Minnesota's BEARING TREE DATABASE

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The text that follows is reproduced from a 1996 publication. The current contact to acquire bearing tree data in computerized formats as described in this document is :

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Maintained within the
Natural Heritage Information System
Section of Ecological Services
Division of Fish and Wildlife
Minnesota Department of Natural Resources

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Ecological Classification System Program
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Introduction

Brief Background on the Public Land Survey

Survey records and notes from the rectangular survey of public lands (PLS) in the United States can provide ecologists with valuable information about trees and vegetation. These historical data predate widespread settlement by Europeans and thus, are especially valuable where the vegetation has been altered greatly in the past century. The fact that the PLS predates settlement is no accident. The survey was prerequisite for the public sale of lands in what was then the western territory. On 20 May 1785 Congress passed "An Ordinance for Ascertaining the Mode of Disposing of Lands in the Western Territory," thus initiating the PLS. Except for some experimentation in the early phases of the survey in Ohio, the survey of the historic Seven-Ranges in eastern Ohio set the precedent of six-mile square townships with 36 mile-square sections that would be followed throughout the history of the PLS -- including the survey of Minnesota. Grimm provides a useful summary of the "Administrative and Statutory History of the Public Land Surveys" in his Dissertation (1981) as it pertains to Minnesota, and those interested in these historical aspects of the PLS should consult White (1983), Rhorbough (1968), Gates (1968), Stewart (1935), or Lester (1860).

The PLS started in 1847 in Minnesota with the westward extension of standard parallels from the fourth principal meridian. The PLS was essentially complete for lands available for public sale by 1908, at which time, the office of the Surveyor General was closed in St. Paul and the "original" records were transferred to the State. The passage of the Civil Appropriations Act of June 25, 1910 brought an end to the contract survey system and reorganization of the General Land Office. Further surveys in the United States and Minnesota were then accomplished by government surveyors ("direct system") rather than by contractors appointed as Deputy Surveyors. In Minnesota these government surveyors were occupied by: 1) surveying any missing subdivisions of townships in Indian reservations and "unwanted" lands, 2) performing resurveys where the surveys were poor or fraudulent, 3) surveying railroads, 4) surveying special forest lands, and 5) performing special surveys upon the request of settlers (i.e. "deposit surveys"). *Except for a very few records from cleanup and resurveys, the Natural Heritage Information System (NHIS) database records do not include survey data from the direct-system era of the PLS. That is, the NHIS* *database contains the oldest survey records available for the standard section and quarter-section corners.*

Information Collected in Conjunction with the Public Land Survey

An important point that is often neglected in the ecological application of PLS notes is the fact that the purpose of the survey was not to sample the vegetation. The PLS was a means of raising revenue for the government through the sale of public lands to private individuals or companies. Thus, the emphasis was on an initial survey to make sales possible, perpetuation of the survey in anticipation of resale and further subdivision, and a means of evaluating a reasonable price for the lands, based mostly on the natural resources present. The exploitive nature of the survey is clearly evident in the instructions issued to surveyors, and the ecologist would do well to keep in mind this bias in applying PLS data to ecological problems. The *Summary of Objects and Data Required to be Noted* in the 1855 instruction manual is reprinted in Appendix A.

The data most often considered in ecological studies consist of hand-copied records of:

- corner monumentation (posts, stones, pits)
- the kind of corner established (township, section, quarter-section, meander)
- the trees marked to relocate the corners (line, witness, and bearing trees)
- points of intersection along the survey lines where there are notable features such as changes in vegetation, physiographic features, lake and river shorelines, soil changes, mineral deposits, fields, cabins, etc. (These are the so-called "line notes.")
- hand-drawn township plat maps based upon the line notes
- timber and soil summaries for each mile of line
- summaries of the vegetation, timber, soils, etc. for the entire township.

The NHIS Bearing Tree Database contains computerized records only of the bearing trees at standard section and quarter-section survey corners. Meander corners, which mark the point of departure from section lines in order to traverse around impassable objects, are not included in the database. Codes for the type of vegetation at each standard survey corner are includes as stated in the line notes or, alternatively, as inferred from the line summary notes (see next section for details).

Ecological Application of PLS Data

Below is a listing of some applications that have found their way into ecological publications.

Ecologists have utilized PLS data to:

- Make maps of presettlement vegetation
- Reconstruct absolute and relative densities of tree types in former forests
- Reconstruct characteristic size (~age) distributions for certain forest types

- Evaluate the importance and character of forest disturbance regimes
- Understand the co-association of major tree types
- Reconstruct the density and distribution of wetlands, lakes, and rivers
- Evaluate the effect of physical factors on the distribution of tree types
- Locate archaeological sites
- Provide vegetational interpretations of presettlement pollen spectra

The use of PLS data for ecological reconstructions and analyses carries with it the responsibility of knowing the survey instructions and likely implementation of those instructions for a given study area. The ecologist must know both of these things in order to construct appropriate study methods and discuss reasonably the reliability of results, given that the PLS was not designed as an ecological sampling method:

> "... not having sufficient familiarity with the nature of the land surveys, many ecologists have made faulty and naive assumptions leading to inappropriate uses of the data and to dubious or incorrect results and conclusions." (Grimm 1981)

Grimm's warning is followed in his dissertation by a comprehensive review of the literature and how various authors have applied or misapplied PLS records in ecological studies. The first chapter of Grimm's thesis (1981) and the classic paper by Bourdo (1956) should be required reading for anyone interested in applying PLS data to ecological problems in Minnesota. A fair summary of the concern about using PLS data is that it is, at best, a biased ecological sampling. Bias does not render data useless, but it does require study and discussion of its effects on ecological interpretation. The great value of PLS data is its spatial comprehensiveness, and many of the concerns about applying PLS data to ecological problems are alleviated by selecting large study areas.

Definition of Bearing Trees and Instructions for their Selection

Bearing trees are a special kind of witness tree which the surveyors notched, blazed, and scribed in a standard way to facilitate the relocation of the survey corner should the wooden corner post or corner stone be lost or moved. The surveyor was required to note for each bearing tree: 1) its type (~species), 2) its diameter, 3) its distance to the corner, and 4) its azimuth or "bearing" from the corner and hence its applied name. *These are the actual data associated with an individual bearing tree that ecologists use.* Witness tree is a broader term that includes trees that were marked on line or near the corner, generally without the required distance and bearing notes required of a true bearing tree. Thus true bearing trees, line trees, and generic witness trees were distinguished in the field with appropriate inscriptions (BT, LT, WT respectively) and are distinguished in the notes as well. Bearing trees were required at both the standard corners of the rectangular survey grid and at points on the survey lines where the surveyors were forced to meander around impassable areas such as lakes . *The NHIS Bearing Tree Database Contains only records of true bearing trees at the standard survey corners*.

Much of the concern about ecological interpretation of bearing tree data has to do with surveyor bias in selecting bearing trees. For this reason, it is important that the ecologist be aware of the surveyor's instructions for selecting bearing trees. Appendix B presents a chronological record of the actual instructions for selecting bearing trees that were issued at various times in the history of the Public Land Survey of Minnesota. The instructions are very general and really only address the method of marking trees and the required number of trees to be marked. The requirement of 5" or larger trees was dropped in the 1851 instructions, and applies only to a comparatively few surveys in Minnesota. If the surveyors were instructed to bias their selection of bearing trees with regard to species or diameter (after 1851), those instructions would have to be in the personal correspondence between the Surveyor General and the individual Deputy Surveyors.

Error, Bias, and Considerations for Ecological Use of Bearing Tree Records

Error Associated with the Versions of PLS Notes and Collection Process

The "original" field notes and corresponding plat maps are now archived by the Minnesota Historical Society. These "original" notes were hand-copied by clerks in the Surveyor General's office in Dubuque, Iowa and then later in St. Paul. These copies were periodically sent to the General Land Office (GLO) in Washington D.C. These GLO copies were microfilmed by the Bureau of Land Management, and these microfilms are available to the public at the Wilson Library, University of Minnesota. A comparison of the "original records" at the Historical Society and the further removed GLO microfilms show that there is approximately a 1-5% error rate for corner records. An error in any of the 16 possible entries (up to 4 per trees X 4 attributes per corner) constitutes an error. One source of this error occurs during transcription of the data from the GLO microfilms to data-entry forms, relating mostly to illegible entries. The other source of error is in the hand-copying procedure executed by the clerks in the Surveyor General's office. *In the NHIS Bearing Tree Database, only the township records collected for Grimm's study of the Big Woods (193 townships, Grimm 1981); the records collected for J.C. Almendinger in his study of jack pine forests (88 townships, Almendinger 1985); and townships missing from or illegible in the GLO microfilms match the "original" notes. Otherwise all data were collected from the GLO microfilms.*

Surveying Error and Resurveys

Cases of outright fraud and poor surveying did occur during the history of the PLS, and government field examiners were used to identify townships in need of being resurveyed. Provisions for withholding payment appear in the instructions to surveyors, and from this I have assumed that inspections closely followed a completed survey. Some of these problems were caught and fixed prior to accepting a survey and incorporation of the data into the "original" notes; others slipped through. *The NHIS has not attempted to substitute data from resurveys of townships that were poorly surveyed or fraudulently contrived. In my experience this was infrequent, but poor or fraudulent surveys could significantly affect ecological interpretations in studies that look at just one or a few townships.*

Error and Ambiguity in Tree Identification

Another source of error is that of tree misidentification or our misinterpretation of the common names that the surveyors used for the trees. Table 1 shows our best interpretation of the taxonomic equivalents for the tree types referenced by the surveyors and also the coding for the tree types that is used in the NHIS Bearing Tree Database. Users of the database should be aware that often tree types are assignable to genus only: oak, pine, maple, ash, etc. In nearly all of these cases of species ambiguity, it is impossible to infer a particular species. In the cases where a common name might be applied to just two species, ambiguity can often be cleared up based on the modern distributions of the trees or known habitat. For example, there are many references to black oak statewide. This name was clearly used to refer to both true black oak and red oak. In the small area of southeastern Minnesota where both black and red oak occur, this is an irresolvable ambiguity; however, north of the Twin Cities, black oak references may be assigned safely to red oak. Up until about 1988, bearing tree records were collected in areas where most tree type assignments could be safely inferred, and the data collectors made the appropriate type assignments to a single type code. As the data collection moved into areas of type ambiguity, it was decided to record exactly what the surveyor called the tree, and several codes were used for what is probably the same species. *It is up to the user to recognize and combine the type equivalents. The best way to approach this problem is to make plots of the bearing trees showing both the lines surveyed by different crews and any modern range limits of the tree types.*

Table 1. PLS bearing tree types, codes, taxonomic equivalents, frequency, and percent of 352,896 bearing trees reported for Minnesota.

PLS Tree Type	Code	Taxonomic Equivalent	Frequency	Percent
Ash	AH	*Fraxinus nigra, F. pennsylvanica, F. americana*	5,602	1.587
Alder	AL	*Alnus incana, A. viridis*	103	0.029
Aspen	AS	*Populus tremuloides, P. grandidentata, P. balsamifera* (in lesser part)	45,702	12.950
Black Ash	BA	*Fraxinus nigra*	1,852	0.525
Black Birch	BB	*Betula nigra, B. alleghaniensis* (in part ?)	10	0.003
Beech	BE	*Fagus grandifolia* (unknown from Minn. possibly *Carpinus caroliniana*	45	0.013
Balm-of-Gilead	BG	*Populus balsamifera* (in greater part)	2,300	0.652
Birch	BI	*Betula papyrifera, B. cordifolia*	20,668	5.857
Black Oak	BK	*Quercus nigra, Q. ellipsoidalis* (in part)	6,758	1.915
Blue Beech	BL	*Carpinus caroliniana*	9	0.003
Bur Oak	BO	*Quercus macrocarpa*	30,283	8.581
Babswood	BP	*Tilia americana*	11	0.003
Black Spruce	BS	*Picea mariana*	12	0.003
Buttonwood	BT	*Platanus occidentalis* (unknown from Minn. ?)	7	0.002
Butternut	BU	*Juglans cinerea*	449	0.127
Black Walnut	BW	*Juglans nigra*	129	0.037
Box-Elder	BX	*Acer negundo*	113	0.032
Buckeye	BY	*Aesculus glabra* (unknown from Minn. ?)	1	0.000
Cedar	CE	*Thuja occidentalis*, rarely *Juniperus virginiana*	10,836	3.069
Cherry	CH	*Prunus serotina, P. pennsylvanica*	262	0.074
Cottonwood	CO	*Populus deltoides*	299	0.085
Crab-Apple	CR	*Crataegus* spp.	4	0.001
Elm	EL	*Ulmus americana, U. rubra, U. thomasii*	13,397	3.796
Fir	FI	*Abies balsamea*	13,714	3.886
Hackberry	HA	*Celtis occidentalis*	174	0.049

Hornbeam	HB	*Ostrya virginiana*	8	0.002
Hickory	HI	*Carya cordiformis, C. ovata*	754	0.214
Hawthorn	HT	*Crataegus* spp.	1	0.000
Ironwood	IR	*Ostrya virginiana*	2,919	0.827
Jack Oak	JO	*Quercus ellipsoidalis*	1,645	0.466
Jack Pine	JP	*Pinus banksiana*	16,541	4.687
Juniper or Red Cedar	JU	*Juniperus virginiana*	9	0.003
Linden or Basswood	LI	*Tilia americana*	7,232	2.049
Maple	MA	*Acer rubrum, A. saccharum, A. saccharinum*	4,624	1.310
Mountain Ash	MH	*Sorbus decora, S. americana*	4	0.001
Mountain Spruce	MS	probably *Picea glauca*	3	0.001
Oak	OA	*Quercus rubra, Q. macrocarpa, Q. ellipsoidalis, Q. velutina, Q. alba, Q. bicolor*	9,068	2.570
Pine	PI	*Pinus strobus, P. resinosa, P. banksiana*	5,861	1.661
Plum	PL	probably *Prunus americana*	3	0.001
Pitch Pine	PP	*Pinus banksiana*	1,080	0.306
Spruce Pine	PS	*Pinus banksiana*	241	0.068
Red Ash	RA	*Fraxinus pennsylvanica*	1	0.000
Red Elm	RE	*Ulmus rubra*	8	0.002
Red Maple	RM	*Acer rubrum*	20	0.006
Red Oak	RO	*Quercus rubra, Q. ellipsoidalis* (in part or as hybrid)	6,766	1.917
Red, Norway, or Yellow Pine	RP	*Pinus resinosa*	10,918	3.094
Soft or White Maple	SM	*Acer rubrum* or *A. Saccharinum*	223	0.063
Spanish Oak	SO	*Quercus ellipsoidalis*	12	0.003
Spruce	SP	*Picea mariana, P. glauca*	33,802	9.578
Sugar Maple	SU	*Acer saccharum*	6,892	1.953
Tamarack	TA	*Larix laricina*	59,651	16.903
Thorn	TH	probably *Crataegus* spp.	7	0.002
Scrub Oak	OU	predominantly *Quercus ellipsoidalis* , but includes *Q. macrocarpa* as well	26	0.007
Burned Pine	UP	*Pinus* spp.	137	0.039
White Ash	WA	*Fraxinus americana, F. pennsylvanica* (in part)	306	0.087
White Birch	WB	*Betula papyrifera, B. cordifolia*	6,159	1.745
White Cedar	WC	*Thuja occidentalis*	492	0.139
Water Elm	WE	*Ulmus* spp.	6	0.002
Witch Hazel	WH	*Hamamelis virginiana*	1	0.000
Willow	WI	*Salix* spp.	1,002	0.284
White Oak	WO	*Quercus alba, Q. macrocarpa* (in part)	8,133	2.305
White Pine	WP	*Pinus strobus*	13,865	3.929
White Spruce	WS	*Picea glauca*	2	0.001
Illegible or Not Recorded	XX	equivalent unknown	28	0.008
Yellow Birch	YB	*Betula alleghaniensis*	1,211	0.343
Yellow Pine	YP	*Pinus resinosa*	495	0.140
		TOTAL	352896	99.995

Bias in Bearing Tree Selection

There is undoubtedly some bias in selecting or rejecting certain species of trees as bearing trees. Species-specific characteristics that may have influenced surveyor selection include size (for sub-trees like ironwood), longevity, bark thickness, persistent lower branches, wood density, visibility, and marketability as the loggers were close at hand. Anecdotes concerning the relative influence of these characteristics on bearing tree selection abound. These anecdotes often are conflicting and are curiously correlated with different social perspectives on forest use. Ecologists have tried many quantitative approaches of measuring species bias by considering diameter or distance distributions that vary among the species, but so many statistical assumptions are violated that the tests are unreliable (Grimm 1981). *Without reliable quantitative approaches to species bias, the user should beware*. In my experience, species bias is not a serious concern over large areas and comparisons of relative tree abundances are useful. My opinion comes from observing consistency of tree references among many surveyors in the same general area and from the fact that many survey corners occurred in places where there were few species present, thus limiting the opportunity to make biased selections. *A reasonably safe interpretation of bearing tree records is to assume that tree type was present at a corner if the surveyor said so (but see error Sections regarding the collection process and trree identification); however, it is unsafe to assume that an unreferenced tree type was absent from a corner because of the small sample size and possibly surveyor bias.*

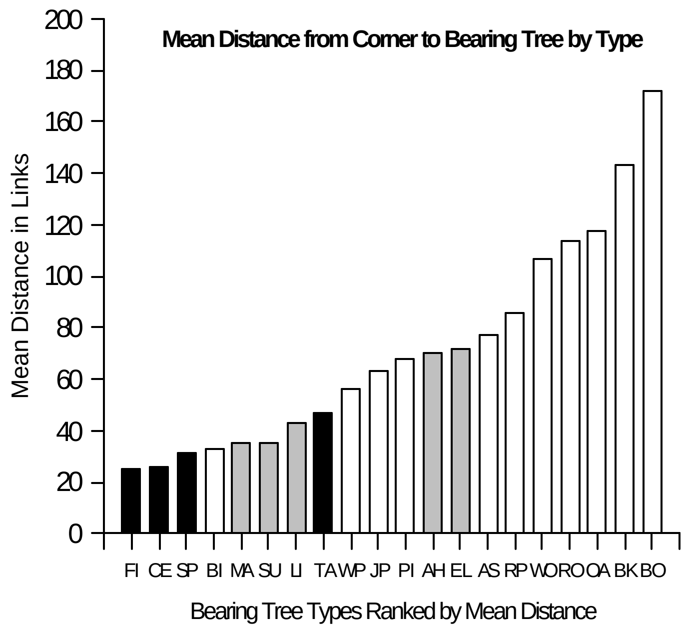

Figure 2. Mean distance from survey corners to tree types: FIr, CEdar, SPruce, BIrch, MAple, SUgar maple, LInden (basswood), TAmarack, White Pine, Jack Pine, PIne, AsH, ELm, ASpen, Red Pine, White Oak, Red Oak, OAk, BlacK oak, Bur Oak.

Although distances can't be used quantitatively to assess species bias, some qualitative interpretation can be made. Figure 1 shows the mean distance from survey corners to particular tree types. Swamp conifers (black bars) show the shortest distances, which is consistent with their tendency to grow in tight stands and in monotypes (no bias options) in modern forests. Upland, fire-sensitive taxa (gray bars: maple, sugar maple, basswood) of forests with gap-phase dynamics tend also to have short distances. The fire-tolerant pines, aspen, and birch (white bars) of forests with coarser-scale patch dynamics have intermediate mean distances. Intermediate distances are characteristic also of fire-sensitive ash and elm (gray bars), which historically regenerated from windthrow due to their shallow rooting in wet areas. Thus, species with intermediate mean distances tend to occur in landscapes where the tree canopy was often patchy due to fire or windthrow. Tree types with long distances are all fire-tolerant oaks (white bars) that occurred along the prairie-forest border. Often the survey corners would fall in small prairie openings, and long distances were traveled to mark an oak tree in the nearest grove. The ranking then is basically a gradient of increasing fire tolerance or disturbance patch size. My interpretation of this is that there was little species bias with regard to the physical properties of trees. Rather, the surveyors had to go long distances in disturbed areas to find any live tree, and trees with long mean distances are those that tend to survive broad-scale disturbances better than others.

This interpretation is consistent with the frequency distributions of individual tree-types. The types with short mean distances tend to have near-normal distributions, and the types with long mean distances have distributions with long tails. The long tails are created mostly from corners falling in areas described as burned, thickets/brush, windthrow, or prairie openings where very long distances (often >10 chains) were recorded for the trees. Obviously, such corners would have to be eliminated from the dataset for any attempt to reconstruct tree density in past forests. Even when this is done, it is my experience that bearing tree distances are 2-4 times greater than distances recorded from point-center quarter samplings of modern forests, which suggests that surveyors did pass up trees close to corners for more distant trees that were better suited for scribing or that had greater estimated longevity. *Based upon this experience, bearing tree distances are useful only within the PLS dataset to make broad-scale interpretations of physiognomy. Tree densities calculated from bearing trees cannot be reasonably compared with modern forest data.*

An alternative approach for estimating species bias in bearing tree selection is to compare the relative frequency of bearing trees with their relative frequency on line descriptions. The surveyors were required to list "the several kinds of timber and undergrowth, in the order in which they predominate." The surveyors could list as many tree types as they wanted, thus the line notes are free from the small sample size problem associated with selecting bearing trees. The surveyors did not have to mark the referenced trees, thus the line notes are free from bias associated with the task of blazing and scribing certain kinds of trees. Table 2 uses the differences in surveyor instructions regarding bearing tree selection and line-notes to infer bias in bearing tree selection.

Table 2. The relative frequency of tree types as bearing trees (15,286 trees) versus relative frequency as types mentioned in line notes (28,782 trees) for the Chippewa National Forest. Clear bias was assumed when a type was mentioned more than twice as often in one set of notes versus the other. Bias listed as "preferred" means that the surveyors tended mark that type as a bearing tree more often than one would guess from the line notes, and "avoided" indicates the converse.

Tree Type	Relative Frequency as Bearing Tree	Relative Frequency as Line-Note Tree	Difference	Inferred Bias as Bearing Tree
Aspen	11.9%	15.9%	-4.0%	somewhat avoided
Balm-of-Gilead	0.6%	0.1%	0.5%	preferred
Sum of Aspen	12.5%	16.0%	-3.5%	somewhat avoided
Paper Birch	10.0%	12.3%	-2.3%	somewhat avoided
Bur Oak	0.8%	0.1%	0.7%	preferred
Red Oak	0.7%	0.1%	0.6%	preferred
Oak	1.0%	1.7%	-0.7%	somewhat avoided
Sum of Oak	2.5%	1.9%	0.6%	somewhat preferred
Jack Pine	5.5%	2.6%	2.9%	preferred
Red Pine	8.1%	4.3%	3.8%	somewhat preferred
White Pine	6.0%	2.8%	3.2%	preferred
Pine	1.2%	7.0%	-5.8%	avoided
Sum of Pine	20.8%	16.7%	4..1%	somewhat preferred
Ash	1.5%	2.1%	-0.7%	somewhat avoided
Elm	1.6%	1.5%	0.1%	somewhat preferred
Ironwood	0.4%	0.1%	0.3%	preferred
Basswood	1.3%	0.9%	0.4%	somewhat preferred
Sugar Maple	1.5%	1.2%	0.3%	somewhat preferred
Maple	2.1%	2.3%	-0.2%	somewhat avoided
Yellow Birch	0.2%	0.1%	0.1%	somewhat preferred
Hardwoods	0.0%	1.7%	-1.7%	avoided
Sum of Hardwoods	8.6%	9.9%	-1.3%	somewhat avoided
Spruce	9.6%	10.6%	-1.0%	somewhat avoided
Balsam Fir	5.4%	5.2%	0.2%	somewhat preferred
Tamarack	20.9%	19.0%	1.9%	somewhat preferred
White Cedar	9.2%	8.5%	0.7%	somewhat preferred

My interpretation of Table 2 is that, for the more common types, there are not great differences between their relative abundance as bearing trees versus line-note trees. That is, there is not a strong case for species bias in selecting bearing trees. The fact that generic oak, pine, aspen, and hardwoods appear to have been avoided, but oaks, pines, aspen and hardwoods identified to species appear preferred, seems to indicate that surveyors tended more often to identify a tree to species if it was a bearing tree and generalize the type in the line-note. If the sum of types with generic terms are compared, there are no cases of clear bias as defined by the doubling or halving rule.

There is clear bias in recording bearing tree diameters. The surveyors were looking for healthy trees to perpetuate the corner and thus, there is a preponderance of 4-10" diameter trees selected (Figure 2). Presumably this is the case because trees of that diameter were clearly established and likely to survive for some time. Figure 2 also shows clear bias for even-inch measurements of smaller trees, and for even feet and tens-of-inches for larger trees. *If diameter data are to be reported for bearing trees, conversion to at least even-inch classes should be performed*. Plots of diameters, comparisons of tree diameters by species within the bearing tree data, and variability of diameters at corners can shed some light on gross vegetation structure and age structure of former forests. *I do not recommend direct comparison of bearing tree diameters with tree diameters in modern forests.*

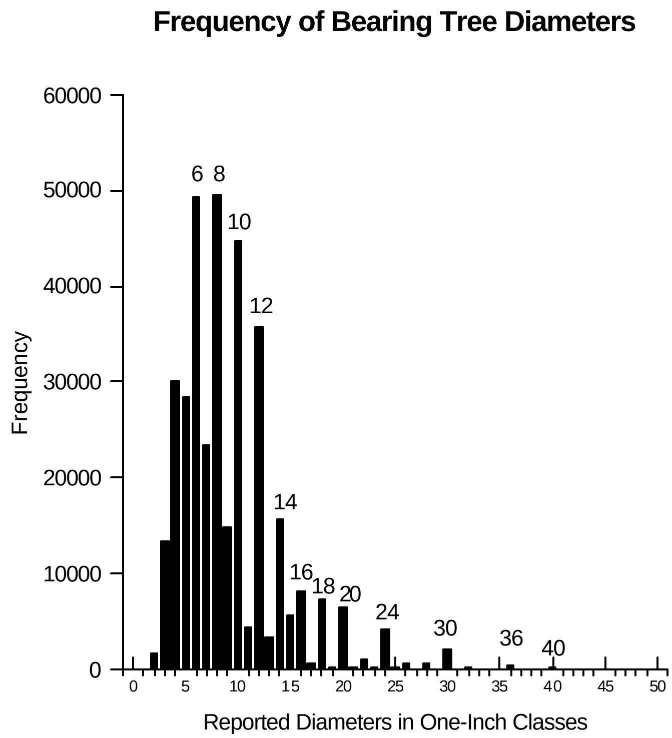

Figure 3. Frequency of bearing tree diameters in Minnesota.

Considerations for Analysis of Association

Understanding how bearing trees were co-associated is essential to the task of making map units for presettlement vegetation. Comparisons of bearing tree associations with modern associations, is also of ecological interest. For many of the published maps (e.g., Marschner 1974) this was done intuitively. More recently, ecologists have applied quantitative measures of interspecific association to bearing tree data (White and Mladenoff 1994, Almendinger 1985, Grimm 1981). Basically, the idea is to calculate for each pair of bearing tree types, a number that indicates the strength and nature (positive or negative) of the association based upon the number of corners where both species occur together (positive association), the number of corners where neither species occurs (positive association), and the number of corners where one species occurs without the other (negative association). Grimm explains nicely the problems and considerations of applying Cole's Coefficient of Association (Cole 1949) to bearing trees; the reader should also consider reading Pielou (1977) for a broader discussion of measures of interspecific association.

The main problem with applying quantitative measures of ecological association to bearing trees is the small sample size at survey corners (4 trees maximum). Most measures of association were contrived with the assumption that it is theoretically possible for all of the species of interest to co-occur in the sample. Most bearing tree datasets have 15-25 bearing tree taxa, and just 4 can be sampled at any single corner. Table 3 shows the frequency of survey corners with 0-4 trees recorded. *Although it greatly reduces the number of corners available for analysis, I recommend using only survey corners with all four trees present for analyses of association.*

Table 3. The number of PLS survey corners, trees per corner, and total bearing trees in the NHIS database.

Number of trees at survey corner	Number of corners	Number of bearing trees
0	106,864	0
1	6,419	6,419
2	96,874	193,748
3	4,507	13,521
4	34,802	139,208
Totals	249,466	352,896

Considerations for Selecting a Study Area

Choosing a study area and units for subanalysis is one of the most important decisions in applying bearing tree data to ecological problems. Size of the study area is the most critical consideration, and appropriate size depends upon the analyses one performs. For example, one of the more common uses of bearing tree data is to show how landforms controlled the distribution of tree types within fairly large areas of Minnesota by looking at maps and by comparing differences in relative abundance of tree types among landforms. In this example, the ecologist needs to configure the study area so that there are enough trees occurring on a landform to calculate reasonable estimates of relative abundance. Increasing the size of a study area increases the reliability of factors estimated from the population of bearing trees in that unit (e.g., relative abundance); however, increased size diminishes the specificity of the results that can be applied back to the landscape. Also, increasing the size of the study area relieves some concern about the errors discussed above. This can also relieve some of the concern about bias, because different survey crews clearly had different biases in selecting bearing trees that may offset one another. *A general rule for analyses influenced by the frequency of bearing tree types is that the study area should be large enough to pick up about 25 individuals of the least abundant type of interest, with rarer types eliminated from the analysis.*

The size of the study area also strongly influences analysis of association. For most measures of association, 2x2 contingency tables are constructed for each pair of tree types where the four cells of the table contain the frequency of their joint occurrence, joint absence, and the two cases where one is present without the other. The ecologist should select a study area large enough so that, for the set of tree types considered (usually ~20), most of the cells of the contingency table cells are filled with numbers other than zero. By restricting the set of tree types to the more common taxa, the ecologist can eliminate survey corners where rare types create lots of zero frequencies in the contingency tables. *In my experience, study areas with less than about 400 corners with the full contingent of four bearing trees (1,600 trees) of the types* *being considered is about the minimum size for analysis of association. For the forested portions of Minnesota, townships have a mean of about 25 survey corners with 4 trees, therefore about 16 full townships are needed to reach the 400 corner minimum.*

Checking and Corroborating Bearing Tree Data

There is no better way to check bearing tree data than to plot the tree types and diameters. Observable pattern in tree types and diameters should make some geographical and ecological sense. Surveyor bias and nomenclature problems are often made obvious by comparing areas mapped by different survey crews. Often, type ambiguity can be reasonably cleared up by studying the plots. Clearly erroneous corners can be eliminated from the analytic dataset. *Any modification of the NHIS bearing tree data that appears justified from the plots should be reported in the methods section of any published work and reported to the NHIS.*

PLS bearing tree data are, for the most part, a landscape-scale tool. Most of the valid criticism of their application to ecological problems comes when the ecologist tries to reconstruct or characterize presettlement vegetation for areas that are simply too small. All applications of bearing tree data benefit from corroboration of historical descriptions of presettlement vegetation, but such corroboration is essential for small study areas. The PLS line notes and line descriptions are an excellent source of additional finer-scale data to help interpret bearing tree analyses. The line notes are comprehensive and can be associated with survey corners. The line descriptions were to contain, in order of abundance, *all* of the tree types encountered and therefore, can help ecologists get around the problem created by selecting just two or four trees at a survey corner. The types listed in the line notes should also be free of any surveyor bias associated with ease of marking bearing trees and bias based upon expected longevity. Historic journals from early expeditions, notes from the construction of the military road system, the writings of N.H. Winchell and W. Upham associated with the Minnesota Geological and Natural History Survey (*ca*. 1875-1890), and the personal journals of the Deputy Surveyors can all contribute to a better interpretation of bearing tree data.

Description of the NHIS Bearing Tree Database

The NHIS Bearing Tree Database consists of two flat files, linked by a single overlap variable, TWP_RNG, formed from the combination of township and range number, e.g. T143NR36W. One database, BTSTWP, contains a single record for each of the 2,674 townships in Minnesota. The other database, BTS, contains a single record for each survey corner associated with a township, including section corners, quarter-section corners, the north township boundary, the east township boundary, and the south township boundary for townships just north of standard "correction" parallels. There are 108 corners for standard townships, and 120 for townships that include also the south boundary, where the corners do not match the north boundary of the township below. A schematic showing the standard corner numbering is shown in Appendix C. Tables 4 and 5 below present the table definitions of the variables, their type, and length in the two flat files containing the bearing tree data.

Except for the bearings (DIRECT1-4), there are few unfilled variables in the BTS database. Grimm (1981) and Almendinger (1985) did not record the bearings, and many of the first townships collected by the Minnesota County Biological Survey also do not have bearings recorded. *Consequentially, GIS plots of*

actual *bearing tree locations are possible only for part of the state*. In practice this is generally not important for maps of many townships, where the convention has been to add or subtract 200m from both the northings and eastings of the Universal Transverse Mercator (UTM) coordinates for a survey corner in order to produce a point cover of bearing trees. For example, 200m would be added to both UTM coordinates for a bearing tree NE of a survey corner, and 200m would be subtracted from both UTM coordinates for a bearing tree SW of a survey corner. The net effect of making plots this way is to form a near-perfect grid of coordinates for bearing tree plots that can serve as the centers of map symbols.

Table 4. Variable names, length, type, and description for data records associated with standard PLS survey corners in Minnesota (BTS database).

Variable Name	Length	Type	Description
TWP	5	A	township number, e.g. T154N
RNG	4	A	range number, e.g. R23W
TIC	4	N	standard survey corner number, see attached
VEGTYPE	1	A	code for vegetation type, see below
SPECIES1-4	2	A	code for tree type, see Table 1 for codes
DIAM1-4	2	N	tree diameter in inches
DIRECT1-4	4	A	bearing, e.g. S15^{0}E (=165^0 azimuth)
DIST1-4	4	N	distance from corner in links (7.92 inches)
XTIC	6	N	corner UTM coordinate relative to Zone 15
YTIC	6	N	corner UTM coordinate relative to Zone 15, shifted -4,700,000m
TWP_RNG	9	OV	overlapped TWP and RNG fields

Table 5. Variable names, length, type, and description for data records associated with each PLS township in Minnesota (BTSTWP database).

Variable Name	Length	Type	Description
TWP	5	A	township number, e.g. T154N
RNG	4	A	range number, e.g. R23W
MERIDIAN	1	A	principle meridian (4th or 5th)
COLLECTOR	20	A	name of person collecting the data
SUBDIVNAME	20	A	name of surveyor performing township subdivision
SUBDIVDATE	20	A	date of the subdivision
NBOUNDNAME	20	A	name of surveyor of the north township boundary
NBOUNDDATE	20	A	date of survey of north township boundary
EBOUNDNAME	20	A	name of surveyor of the east township boundary
EBOUNDDATE	20	A	date of survey of east township boundary
TWP_RNG	9	OV	overlapped TWP and RNG fields

In addition to the standard listing of bearing tree type, diameter, bearing, and distance from the corner, the collectors were instructed to record the vegetation type at the corner. This information was recorded from the line notes when stated, or inferred from the line summary if not specifically referenced in the line notes. *These codes are especially valuable in reconstructing the gross physiognomy of the vegetation and help with interpretation of the bearing tree data.* Tree distances and diameters are correlated with the vegetation codes. *The vegetation types allow the ecologist to subdivide the bearing tree datasets for more limited analyses.* For example, one might eliminate all aquatic and wetland corners in order to understand tree associations on upland habitats. The vegetation codes and descriptions are presented below in Table 6.

Table 6. Vegetation codes, description, frequency, and percent for 249,466 PLS survey corners in Minnesota.

Vegetation Code	Description	Frequency	Percent
A	creek	155	0.06
B	oak barrens	1,391	0.55
C	plowed field, field	98	0.03
D	dry ridge	513	0.20
E	meadow	1,682	0.67
F	forest, timber	76,344	30.60
G	grove	289	0.11
H	bottom	2,863	1.14
I	pine openings, pine barrens, scattered pine	505	0.20
J	pine grove	28	0.01
K	scattering oak, scattering timber	7,957	3.18
L	lake, slough, pond	9,786	3.92
M	marsh	11,670	4.67
N	dry land	293	0.11
O	oak openings	2,167	0.86
P	prairie	81,439	32.64
R	river	1,268	0.50
S	swamp	30,401	12.18
T	thicket, brush, underbrush	8,989	3.60
U	burned area	3,536	1.41
V	valley, ravine	226	0.09
W	windthrow, windfall	1,384	0.55
X	only tree around	259	0.10
Y	island	57	0.02
Z	wet prairie	986	0.39
blank	no code recorded by collector	5,180	2.07
	Totals	249,466	99.86

Obtaining and Citing Bearing Tree Data

Data Sources

Bearing tree data in computerized formats as described in this document are obtainable from the Minnesota Natural Heritage & Nongame Research Program.

> Richard Baker, Information Systems Manager
> Minnesota Natural Heritage and Nongame Research Program
> Department of Natural Resources
> Box 25
> 500 Lafayette Rd.
> St. Paul, MN 55155
> (612) 297-3764

Microfilms of the General Land Office's hand-copies of the "original" PLS notes can be viewed at the Wilson Library.

> Wilson Library
> University of Minnesota, West Bank Campus
> Minneapolis, MN 55455
> (612) 626-2227

The bound volumes of the "original" PLS notes and plat maps turned over to the State of Minnesota are housed at the Minnesota Historical Society.

> Minnesota Historical Society
> Attn: Charles Rodgers
> 345 Kellogg Bvd. W
> St. Paul, MN 55102
> (612) 297-2344

Scanned microfilms of the "original" PLS notes and plat maps are housed at the Minnesota Secretary of State's office.

> Minnesota Secretary of State
> Attn: Bert Black
> 180 State Office Bldg.
> 100 Constitution Ave.
> St. Paul, MN 55155
> (612) 296-9215

Appropriate Citation and Acknowledgment

The PLS survey notes are some of the first truly public information collected by the Federal Government and have always been available for use. Ecologists at the University of Minnesota and other academic or government institutions in Minnesota have long used these data for ecological interpretations. The collection of PLS data in a computerized format was initiated by Eric Grimm and Edward Cushing of the University of Minnesota, and they deserve much of the credit for the database design and the collection of 193 townships in the area of the Big Woods. Also under the tutelage of Edward Cushing, John Almendinger later collected 88 townships of PLS bearing tree data in north-central Minnesota. These 281 townships formed the initial core of the computerized records, and studies using data from these townships should acknowledge these individuals as the source of computerized data or cite their respective theses (Grimm 1981, Almendinger 1985). The initiative for collecting the remaining 2,393 townships was provided by the Minnesota County Biological Survey (MCBS), Division of Fish and Wildlife with support from the Division of Forestry, Minnesota Department of Natural Resources. Sharron Nelson (MCBS) directed the data collection. The data from these three sources are managed by the Minnesota Natural Heritage and Nongame Research Program, and they request the following acknowledgment:

> The bearing tree data included here were provided by the Minnesota Natural Heritage and Nongame Research Program of the Division of Fish and Wildlife, Minnesota Department of Natural Resources (DNR). The DNR is not responsible for any inaccuracies in these data. Use of these data does not imply endorsement or approval by the DNR of any interpretations or products derived from the data.

The PLS records have been variously cited in ecological literature. The following citation is appropriate for the records pertaining to Minnesota:

> U.S. Surveyor General. 1847-1908. Field notes: Township and exterior subdivision lines. Minnesota State Archives, 57.J.5.9B-57.J.8.8F, Minnesota Historical Society, St. Paul.

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Appendices

Appendix A -- Instructions for Information to be Collected

Most of Minnesota was surveyed according to the 1855 instructions to the surveyors. Below is the appropriate excerpt from White's (1983) reprinting of that manual covering the information required in a contract PLS survey. Italics and capitalizations are theirs in all cases.

SUMMARY OF OBJECTS AND DATA REQUIRED TO BE NOTED.

1. The precise length of every line run, noting all necessary offsets therefrom, with the reason and mode thereof.
2. The kind and diameter of all "*bearing trees*," with the course and distance of the same from their respective corners; and the precise relative position of WITNESS CORNERS to the *true corners*.
3. The kinds of materials (earth or stone) of which MOUNDS are constructed -- the fact of their being conditioned according to instructions -- with the course and distance of the "*pits*," from the centre of the mound, where necessity exists for deviating from the *general* rule.
4. *Trees on line*. The name, diameter, and distance on line to all trees which it intersects.
5. Intersections by line of *land objects*. The distance at which the line first intersects and then leaves every *settler's claim and improvement*; prairie; river, creek, or other "bottom;" or swamp, marsh, grove, and wind fall, with the course of the same at both points of intersection; also the distances at which you begin to ascend, arrive at the top, begin to descend, and reach the foot of all remarkable hills and ridges, with their courses, and *estimated* height, in feet, above the level land of the surrounding country, or above the bottom lands, ravines, or waters near which they are situated.
6. Intersections by line of *water objects*. All rivers, creeks, and smaller streams of water which the line crosses; the distance on line at the points of intersection, and their *widths on line.* In cases of *navigable* streams, their width will be ascertained between the *meander corners*, as set forth under the proper head.
7. The land's *surface*--whether level, rolling, broken, or hilly.
8. The *soil*--whether first, second, or third rate.
9. *Timber*--the several kinds of timber and undergrowth, in the order in which they predominate.
10. *Bottom lands*--to be described as wet or dry, and if subject to inundation, state to what depth.
11. *Springs of water*--whether fresh, saline, or mineral, and the course of the stream flowing from them.
12. *Lakes and ponds*--describing their banks and giving their height, and also the depth of water, and whether it be pure or stagnant.
13. *Improvements*. Towns and villages; Indian towns and wigwams; houses or cabins; fields, or other improvements; sugar tree groves, sugar camps, mill seats, forges, and factories.
14. *Coal* banks or beds; *peat* or turf grounds; *minerals* and ores; with particular description of the same as to quality and extent, and all *diggings* therefor; also *salt* springs and licks. All reliable information you can obtain respecting these objects, whether they be on your immediate line or not, is to appear in the general description to be given at the end of the notes.
15. *Roads and trails*, with their directions, whence and whither.
16. Rapids, cataracts, cascades, or falls of water, with the height of their fall in feet.
17. Precipices, caves, sink-holes, ravines, stone quarries, ledges of rocks, with the kind of stone they afford.
18. *Natural curiosities*, interesting fossils, petrifactions, organic remains, &c.; also all ancient works of art, such as mounds, fortifications, embankments, ditches, or objects of like nature.
19. The *variation* of the needle must be noted at all points or places on the lines where there is found any material *change* of variation, and the position of such points must be perfectly identified in the notes.
20. Besides the ordinary notes taken on line, (and which must always be written down on the spot, leaving nothing to be supplied by memory,) the deputy will subjoin, at the conclusion of his book, such further description or information touching any matter or thing connected with the township (or other survey) which he may be able to afford, and may deem useful or necessary to be known--with a *general description* of the township in the *aggregate*, as respects the face of the country, its soil and geological features, timber, minerals, waters, &c.

Appendix B -- Instructions for Selecting Bearing Trees in Minnesota

FOR SURVEYS RELATIVE TO THE 4TH PRINCIPAL MERIDIAN, 1847-1852

On 12 June 1838 Congress approved a statute (5 Stat. 235) that divided the Iowa Territory from the Wisconsin territory, thus placing the portions of Minnesota east of the Mississippi river in the Wisconsin Territory and the portions of Minnesota west of the Mississippi river in the Iowa Territory. In 1846 the 4th Principal Meridian was extended northward from southern Wisconsin to Lake Superior and provided the starting point for the survey of standard parallels westward into Minnesota. Thus, land surveyed prior to 1852 in Minnesota relative to the 4th Principal Meridian were executed under the *General Instructions* issued by the Office of the Surveyor General of Wisconsin and Iowa, Dubuque, May 28, 1846 (see White 1983 p. 339). The instructions for establishing bearing trees are extracted from that document and presented below:

> "Bearing trees are those of which you take the course and distance from a corner. They are distinguished by a large smooth blaze or chop, fronting the corner, upon which is marked, with an iron made for that purpose, the number of the range, township and section, except at quarter section corners where 1/4 S. will supply the number of the section, thus;
>
> R -------- E. or W.
> T -------- N.
> S -------- or 1/4 S.
>
> The letters B.T. are also to be marked upon a smaller chop, directly under the large one and as near the ground as practicable."

> "Fromall posts established for township corners, or for section corners upon township lines, four bearing trees, if within a reasonable distance, must be taken; one to stand within each of the four sections."

> "At the interior section corners, one to stand within each of the four sections, are to be marked; two of them as bearing and two as witness trees."

> "From quarter section and meander corners two bearing trees are marked, one within each of the adjoining sections."

FOR SURVEYS RELATIVE TO THE 4TH AND 5TH PRINCIPAL MERIDIANS 1852-1855.

On 3 March 1849, the Territory of Minnesota was created, and the Surveyor General of Iowa and Wisconsin was to administer the continued survey of Minnesota. On that very same date, the U.S. Department of Interior was created and absorbed the General Land Office among other agencies. One of the first things accomplished by the Department of Interior was the publication of *Instructions to the Surveyor General of Oregon; Being a Manual for Field Operations* (White 1983, p.433) in 1851. This manual was prepared for the initial rectangular survey of Oregon, and on 10 July 1852 the Surveyor General of Iowa and Wisconsin was instructed to use the Oregon instructions for surveys in Minnesota relative to the 5th Principal Meridian. My interpretation of White (1983) is that surveys relative to the 4th Principal Meridian also fell under these instructions at that time. The instructions for establishing bearing trees are extracted from that document and presented below:

> “The position of all corner posts, or corner trees, of whatever description, which may be established, is to be perpetuated in the following manner, viz: From such post or tree the courses shall be taken, and the distances measured, to two or more adjacent trees, in opposite directions, as nearly as may be, which are called “*bearing trees*,” [italics theirs] and are to be blazed near the ground, with a large blaze facing the post, and have one notch in it, neatly and plainly made with an axe, square across, and a little below the middle of the blaze. The kind of tree and the diameter of each are facts to be distinctly set forth in the field book.
>
> On each bearing tree the letters B.T., to denote the fact of its being a bearing tree, must be distinctly cut into the wood, in the blaze, a little above the notch, or on the bark with the number of the range, township, and section.
>
> At all township corners, and at all section corners, on range or township lines, *four* [italics theirs] bearing trees are to be marked in this manner, one in each of the adjoining sections.
>
> At interior section corners *four* [italics theirs] trees, one to stand within each of the four sections to which such corner is common, are to be marked in manner aforesaid, is such be found.
>
> ... From quarter section and meander corners two bearing trees are to be marked, one within each of the adjoining sections.”

FOR SURVEYS RELATIVE TO THE 4TH AND 5TH PRINCIPAL MERIDIANS 1855-1864.

A new manual, *Instructions to the Surveyors General of Public Lands of the United States, for Those Surveying Districts Established in and since the Year 1850; containing, also A Manual of Instructions to regulate the Field Operations of Deputy Surveyors, Illustrated by Diagrams,* was published in 1855. This was the manual that guided the rectangular survey of most lands in the United States, and set the standards for the survey with only slight modification in later years. The instructions for establishing bearing trees are extracted from that document and presented below:

> The position of all corner posts, or corner trees, of whatever description, that may be established, is to be evidenced in the following manner, viz: From such post or tree the courses must be taken and the distances measured to two or more adjacent trees in opposite directions, as nearly as may be, and these are called “bearing trees.” Such are to be distinguished by a large *smooth blaze*, [italics theirs] with a *notch* [italics theirs] at its lower end, facing the corner, and in the blaze is to be marked the number of the *range*, *township*, and *section* [italics theirs]; but at quarter section corners nothing but 1/4 S. Need be marked. The letters B.T. (Bearing tree) are also to be marked upon a smaller blaze directly under the large one, and as near the ground as practicable.
>
> At all township corners, and at all section corners, on range or township lines, *four* [italics theirs] bearing trees are to be marked in this manner, one in each of the adjoining sections.
>
> At interior section corners *four* [italics theirs] trees, one to stand within each of the four sections to which such corner is common, are to be marked in manner aforesaid, if such be found...
>
> ... From quarter section and meander corners two bearing trees are to be marked, one within each of the adjoining sections.

During this period, the office of the Surveyor General was opened in St. Paul (23 May) with no changes in instructions.

For Surveys Relative to the 4th and 5th Principal Meridians 1864-1907

An instruction circular, *Instructions to the Surveyors General of the United States, Relating to Their Duties and to the Field Operations of Deputy Surveyors*, was published in 1864 with a minor revision in instructions for selecting bearing trees.

> "Where a tree not less than two and a half inches in diameter can be found for a bearing tree within 300 links of the corner, it should be preferred to the trench or pit."

The 1864 circular was reprinted in 1871 with no changes concerning bearing trees. The manual published as *Instructions of the Commissioner of the General Land Office to the Surveyors General of the United States relative to the Survey of the Public Land and Private Land Claims* was published in 1881, and it too, had no further instructions for selecting bearing trees than those spelled out in the 1855 Manual and the 1864 note.

The office of the Surveyor General of Minnesota was closed on 4 February 1908, and the records transferred to the State of Minnesota.

Appendix C -- Schematic of Standard Township Corner Numbers for Computerized Records

Below is the standard numbering system for referencing section and quarter-section corners in the computerized database (variable TIC) for bearing trees. The order for interior corners follows the standard path of township subdivision. The orders for the north, east, and south township boundaries were assigned to increase in the standard direction of survey. Corners 109-120 are recorded only when the south township line is also a standard correction parallel (e.g., corner 119 does not correspond with corner 95 of the next township south).