two. The addition of 2 in. (1 in. = 2.54 cm) to each diameter before taking the log was made to remove the influence of very small diameters in the transformation.

The nonparametric Friedman test (Conover 1980) was used to determine if there was a consistent pattern in the rank order of surveyors among species, where the ranking was based on the mean tree species diameter for each surveyor; this test was used on only the core species. We performed this test using core species as the block and surveyor as the treatment. The null hypothesis is that there is no consistency in the ranking of surveyors within the different species. The Friedman test was also used to test for patterns in the rank order of surveyors for diameter ranges, again using core species as the block and surveyor as the treatment. Finally, Levene's test (Snedecor and Cochran 1989) was used to determine if the variability of tree diameters chosen by each surveyor were similar. The null hypothesis is that the variances for diameter are equal for surveyors; this test was performed separately for each of the core species.

Surveyor variability for distance

Differences among surveyors in the mean distance traveled to record trees of each species were compared using ANOVA with the GLM and LSD test. The Friedman test was used to determine if there was a consistent pattern in the rank order of surveyors among species, this time using mean distance to rank each surveyor. Core species were the block, and surveyor was the treatment.

Fig. 3. Townships that contain trees used in the surveyor bias analysis. Thick lines represent county boundaries. Although entire townships are shaded, only points within a township that also reside within an appropriate LTA were used in analysis.



We also tested if a relationship existed between the tree size chosen by surveyors and the distance traveled to record them. This question was tested using Spearman rank correlation test (Snedecor and Cochran 1989) on data for each individual core species. The null hypothesis is that there is no correlation between diameter and distance rankings of the surveyors.

Overall tree density (trees/ha) was examined using calculations based on the point-quarter sampling method (Cottam et al. 1953). Density values provide an alternative means of examining surveyor distances, because they are calculated across species. To determine relative density, first the mean area per tree at each point was calculated using

$$[1] \qquad \mathrm{MA} = \left(\frac{(\sum d)/n}{c \times 0.66 \ \mathrm{ft/link}} \right)^2$$

where MA is the mean area per tree (ft^2/tree), d is the distance(s) of the witness tree(s) at a point (links), n is the number of trees, and c is a correction factor based on the number of trees per point (1 tree = 0.50, 2 trees = 0.66, 3 trees = 0.81, 4 trees = 1.00; Cottam and Curtis 1956). One link is equal to 7.92 in. Overall density at the point was then calculated using

$$[2] \qquad D = \left(\frac{1}{\mathrm{MA}} \right) (107\,600 \ \mathrm{ft^2/ha})$$

where D is the relative density (trees/ha). Potential differences among surveyors were analyzed using ANOVA with GLM and LSD tests.

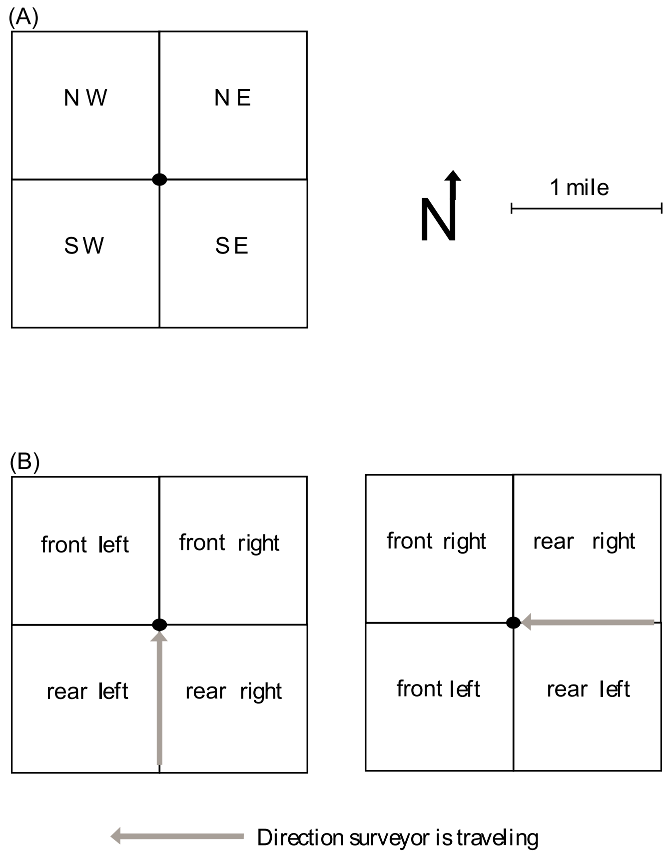
Surveyor variability for location

The quadrant where witness trees were found as well as the bearing (or angle) within quadrants were compared among surveyors. For each individual surveyor we compared the number of trees within each quadrant to determine if each quadrant was equally likely to be chosen by the surveyor. This hypothesis was tested using chi-square analysis and included all species recorded at a quarter or section corner. Meander corners were excluded, as the purpose for meanders (e.g., a lake) would automatically exclude some areas around the point. Quadrants were compared by examining the cardinal direction of each quadrant (NE, SE, NW, and SW) as well as the position of the quadrant based on the direction traveled by the surveyor (front left, front right, rear left, rear right; Fig. 4). Each quadrant was also divided into six segments (0–15,

Table 1. The 13 species used in this study, their scientific names, and the percentage of each in the final data base.

Common name	Species	Percentage
Aspen	*Populus tremuloides, Populus grandidentata*	1.3
Birch	Mostly *Betula alleghaniensis,* some *Betula papyrifera*	18.9
Cedar	*Thuja occidentalis*	11.5
Elm	*Ulmus americana*	2.0
Fir	*Abies balsamea*	6.0
Hemlock	*Tsuga canadensis*	22.0
Linden	*Tilia americana*	1.6
Maple	Most likely *Acer rubrum*	1.8
Pine	*Pinus strobus, Pinus resinosa, Pinus banksiana*	1.4
Spruce	*Picea glauca*	7.1
Sugar maple	*Acer saccharum*	11.9
Tamarack	*Larix laricina*	12.4
White pine	*Pinus strobus*	2.0

Fig. 4. Bias for quadrants was examined in two ways. The first (A) used cardinal directions (NW, NE, SW, and SE). These directions are unaffected by the direction traveled by the surveyor. The second (B) used the position of the quadrant for the surveyor relative to his direction of travel (front left, front right, rear left, and rear right).



16–30, 31–45, 46–60, 61–75, and 76–90°) and the number of witness trees in each of the segments, regardless of quadrant, was compared for each surveyor. Because the bearing to several trees was recorded as 0° and 90°, two segments (0–15, 76–90°) are slightly larger than the others. This inequality does not affect our results.

Additional analyses

Additional analyses were performed to test for differences among surveyors due to factors such as the geographical location, local environment, or disturbance history of the area recorded by each individual surveyor. Because the general mesic data base consisted of several different LTAs, we wished to verify that any differences among surveyors were not caused by differences in these local environments. Therefore, we created several subsets of the original data base at different scales. The first subsets were for two individual subsections (ECOMAP 1993). Subsections are one level above LTAs in the U.S. Forest Service’s classification hierarchy, so this method grouped like LTAs. Next, we examined the data of two individual LTAs, the smallest scale at which the data could be grouped using ecological factors while still having enough records for statistically significant results. The subsections and LTAs to be examined were determined by choosing those with the largest proportion of points within the general mesic data base. The same analyses of species, diameter, and distance (as described in the previous sections) were performed.

Differences in the amount of wetlands in each surveyor area could also affect the number of upland versus lowland species selected. The PLS data map was examined in conjunction with a map of the Wisconsin wetlands inventory (Wisconsin Department of Natural Resources 1992) using GIS. Corners in wetland areas were summed for each surveyor. We compared the proportion of corners in wetland areas among the surveyors using chi-square analysis. The proportion of points within any disturbances (e.g., fire or windthrow) recorded by each surveyor was also compared using chi-square analysis.

Multiple logistic regression analysis was conducted to examine the combined influence of environment, geographical location, and surveyor on the results of the analyses. The response variable was the presence or absence of an individual tree species. Environment was represented by the subsection in which each point resided. Geographical location was represented by the x, y coordinate, calculated by placing each township on a 21 × 16 township grid (Fig. 3).

Results

Surveyor variability for species

Results for the two chi-square analysis methods (individual surveyors vs. all other surveyors and individual surveyors vs. each other) were consistent in assessing variability in species. Therefore, we will only discuss the results for comparing individual surveyors to each other. For each of the 13 species, 9 or more pairs of surveyors differed significantly in the frequency that species was chosen as a witness tree (Table 2). (For all formal testing significance is declared if $p < 0.05$ unless otherwise stated.) The pattern of differences among surveyors varied by species. For three species (aspen, birch, and maple), any significant differences found were a result of three or fewer surveyors who were different from the remaining surveyors. For the other species, several small groups of like surveyors appeared.

The frequency with which most core species were chosen as witness trees varied strongly among surveyors (Fig. 5). For example, the frequency with which surveyors chose hemlock as a witness tree varied between 10 and 48%. These ranges resulted in the large number of significant differences among surveyors. The core species with the smallest range was birch, which only varied among surveyors by 8%. Birch also had the fewest significant differences among surveyors of all species examined (Table 2).

During this part of the investigation we noticed that one surveyor, J.L.P., used naming conventions for his witness trees that differed from those of the other surveyors. J.L.P used only general descriptors (e.g., pine, maple) versus the more detailed names used by the others (e.g., white pine, sugar maple). Therefore, he had significantly more undifferentiated species and significantly fewer fully named species than other surveyors. Removal of J.L.P. from the analysis, however, did not change the results for any other species or other surveyor.

Surveyor variability for diameter

There were fewer instances of significant differences among surveyors for species diameters recorded (using the LSD test) than found for species choice (Table 3). One species, linden (*Tilia americana* L.), had only three significantly different surveyor pairs, marginally more than would be expected by chance. The Friedman test determined that there was consistency in the rankings of surveyors by diameter across species pairs. This means that surveyors who tended to record smaller diameters for one tree species also recorded smaller diameters for all other species, with a similar relationship holding for larger diameter trees ($p < 0.001$).

Median diameters for each species usually ranged from 8 to 14 in. (20–36 cm; Fig. 6). Pine and white pine had the largest median diameters (>16 in. or 40.64 cm). Significant differences among surveyors in the variances of tree diameters for individual species were also found for all core species except fir (Table 4).

Surveyor variability for distance

There were fewer significant differences among surveyors for distances between the survey point to the tree, compared with other response variables (Table 5). Four species (fir, tamarack, maple, and pine) had fewer significantly different pairs of surveyors than would be expected by chance. Birch, hemlock, and sugar maple are the species with the greatest number of significant differences. The distance distribution among surveyors for aspen, elm, linden, spruce, and white pine exhibit wide ranges (Fig. 7). The ranges for these five species result largely from the effects of one surveyor. Which surveyor was the "outlier" differed depending on the species. For four of the five species, the outlier recorded only a few trees (<10) but traveled large distances to do so. Spruce is the exception; the outlier surveyor traveled long distances for close to 100 trees. The median distances traveled for white pine were much higher than for other species, even when the data for the outlier are removed. Significant differences were found when comparing pairs of surveyors for mean tree densities. Mean densities ranged from 241 to 714 trees/ha (Table 6).

The Friedman test indicated a consistent pattern in the rankings of surveyors by distance across species pairs. There was also positive correlation between the diameter rankings and the distance rankings of surveyors for all seven core species. The Spearman rank test showed a significant correlation ($p < 0.10$) for two species: fir and hemlock. Although this test was only significant for two species, the fact that all seven species had a positive correlation provides evidence against the null hypothesis of no correlation between diameter and distance ($p < 0.05$).

Surveyor variability for location

No significant preferences were found for the directional quadrant in which a surveyor placed witness trees. There was, however, significant bias for the degree segment within quadrants (0–15, 16–30, 31–45, 46–60, 61–75, and 76–90°) in which a witness tree was located. Eight of 10 surveyors had significant differences among the six segments. Most surveyors were less likely to record trees located in the degree segments at either edge of a quadrant (0–15 and 76–90°).

Additional analyses

No significant differences were found among surveyors in the proportion of points they recorded within disturbances. However, significant differences were found for the proportion of points recorded within wetlands by each surveyor. Surveyors were divided into two groups, by the proportion area surveyed that was wetland (~26–33% vs. ~41–46% of total area). When the tree species, diameter, and distance analyses were redone separately within these groups, significant differences remained among surveyors. Significant differences among surveyors also remained when the analyses were done within individual ecological units (LTAs and subsections). In these analyses the number of surveyor pairs that had been significantly different was reduced by about one third.

Multiple logistic regression was unable to explain much of the pattern relating to the presence or absence of a species. The small part that was explained showed that all three groups of variables (environment, surveyor, and geographic location) play a small role in predicting the occurrence of each species. Geographic location appeared to have the least amount of influence of the three variables. Differences between the influence of the environment and surveyor were difficult to separate, and although we tried to control for it, the environment seemed to be slightly more important than surveyor.

Table 2. Summary of the chi-square analyses comparing the frequency with which each species was chosen as a witness tree among surveyors.

Species	No. of significant differences among surveyors
Birch[a]	9
Cedar[a]	23
Fir[a]	22
Hemlock[a]	33
Spruce[a]	33
Sugar maple[a]	33
Tamarack[a]	36
Aspen	17
Elm	20
Linden	14
Maple	15
Pine	25
White pine	26

Note: The number of significant differences ($p < 0.05$) found among surveyors, out of a possible 45, are listed. We would expect 2.25 differences due to chance alone. Numbers of differences larger than this suggest significant variability.

[a]Core species.

Discussion

We found significant differences among the surveyors in most aspects of the PLS data, with the exception of the quadrant in which witness trees were located. Species selection was most likely to vary with surveyor, although there did not appear to be any consistent patterns of preferences. In other words, knowing that a surveyor was more likely to choose one species as a witness tree did not help predict preferences for or against other species. Bourdo (1956) also observed this in PLS data for Michigan. Preferences for species probably were dependent on tree characteristics such as size and bark roughness. The degree of any biases for or

Fig. 5. Frequency distribution of species chosen as witness trees, averaged for each individual surveyor (n = 10). Bars of the Cleveland box plot represent the 5th and 95th percentile. Lower and upper limit of the box represents the 25th and 75th percentile. Line within box is the median. Core species are shown in uppercase.

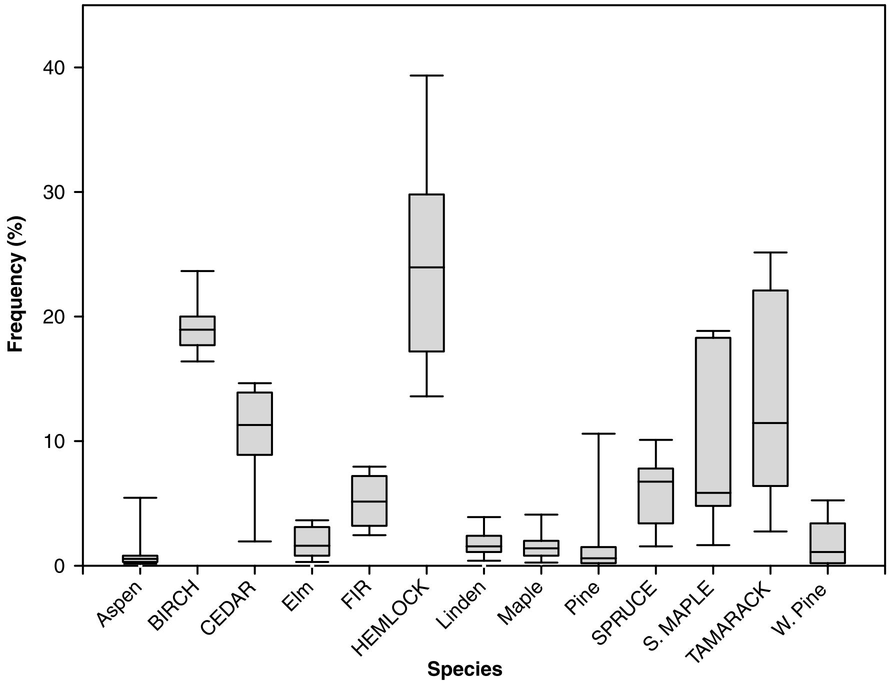


Table 3. Summary of the least squared differences tests comparing the mean diameters among surveyors, separately, for each species.

Species	No. of significant differences among surveyors	Maximum no. of differences	No. of differences expected by chance
Birch[a]	22	45	2.25
Cedar[a]	15	45	2.25
Fir[a]	15	45	2.25
Hemlock[a]	24	45	2.25
Spruce[a]	24	45	2.25
Sugar maple[a]	21	45	2.25
Tamarack[a]	15	45	2.25
Aspen[b]	5	36	1.80
Elm	14	36	1.80
Linden[b]	3	36	1.80
Maple	5	36	1.80
Pine	5	28	1.40
White pine	10	28	1.40

Note: The number of significant differences (p < 0.05) found among surveyors and the number of possible differences are listed. The maximum number of differences for a species was less than 45 if one or more surveyor had too few records to perform the analysis.

[a]Core species.

[b]LSD test was still performed, although the GLM p value was >0.05.

against these characteristics most likely varied among surveyors.

No relationship was found between the frequency with which a species was chosen as a witness tree and the mean distance traveled by the surveyors to record them. It has been hypothesized that if strong species biases were present such a relationship would exist. The fact that no such relationship was found indicates that if any species bias by the surveyors existed it was not systematic enough to significantly affect the distance measurements.

Tree diameters and distances recorded in the PLS data were also affected by surveyor variability. In particular, the range of values among surveyors for tree diameters was quite large for the two pine species (red and white pine). Both of these species had larger median diameters than other species. These large values probably reflect the highly variable distribution of pines within general mesic forests, since pines in this ecosystem were often large, solitary, emergent trees. White pine also had unusually large point-to-tree distances. This could suggest that some surveyors preferred white pine or it could indicate low density, older stands that contain large trees. Although there were significant differences in median diameters and median distances among surveyors for the pines, there were usually fewer significant differences for the pines than for the core species. This is probably due to smaller numbers of pines in the data base compared with the core species. A similar argument can be made for some of the other noncore species.

It is interesting that for all core species the rank order of surveyors for mean tree diameters is positively correlated to the rank order of mean tree distances. This result suggests that the surveyors who traveled shorter distances to record trees also recorded smaller diameters for these trees. One possible explanation for this result is that some surveyors targeted a wider range of diameter classes for their witness trees. Those who were more willing to mark smaller trees (hence the smaller average diameters) did not have to travel as far to obtain witness trees, resulting in smaller mean dis-

Fig. 6. Diameter distribution of trees measured by individual surveyor (n = 10). Bars of the Cleveland box plot represent the 5th and 95th percentile. Lower and upper limit of the box represents the 25th and 75th percentile. Line within box represents the median. Core species are shown in uppercase. One inch = 2.54 cm.

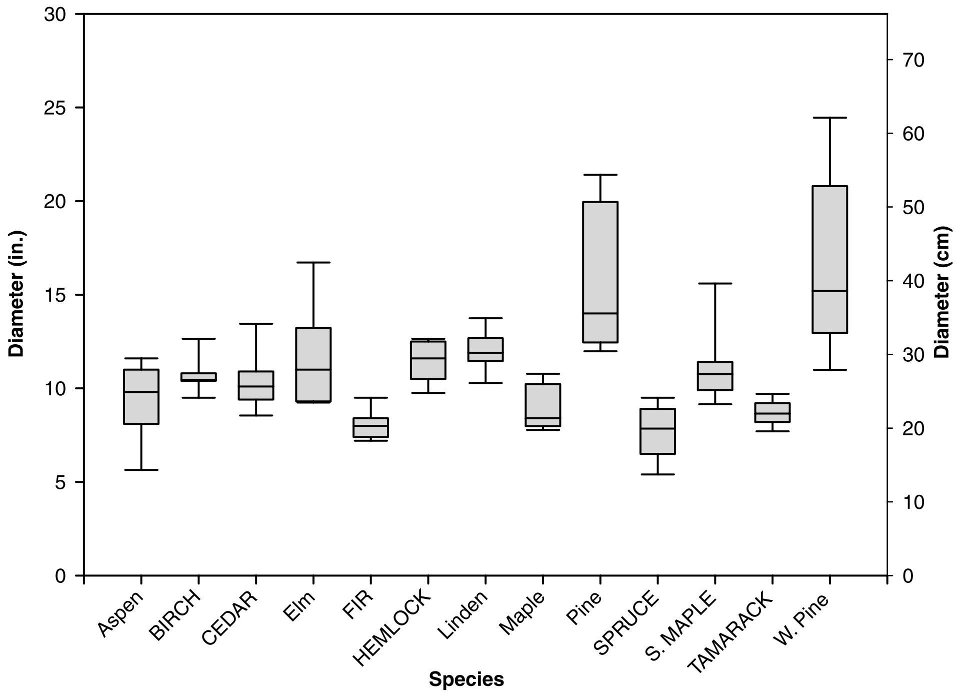


Table 4. Summary of results from Levene's test, comparing the variances of diameters among surveyors separately for each species.

Species	No. of significant differences found among surveyors	Maximum no. of differences	No. of differences expected by chance
Birch	17	45	2.25
Cedar	8	36	1.80
Fir	0	36	1.80
Hemlock	15	45	2.25
Spruce	11	36	1.80
Sugar maple	4	36	1.80
Tamarack	20	45	2.25

Note: The number of significant differences found among surveyors is for $p < 0.05$. The maximum number of differences for a species was less than 45 if one or more surveyor had too few records to perform the analysis. Only core species are listed.

tances and densities as well. Alternatively, this trend could be due to differences in forest structure among areas in which each surveyor worked.

The quadrant in which surveyors placed their witness trees was the only variable for which no significant differences were found. However, bias was found in tree direction (angle) within a quadrant. This last bias was the only bias that was fairly consistent among surveyors. It is also the only bias that should not be affected by nonsurveyor factors (e.g., environmental factors). Therefore, it further supports the idea that surveyors used some subjective criteria when recording witness trees.

Results from the additional analysis performed suggest that surveyor variability plays a role in explaining patterns in the data (along with geography and the environment). We also continued to find significant differences between surveyors in species chosen, diameters, and distance when accounting for two other factors that may have influenced the results: wetlands and ecological units within the general me-

Table 5. Summary of the least-squared differences tests comparing the mean distances among surveyors, separately, for each species.

Species	No. of significant differences found among surveyors	Maximum no. of differences	No. of differences expected by chance
Birch[a]	23	45	2.25
Cedar[a]	8	45	2.25
Fir[a,b]	1	45	2.25
Hemlock[a]	24	45	2.25
Spruce[a]	6	45	2.25
Sugar maple[a]	18	45	2.25
Tamarack[a]	2	45	2.25
Aspen[b]	4	36	1.80
Elm[b]	4	36	1.80
Linden	11	36	1.80
Maple[b]	1	45	2.25
Pine[b]	0	28	1.40
White pine	10	28	1.40

Note: The number of significant differences ($p < 0.05$) found among surveyors and the number of possible differences are listed. The maximum number of differences for a species was less than 45 if one or more surveyor had too few records to perform the analysis.

[a]Core species.

[b]LSD test was still performed, although the GLM p value was >0.05.

Fig. 7. Distances traveled by individual surveyor ($n = 10$). Bars of the Cleveland box plot represent the 5th and 95th percentile. Lower and upper limit of the box represents the 25th and 75th percentile. Line within box represents the median. Core species are shown in upper case. One link equals 7.92 inches or 20.12 cm.

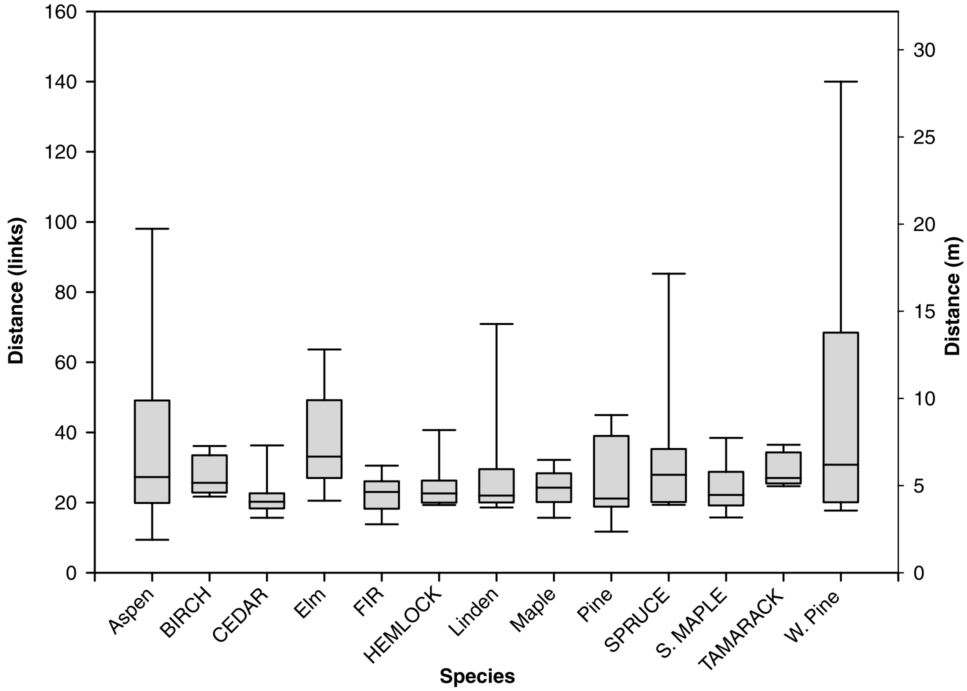


Table 6. Results of the least squared differences test comparing the mean density among surveyors.

Trees/ha		A.C.S.	J.L.P.	D.E.N.	A.G.E.	W.E.D.	E.S.N.	A.A.	H.C.F.	E.D.P.
241	A.C.S.	—								
278	J.L.P.		—							
360	D.E.N.			—						
385	A.G.E.	*			—					
402	W.E.D.	*				—				
464	E.S.N.	*	*	*			—			
478	A.A.	*	*					—		
492	H.C.F.	*	*	*	*	*			—	
597	E.D.P.	*	*	*	*	*	*		*	—
714	J.M.	*	*	*	*	*	*	*	*	*

Note: Significant differences ($p < 0.05$) found among surveyors are shown with asterisks. Abbreviations in the table are individual surveyor names (Manies 1997).

sic data base. We note, however, that the number of significant differences among surveyors for species, diameter, and distance decreased when examining the data within subsection, LTA, or wetland group. There are two possible reasons for this reduction. One may be a decrease in analysis power. The reduced number of observations available for each surveyor in the analysis will decrease the probability of finding significant results. A second reason for this reduction could be that isolating the data eliminated some of the differences between surveyors that were due to environmental factors rather than personal differences. The number of disturbances, another factor that may have affected the analysis, did not appear to do so. In fact, the similarity in proportions of disturbed areas recorded by each surveyor supports the idea that these landscapes had comparable disturbance rates and were located within similar environments.

It was not possible for us to fully control for all factors influencing the results beyond surveyor preference. Therefore, our results are likely affected by environmental variables, especially those not captured at the scale of LTAs or differences in stand history that we could not detect with the available data. Some of the diameter differences we found may also result from variations in the ability of each surveyor to estimate diameters. Further analysis could also be conducted to analyze the randomness of trees within the forest and the potential impact a lack of randomness might have on our conclusions. Given the large spatial extent of our study, however, we are confident that such an analysis would not cause us to alter our conclusions in a meaningful way.

As stated earlier, we assumed that the forests within our data base are sufficiently homogeneous over a broad spatial scale so that the observed differences can be attributed largely to surveyor variability and not to variability in forest structure. In some ways our assumption was supported. First, we continued to see differences among surveyors within single LTAs, which reduced environmental variability to an even greater degree. Second, it seems unlikely that factors other than surveyor could account for the variability found among surveyors for four different variables (species, diameter, distance, and bearing within a quadrant). However, we cannot and should not rule out the effect these other influences may have on our results. Although some of the variability we found is likely due to these other factors, we feel that because evidence was found suggesting surveyor bias in four of the five variables we examined, individual surveyor differences also affected the PLS data.

Recommendations

Our results suggest that differences among surveyors may affect analyses or maps based on the PLS data. These differences may obscure any real differences among different regions or falsely differentiate similar areas. These biases may affect the data of a single surveyor or location. For example, the influence of the surveyor on the species, diameters, and distances recorded could affect calculations of stand attributes and how they have changed over time.

The depth of an investigation needed to discover surveyor bias might vary depending on the variables being considered and the scale at which the data are being used. PLS data used at smaller scales (e.g., less than a township) will probably be more affected than at larger scales (e.g., several counties). Studies that use diameter values to calculate stand characteristics (e.g., importance values) should use a relative scaling or include an investigation of the data for surveyor bias. Studies using quadrant or distance variables, however, will be less affected. If possible, it may be wise for researchers to limit the number of surveyors used in their studies to minimize any effect differences among surveyors may have. For all studies, even basic inquiries are necessary to determine factors such as differences in tree species naming conventions.

The factors that varied among surveyors in our study may differ in other regions. Relatively homogeneous forested landscapes occur in this area, primarily because disturbances tend to be the result of small tree-fall gaps, with larger blowdowns occurring at return intervals of >1000 years (Frelich and Lorimer 1991).

The methods used in this study can be used to examine the extent of surveyor variability in other locations and environments. Because both chi-square methods (individual surveyor versus all other surveyors and individual surveyor versus each other individual surveyor) used to determine differences among surveyors' species selection gave similar results, future studies need only use one test. We recommend comparing each individual surveyor with every other individual surveyor. There are fewer problems with this method than in comparing each individual surveyor to all others combined, as surveyors with more records do not exert as much influence upon the results. Chi-square analysis was also helpful for examining differences in the location of witness trees among surveyors. The ANOVA with GLM and LSD tests examining differences among diameters and distances also worked well with the PLS data. These tests are also easy to implement and available in many statistical packages.

Conclusion

Since our study found some degree of variability among surveyors within the PLS survey records, users of these data must keep certain caveats in mind. These records do not, as Curtis (1959) stated, "… constitute an unbiased sample of vegetation as it existed in presettlement times." Instead, one must understand the PLS data in their historical context. The data were created for legal not ecological purposes. These purposes affected the manner in which the surveyors collected the data. The surveyors also independently interpreted how best and easiest to meet these purposes. Sometimes these interpretations result in significant differences among surveyors as to the species they chose as witness trees, the diameters of those trees, and the distances traveled to record them.

The important question is how these levels of variability affect the biological significance of the PLS data, especially when representing large areas ($>10^4$ ha). At such scales the effect of surveyor variability may not be strong enough to greatly influence results. For example, surveyors were constrained by which species were present at each point. These forests are usually dominated by only a few species. Thus, great deviations from which species would occur at a site could not be very common. Differences due to environmental variability (e.g., different LTAs) may also exceed the effect of surveyor differences when examining the PLS data over areas of great extent. One case study (Manies and Mladenoff 2000) found that variability within data sets representing larger areas are likely to be minimized. Exceptions are instances of outright fraud, which were generally detected and resurveyed (Bourdo 1956).

In conclusion, we believe the PLS data are valuable for reconstructing the vegetation before European settlement. However, use of these data must be accompanied by an understanding of surveyor biases and how this variability may affect the resulting analyses. Differences among surveyors are likely to have the least effect on the resulting picture of the vegetation if used to recreate the vegetation over a large extent.

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