Cloquet Forestry Center

Continuous Forest Inventory Update for 2014

by

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ABSTRACT

The Cloquet Forestry Center (CFC) is a field research and instructional station administrated by the University of Minnesota. This report compiles CFC Continuous Forest Inventory (CFI) results from the summer 2014 re-measurement of 402 permanent field plots. These plots serve both research and forest management on the CFC. The individual plots are 1/7 acre in size and were installed and first measured in 1959. The plots have been subsequently remeasured in 1964, 1969, 1976, 1982, 1990, 2000 and in 2014. Three more plots were also added in 2014 (totaling 405) on newly acquired acreage. The report also describes changes in the forest since 2000 and longer-term trends. Summaries provided include 2014 number of trees, basal area, volume and biomass per acre by covertype, and acreage by age class distributions. Longer-term trends from 1959 are also described. The report also details the inventory design and associated details for the permanent plots, including measurement technologies. Data collection and analysis procedures were developed using Microsoft Access and the R statistical analysis package. Access to the compiled data and preliminary analysis is also describe

INTRODUCTION

The University of Minnesota's Cloquet Forestry Center (CFC) was established in 1909 for the purpose of serving as an experimental and demonstration forest for Minnesota students, researchers and forestry professionals alike. The Cloquet Forestry Center (CFC) Continuous Forest Inventory (CFI) began in 1959, and has since been repeated every five to fourteen years. It was initially established for the purposes of (1) testing systematic sampling with multiple random starts, (2) testing field plot configurations (fixed and variable radius plots) for estimating mortality and other forest variables and (3) for providing up-to-date inventory information for CFC management. Reber and Ek (1982) describe much of this background and design details.

Repeated forest inventories are an expensive yet invaluable tool for research aimed at assessing forest growth, change and management responses over time, particularly when the same set of plots are observed on each inventory occasion. Such inventories enable researchers and forest managers to see and study forest change and stand and landscape dynamics in detail. Additionally, the inventory design allows researchers to travel back through time to examine not only the effects of forest management, but in some cases the effects of changing environmental conditions, including invasive species and atmospheric change, etc.

The CFC serves as a field research station for study, outreach and demonstration purposes for a wide range of forestry practices. To date the CFC CFI data have been used for calibrating regional forest growth models, examining harvest scheduling methodology and much more (Moeur et al, 1980). This research focused inventory is the most extensive of its kind in the Lake States (Reber & Ek, 1982). Through the CFC CFI we have also been able to examine forest growth and change with respect to a wide range of research questions.

The objectives of this study were:

1) To describe and compile the CFC CFI data from the 2014 re-measurement as the basis for describing and understanding current forest conditions and trends.
2) To analyze these data to provide useful summaries to aid in planning future research and forest management on the CFC.

DESCRIPTION OF THE CFC AND CFI

CFC area description: The CFI is a repeated representative sampling of forest within the CFC's 3,347.5-acre contiguous main ownership block of land in Carlton County in northeastern Minnesota. This block encompasses all of sections 29, 30, 31 and 32 in T49N R17W, section 36 of T49N R18W, and the N ½ of the NE ¼ of section 6 of T48N R17W (Reber and Ek 1982; (U of MN: 2004 Real Estate Inventory Report). Figure 1 provides a description of the CFC main owner ship block in the form of boundaries and forest cover classification. Figure 2 also shows an addition of 48.3 acres in 2003 on the east side of the forest. However, due to a lack of inventory history, that tract is not included in the definition of the main ownership block referenced later in this report. Figure 2 further shows a land classification that was produced

using remote sensing data and eCognition software (Definiens 2009). The list of operational covertype classifications found at the CFC is shown in Appendix 8. Figures 1 and 2 were produced to provide students with an understanding of the kinds of forest types on the CFC, and to act as a reference map for field work purposes. Note this map covers most, but not all of the CFC property.

The topography of the forest is gently rolling with most of the area containing upland forest. The soils are loamy sands to sandy loams, with peat soils covering the lowland areas (Severs et al 2012). Most of the landscape may be described as sub-boreal forest growing on sandy outwash plains. The predominant tree species on the CFC are red pine, jack pine, aspen and paper birch (Reber and Ek 1982).

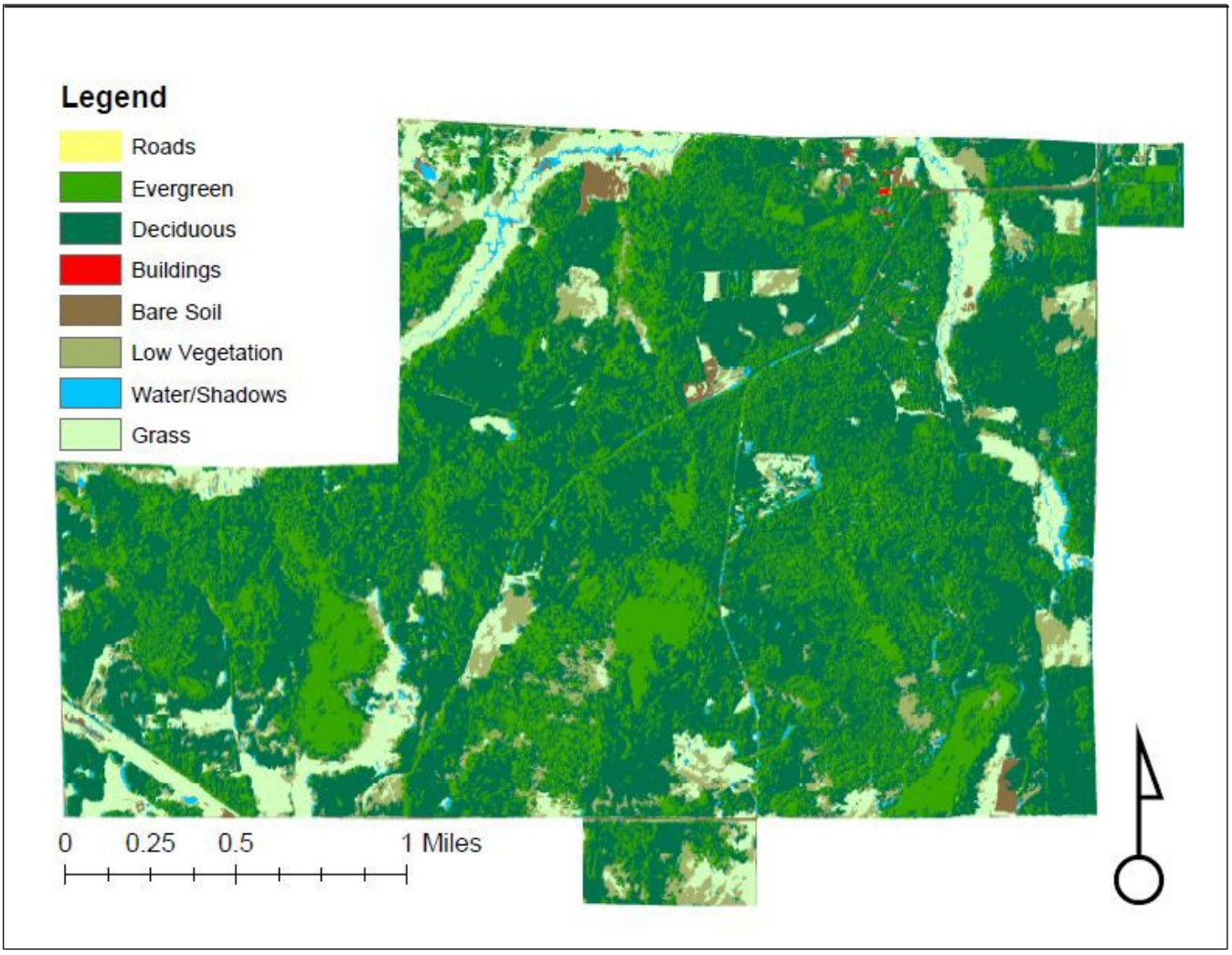

Figure 1. CFC Land Classification Map. Based on 2011 LiDAR and 2008 NAIP imagery (Loeffelholz and Zimmerman 2011).

CFI description: Systematic sampling with multiple random starts, which allows the computation of sampling error, was used as the basic sampling design for plot center location for the inventory (Tuhus, Walters and Ek 1994). Reber and Ek (1983) concluded that this design ensures a representative sample.

Within the CFC contiguous main ownership block, 402 plots have been established. The full set of field data entry procedures are listed in Appendix 1. The plot locations were first identified using the 1959 systematic sample with four random starts set out by Shiue (1959). However, at that time, only the 353 upland plots were established. The lowland plots locations were subsequently identified, and established in 1982 as reported by Reber and Ek (1982). Addition of the lowland plots increased the total number to 402. The database for the lowland plots has since been extended back to 1959 for plot level descriptors. The addition of a 38-acre tract on the northeast corner of the CFC in 1964 also led to the establishment of 4 new plots there in 1982. The acquisition of a 48-acre tract on the east side of the CFC in 2003 also led to the establishment of additional plots there in 2014.

Tree-level measurements were collected on each $1/7^{th}$ acre CFI plot. Observations were recorded for trees 5 inches in Dbh and greater, including species, Dbh, height, crown ratio, distance and direction from plot center (Dieser and Ek, 2011). Observations of tree health, damage etc., were also recorded. Trees > 0.95" Dbh but less than 4.95" Dbh were observed on a concentric $1/100^{th}$ acre circular plot. The actual field data entry was accomplished using Microsoft Access forms displayed on a Microsoft© SurfacePro tablet computer as described in Appendix 2. Additional variables of interest, notably tree volume and biomass, were subsequently developed from equations described in Appendix 4.

The most recent set of reference maps used for field work on the CFC CFI were created in 2011. These maps were very basic and rely on stand boundaries and field measurements for the identification of covertype. For this report, an updated map of the CFC was developed using eCognition (Definiens 2009). This step utilized the following satellite imagery: Light Detection and Ranging (LiDAR) 2011 from Minnesota Geospatial Information Office; National Agricultural Imagery Program (NAIP) 2013 from the United States Department of Agriculture (USDA) Natural Resources Conservation Service's (NRCS) Geospatial Data Gateway; Color InfraRed (CIR) from MnGEO NAIP Imagery WebService; and the CFC stand boundary layer, road layer and xy-coordinates for plot centers derived from a 2005 vegetation mapping effort at CFC. The use of eCognition allowed rapid automation and classification of the CFC's contiguous block.

This classified image noted has been used for both forest management and research purposes. In addition, the map has provided students with a basic understanding of the forests types present. It can also serve as a reference map for locating field work.

DATA COLLECTION, ORGANIZATION AND ANALYSIS

Figure 2 depicts the basic covertypes and stand boundaries developed for the CFC. This delineation and classification shows the main covertype (evergreen/deciduous) for the forested area. Additionally, stand boundaries with their associated covertype and roads are shown.

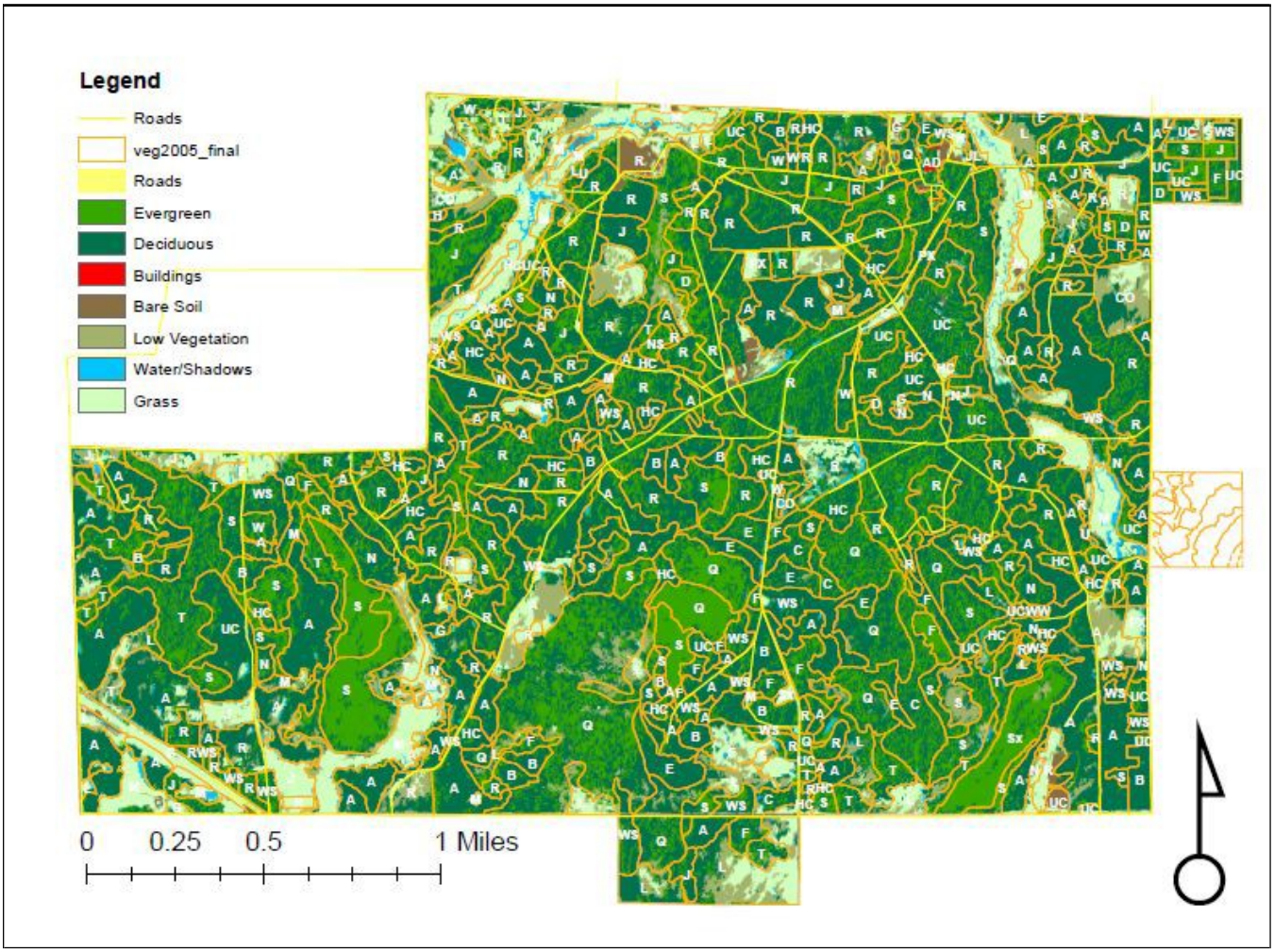

Figure 2. CFC stand map. Covertype labels based on 2011 LiDAR imagery, 2008 NAIP and 2005 stand boundaries and covertype (legend shown in Appendix 8 (Loeffelholz and Zimmerman 2011)).

Field Observations

The detailed field measurement was conducted by undergraduate and graduate student crews from the Department of Forest Resources. The data were recorded in a Microsoft Access database forms (see Appendix 2) using Microsoft Surface Pro 2 tablet computers in the field. Data entry forms were built directly in the historic CFC CFI Access database, and linked to tables storing the observed records. This electronic data entry in the field was designed to help the crew in checking for errors and to provide ready access to earlier inventory data, plot location information, field instructions and remote sensing and map data. Field crews also took videos

covering a 360 degree sweep from each plot center. These plot videos for all CFC plots are currently on google drive and will soon will be added to the IIC website. Plot centers were identified and monumented using 2" x 2" treated wooden stakes cut to 3 to 4 ft in length (most from wooden or wood composite material) in the center of the plots. In fact, most stakes were replaced with wood composite stakes in 2014 as the originals were nearing the end of useful life due to decay.

The $1/7^{th}$ and $1/100^{th}$ acre permanent plots were employed for all plot-level and tree-level measurements around the plot centers. Trees greater than 5" Dbh were measured on $1/7^{th}$ acre plots. Dbh, height, and other information for each tree in $1/100^{th}$ and $1/7^{th}$ acre plots were recorded. Stand age and height data for each stand were also observed, typically from 3 dominant or co-dominant trees on or just off the $1/7^{th}$ acre plot.

The plot table forms in Microsoft Access (Appendix 2) contained old tree numbers and sometimes painted tree number information which made it easier for the crew to identify the trees in each plots. UTM coordinates for all CFC CFI plots in the table were also used along with printed maps to help identify the location of each plot and plot centers.

Painted Trees Numbers (PTN) were unique for each plot but they were not always a unique identifier for trees within plots. Trees in some plots were found dead (mortality) and some new (ingrowth) trees were recorded. Most of the new and some old trees were painted with tree numbers. Witness trees were also marked with painted arrows near the base and pointed at the plot center.

Some of the plots that had been clear-cut had lost evidence of the plot center location. For those sites, hand-held GPS navigation was used to reestablish the plot centers.

Database Development

The 2014 CFC CFI database was created with Microsoft Access 2010. A first step in that effort was to create electronic data entry forms so that the field crew could enter the data directly while on a subject sample plot. The Tree table contained data related to the observation of individual trees, whereas the Plot table contained information related to each plot. The relation of each tree with the subject plot was effected by connecting the plot numbers of both tables.

Plot Table: The data entered for each plot in the plot tables were: plot number, condition class, covertype, land use, slope, aspect etc. UTM coordinates were also recorded from the last measurement in 2000. GPS coordinates were used only for those plots where plot centers were missing or for the clear-cut plots.

Tree Table: The data entered for each tree in the tree tables were: plot number, tree number, painted tree number, Dbh, height, azimuth, distance from the plot center, species code, damage code, tree class, crown class, crown ratio, etc. An example of a tree table form can be found in Appendix 2.

Coarse Woody Debris: Coarse woody debris (CWD) data collection was conducted on all plots in random starts 1 and 2. However, these data have yet to be compiled. It is anticipated that

CWD data collected in 2014 may serve as a starting point for monitoring and assessing the carbon balance of CFC and regional forests given different treatments and demographic conditions

Plot maps: Plot maps for each plot were made using R software (example: Plot 149, Appendix 5). Such maps were made in order to help field crews identify and locate the trees on each plot. These R maps also contain information about trees per acre, basal area, volume and biomass for the 377 plots supporting live trees. Maps were not produced for plots with no trees, or for the plots that were clear-cut.

Site index, tree height, volume, and biomass equations

The volume and biomass calculations presented here did not include any missing, harvested, damaged or dead trees. Queries were created in MS Access to summarize variables of interest while filtering out trees with little or no timber value. The description of the damage codes and tree classes that were not used for calculations are mentioned in Appendix 6.

1. Site Index: The concept of Site Index (SI) is typically used to evaluate the combined contribution of all factors on a site to the potential growth of trees on that site (Carmean 1975, Carmean 1977, Carmean and Vasilevsky 1971, Carmean et al. 2013). The value of SI is determined by measuring the height of dominant and co-dominant trees on a site and comparing the measured height to the expected height at some index age (usually 50 years in the Lake States Region). Because SI is a measure of realized growth, it is also a simultaneous measure of all site level factors contributing to the potential for tree growth at that location. As tree height, volume, and potential stocking density are also related to site index, this measure helps to determine the expected productivity of a site for a given tree species.

   Hahn and Carmean (1982) developed equations to calculate species site index at base age of 50 years (Appendix 4). Three dominant trees from each plot were selected for which height and age were observed. These data were later used to calculate site index. The curves in Carmean et al. (1989) were used to verify the calculated site indices for each species.

2. Height: Calculated site index was used to compute height for each tree. For plots lacking site index, site index from a previous year was used to calculate the height where available, otherwise the average site index for the covertype was used. The height of all trees over 1" Dbh, with site index greater than 0, were calculated. Height for 1-4.95" Dbh was determined using d=0. Height for trees greater than 5" Dbh was determined using d=4. Species specific coefficients were used in the height calculations following Ek et al. (1981) (Appendix 4).

3. Volume: Gross cubic feet volume for all merchantable trees (Dbh $\geq$ 4.95" was calculated. This volume was calculated using an equation developed by Robert N. Stone (see Hahn, 1984) for table 6 from Gevorkiantz and Olsen 1955). Note that bole soundness was not considered. However, species specific coefficients (from Hahn, 1984) can be used to calculate the net (sound) cubic foot volume as needed. Stone's equation

form is also noted in appendix table 1 of Woodall et al (2011).

4. Biomass: Above ground biomass was computed for all live trees. Biomass for trees smaller than 5" Dbh, measured on 1/100th acre plots, was calculated using equations from Hahn (1984). Biomass for trees $\geq$ 5" Dbh, measured on 1/7th acre plots, was calculated by separate equations for stump, bole, bark and top components. (Appendix 4).

Plot-level observations

Plot-level observations were based on FIA condition class details and the year 2000 CFC inventory (Dieser and Ek 2000). The observation of condition class included covertype, stand size, and density classes. Up to three condition classes were recorded for each plot to differentiate between portions of plots with substantially different characteristics from the remainder. These observations were recorded for each condition class and entered into the Microsoft Access database.

The Microsoft Access database described in Appendix 3 is a compilation of data and record sets collected for each inventory year of the Cloquet Forestry Center property since 1959. The database also contains a complete set of inventory forms and lookup tables used during the 2014 re-inventory. These data entry forms have been extensively field tested on Microsoft Surface Pro 2 devices. Thus they could be used for future inventories with minor adjustments to the Visual Basic programming and SQL used to reference prior and current data tables. Extensive error checking and quality assurance checks have also been implemented as a part of these forms to ensure accuracy and completeness of the data entered. All calculations of trees per acre, basal area, height, volume, and biomass for the 2014 re-inventory were completed using SQL queries developed in Access. Sometimes, intermediate calculations or summaries were needed to achieve the desired end result, thereby producing additional tables contained in the database. Additional analysis of site index data was also incorporated into this Access database from a tabular dataset assembled by the 2014 field crew.

For aspen and red pine, summaries of volume and biomass were calculated for the whole forest using a pivot table in Microsoft Excel. The Excel Workbook calculated number of trees, basal area, gross merchantable volume, and biomass to produce per acre results for input to the Summary Table. A spreadsheet works from CFC CFI Access database tables tree2014, tree14_Merch, tree14_Biomass, etc., and calculates values contained in the corresponding TPA, BA, MerchVolume and Biomass worksheets. The BiomassCoeffs Worksheet contains the coefficients from Table 4 of Hahn (1984) for biomass calculations.

Resulting summaries were filtered on the basis of diameter and broken down according to species. This computation included trees per acre, basal area per acre, merchantable volume (cubic ft/acre) and total biomass (tons/acre). Summaries were created for hardwoods, softwoods, and for major covertypes occurring at CFC (e.g., red pine and aspen plots). These summaries are presented in Appendix 7.

ANALYSIS RESULTS FOR 2014

Covertype Acreage: Based on plot level distribution, Figure 3 shows the CFC acreage by covertype for 2014. Red pine covers the greatest area, followed by aspen. Cutovers have been compared to the 1959 inventory. Since each plot was 1/7th of an acre, a factor of 7 was used to expand the value on a plot level. Further expansion to 8.23 acres per plot was also used to estimate total acres for each sampled condition. This method of plot expansion is applicable for all CFI efforts conducted at CFC (Reber and Ek 1982).

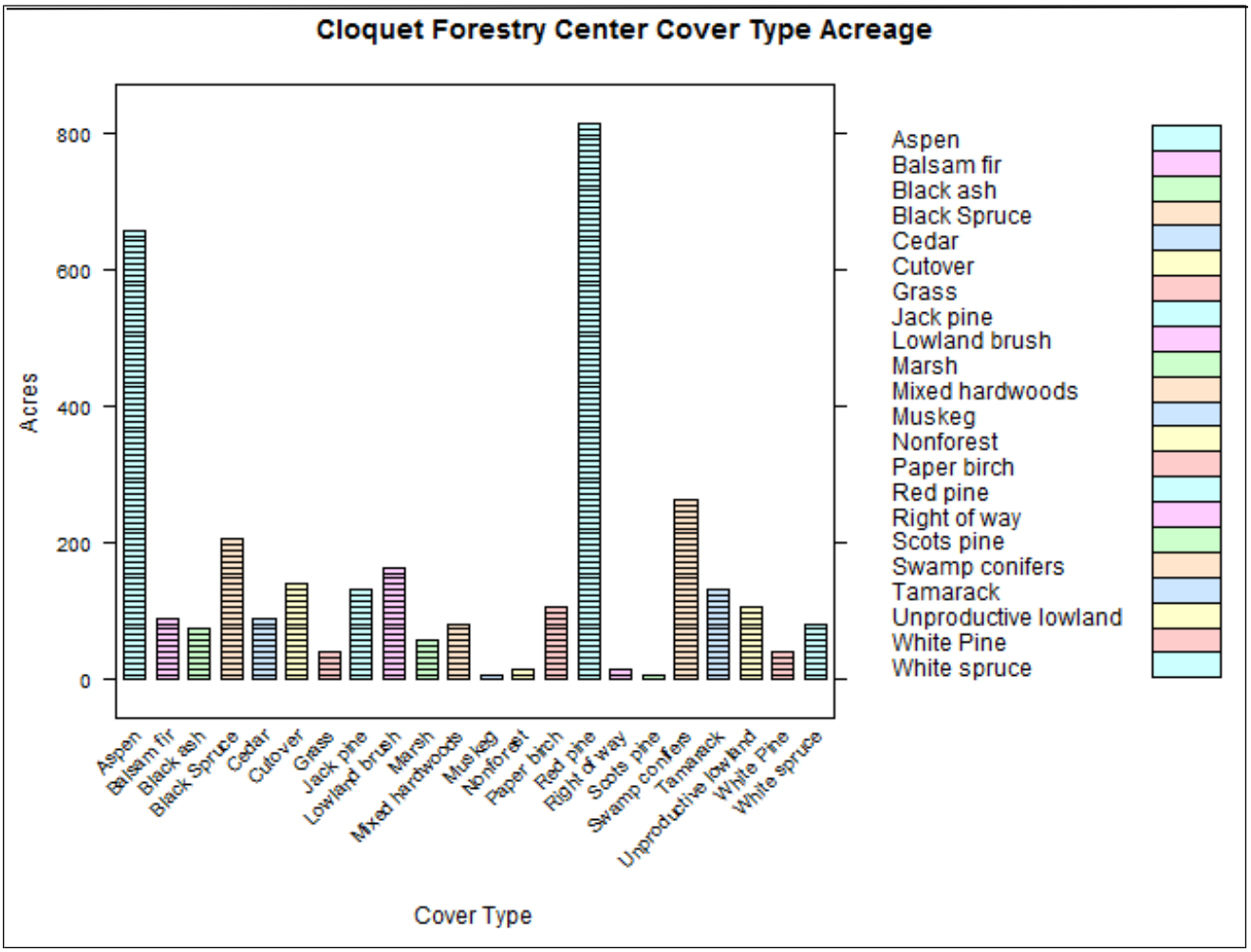

Figure 3. CFI main block covertype vs. acreage distribution for n= 405.

Figure 4 shows the CFC covertype acreage by physiography for year 2014. Rolling uplands, with more than 1000 acres, comprise the main physiographic class at the Cloquet Forestry Center, followed by swamps/bogs and flatwoods.

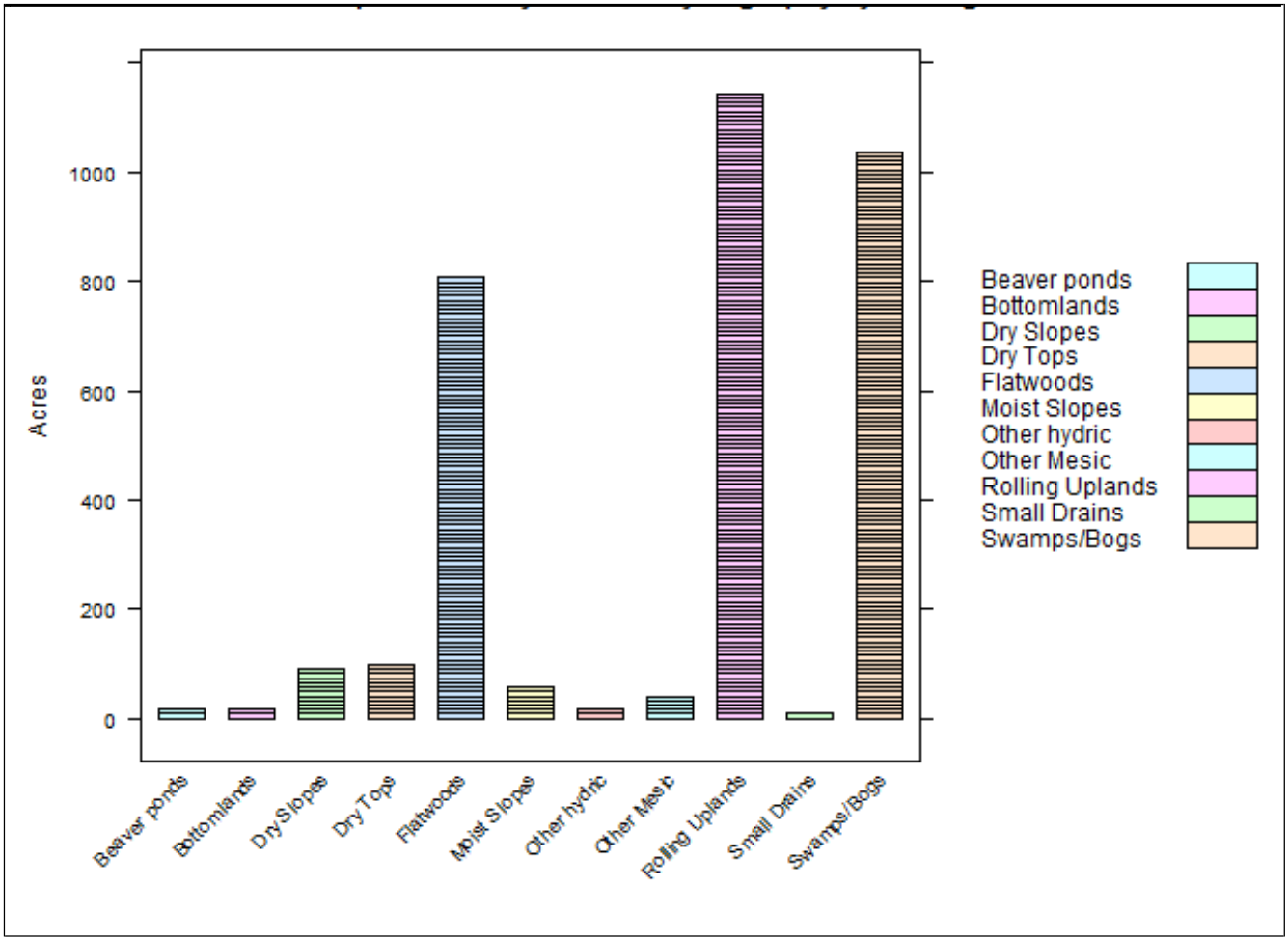

Figure 4. CFI main block physiography vs. acreage distribution for n= 405 plots.

In Figure 5**,** each small graph shows the plot count for each covertype by plot age (based on dominant and codominant trees). As an example, the small graph for red pine indicates a large number of plots, especially within the 60 to 80-year-old age range. The next most common covertype, with a correspondingly high number of plots, is aspen, followed by swamp conifers.

Covertype Change Trends: Table 1 shows the CFI plot level covertype change matrix from 1959 to 2014 and illustrates the covertype trend over the entire period for which we have data. Total plots (n=385) includes only plots surveyed in both 1959 and 2014, including some lowland and unproductive plots reconstructed back to 1959 from historic records. As an example, this matrix shows that 45 jack pine plots have converted to red pine and 19 plots have changed to aspen

Table 2 shows the CFI plot level covertype change matrix from 2000 to 2014 with the covertype trend over the inventory period of fourteen years. Again, for n=385) this plot. Note the six aspen plots that changed to red pine. Additionally, eight red pine plots were clear cut.

Species Trends: Table 3 results are an example of the database usage. It summarizes number of trees, basal area, gross merchantable volume and biomass per acre estimates for major species. The summary table shows the species average by Dbh class and plot statistics (at the bottom) for all of the 405 plots observed in 2014. The large volume for red pine indicates it is the dominant tree species, with many mature stands. Conversely, the trees per acre for balsam fir suggests it is the most common tree species. Softwoods also show the highest volume, biomass and basal area when compared with hardwoods (including aspen).

Further computation of summaries of trees per acre, basal area, volume and biomass from previous inventories can also detail the change in these variables through time.

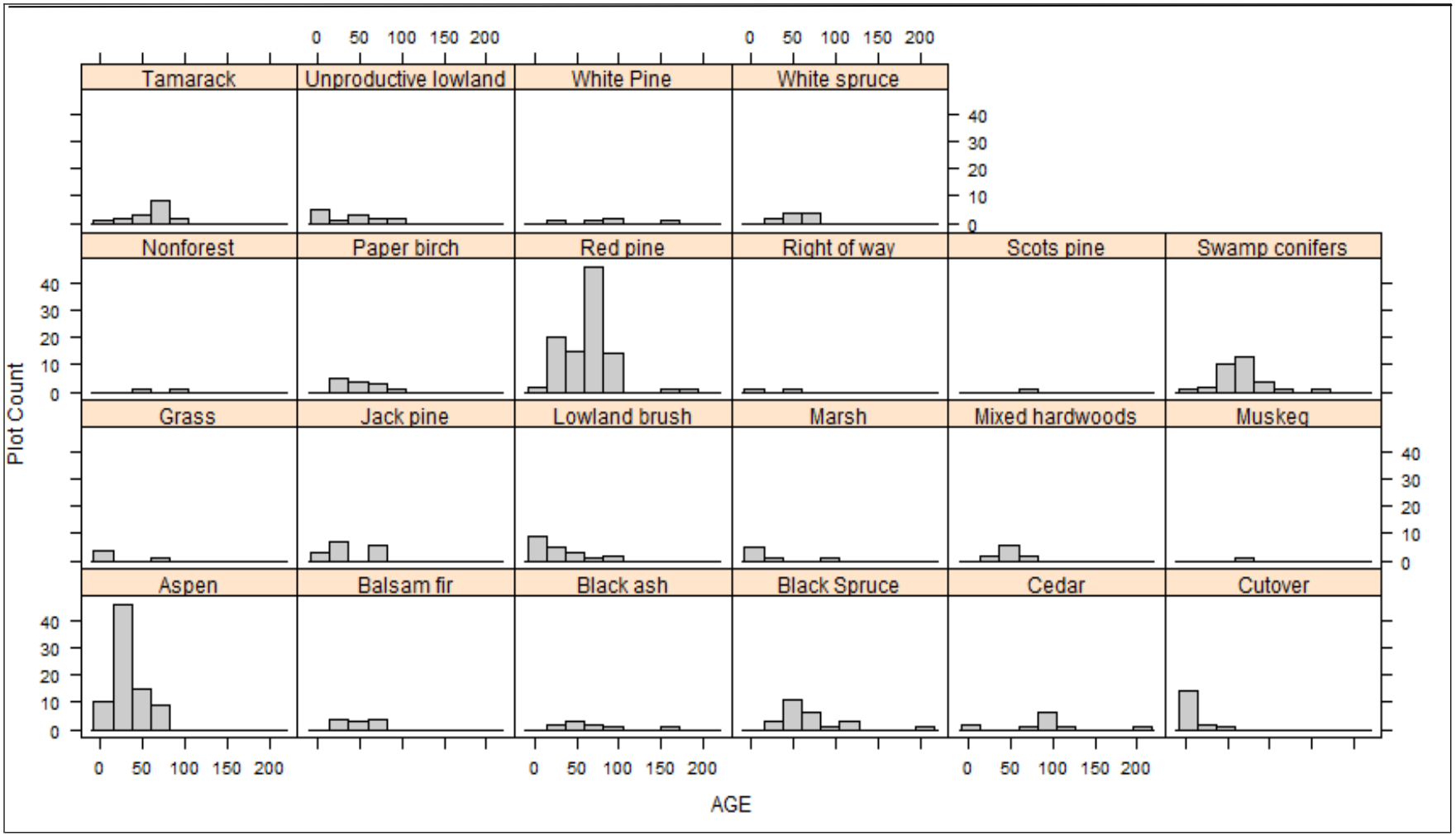

Figure 5. Plot distribution by covertype and age class for each observation from the 2014 CFI

Table 1: CFI main block plot level covertype change matrix 1959 to 2014.

Code	Plot Cover 1959	Plot Cover 2014																						Total
		1	2	3	4	5	6	7	8	9	10	44	52	55	60	61	70	71	72	80	90	96	97	98	Plots 1959
1	White Pine	3	1																					1	5
2	Red Pine		40									5			2	1	1							1	50
3	Jack Pine	2	45	13	2	2			2			7	4		19	2	2					1		2	103
4	Balsam Fir				5	2	14	1	1	2		1		2	8	3			3						42
5	White Spruce					1									2										3
6	Swamp Conifers						1																		1
7	Black Spruce		1		1		8	18	1	1			2			1			1	1					35
8	Tamarack						1		10										1		1	1			14
9	Cedar						2			6				1											9
10	Scotch Pine										1														1
55	Black Ash						1							2											3
60	Aspen		7	1	3	4		1	1			2	2	1	37	5	3	1	5					2	75
61	Paper Birch		2						2				1		14	1									20
70	Grass											1													1
71	Upland Brush		2		1								1		5										9
72	Lowland Brush						1							1					4						6
80	Unproductive lowland						1												1	2					4
81	Christmas tree bog						1	2																	3
97	Muskeg																						1		1
	Total	5	98	14	12	9	30	22	17	9	1	16	10	7	87	13	6	1	15	3	1	2	1	6	385

Table 2. CFI main block plot level covertype change matrix 2000 to 2014.

Code	PlotCover2000	PlotCover2014																						Total
		1	2	3	4	5	6	7	8	9	10	44	52	55	60	61	70	71	72	80	90	96	97	98	Plots 2000
1	White Pine	3						1																1	5
2	Red Pine	1	84			1						8			5		1							5	105
3	Jack Pine		2	13	1	1						5			1	1	1								25
4	Balsam Fir				7				1						2	2									12
5	White Spruce					5		1									1		1						8
6	Swamp Conifers						29			2			1	1	1										34
7	Black Spruce				1			17	1											1					20
8	Tamarack		2					2	13				2			1									20
9	Cedar									7				1											8
10	Scotch Pine										1														1
44	Cut	1	3		1				1			2	1		4	2	2								17
52	Upland Mixed hdwd											1													1
55	Black Ash													4											4
60	Aspen		6	1	2	2		1	1				3		69	2			1						88
61	Paper Birch												1		2	5									8
70	Grass																1					1			2
71	Upland Brush		1										2		1			1							5
72	Lowland Brush						1							1	2				13	1					18
80	Unproductive lowland																			1		1			2
90	Non-forest																				1				1
97	Muskeg																						1		1
	Total	5	98	14	12	9	30	22	17	9	1	16	10	7	87	13	6	1	15	3	1	2	1	6	385

Table 3. CFI per acre summary by species and Dbh class for the entire forest for 2014.

	Tree Species	Number of Trees				Basal Area ft^2				Merchantable Volume ft^3			Biomass tons		
		0 - 5	5-9	9+	Sum	0 - 5	5-9	9+	Sum	5-9	9+	Sum	0-5	5+	All Sizes
1	White Pine	1.48	0.85	1.80	4.13	0.12	0.31	3.24	3.67	3.61	89.85	93.47	0.01	3.18	3.18
2	Red Pine	13.58	10.68	21.19	45.45	1.62	4.18	27.09	32.89	49.78	712.93	762.70	0.04	28.59	28.64
3	Jack Pine	12.10	5.17	2.06	19.32	0.87	2.81	5.25	8.93	26.31	35.42	61.72	0.02	2.74	2.76
4	Balsam Fir	100.00	12.82	2.07	114.90	4.81	4.58	2.31	11.70	43.54	26.36	69.90	0.16	2.85	3.02
5	White Spruce	6.67	5.36	3.18	15.20	0.73	1.58	3.17	5.48	22.03	64.46	86.49	0.02	2.67	2.69
6	Norway/Blue Spruce	0.49	0.35	0.38	1.22	0.03	0.09	0.34	0.46	1.37	8.72	10.09	0.00	0.31	0.31
7	Black Spruce	71.11	14.40	1.95	87.46	3.58	3.97	1.52	9.07	57.53	24.25	81.78	0.13	2.36	2.49
8	Tamarack	17.04	6.20	3.73	26.98	0.96	1.77	3.15	5.88	25.84	62.30	88.13	0.03	3.62	3.65
9	N. White Cedar	2.47	5.29	4.61	12.37	0.20	1.55	3.78	5.53	20.49	63.63	84.11	0.01	2.22	2.22
10	Scotch Pine	0.25	0.07	0.12	0.44	0.00	0.02	0.21	0.23	0.23	4.56	4.79	0.00	0.18	0.18
11	Frasier Fir	0.49	0.48	0.02	1.00	0.06	0.13	0.04	0.23	1.93	0.79	2.72	0.00	0.11	0.11
	Sum Softwood	**225.68**	**61.67**	**41.12**	**328.47**	**12.98**	**20.99**	**50.11**	**84.08**	**252.65**	**1093.25**	**1345.91**	**0.42**	**48.83**	**49.25**
21	Yellow Birch	0.49	0.16	0.09	0.74	0.02	0.04	0.05	0.12	0.62	0.92	1.54	0.00	0.08	0.08
51	American Elm	0.25	0.02		0.26	0.01	0.00		0.01				0.00		0.00
60	Quaking Aspen	157.78	20.40	5.06	183.24	7.95	6.43	5.08	19.46	79.76	76.41	156.17	0.21	6.65	6.86
61	Bigtooth Aspen	18.02	2.61	0.66	21.29	1.18	0.68	0.56	2.41	9.91	11.70	21.62	0.03	0.92	0.95
62	Balsam Poplar	0.74	0.26	0.10	1.10	0.07	0.11	0.09	0.27	0.99	1.69	2.69	0.00	0.10	0.10
64	Paper Birch	46.67	6.26	2.97	55.90	2.66	1.85	3.20	7.71	24.50	50.49	74.99	0.09	3.37	3.45
65	Red Maple	51.85	3.77	1.18	56.80	2.55	1.08	1.03	4.67	14.72	18.75	33.47	0.09	1.50	1.59
66	Sugar Maple		0.07		0.07	0.02	0.02		0.04	0.39		0.39		0.02	0.02
67	Black Ash	16.79	3.01	0.73	20.52	0.59	0.86	0.54	1.99	10.55	8.02	18.57	0.02	0.88	0.90
68	Red Oak		0.14	0.02	0.16		0.03	0.02	0.05	0.47	0.49	0.96		0.06	0.06
69	Other	0.49	0.02		0.51	0.02	0.00		0.02	0.03		0.03	0.00	0.00	0.00
	Sum Hardwood	**293.09**	**36.69**	**10.80**	**340.58**	**15.06**	**11.10**	**10.58**	**36.75**	**141.94**	**168.47**	**310.41**	**0.44**	**13.57**	**14.02**
73	Willow	0.74			0.74	0.05			0.05			0.00	0.00		0.00
74	Green Ash		0.02	0.02	0.03		0.00	0.01	0.01	0.09	0.17	0.26		0.01	0.01
80	Mountain Maple	1.48			1.48	0.02			0.02			0.00	0.00		0.00
81	Black Cherry	0.25			0.25	0.02	0.00		0.02			0.00	0.00		0.00
82	Choke Cherry	7.65	0.02		7.67	0.18	0.01		0.18			0.00			
83	Pin Cherry	5.93	0.02		5.94	0.25	0.00		0.25			0.00			
84	Service Berry	2.47			2.47	0.09			0.09			0.00			
85	Mountain Ash	2.47	0.03		2.50	0.05	0.01		0.05	0.05		0.05	0.00	0.00	0.01
86	Dogwood species	0.25			0.25	0.00			0.00			0.00			
90	Alder	17.78			17.78	1.24			1.24			0.00			
91	Hazel	0.49	0.02		0.51	0.11	0.00		0.11			0.00			
93	Hawthorne		0.02		0.02		0.00		0.00						
	Sum Noncommercial	**39.51**	**0.12**	**0.02**	**39.64**	**2.00**	**0.03**	**0.01**	**2.04**	**0.14**	**0.17**	**0.31**	**0.00**	**0.02**	**0.02**
	Sum All Species	**558.27**	**98.48**	**51.94**	**708.69**	**30.04**	**32.13**	**60.70**	**122.87**	**394.74**	**1261.89**	**1656.63**	**0.86**	**62.42**	**63.28**
	Plot Mean				**708.69**				**122.87**			**1656.63**			**63.28**
	Plot Variance				**595638.89**				**3734.79**			**2915594.50**			**3706.44**
	Plot Standard Deviation				**771.78**				**61.11**			**1707.51**			**60.88**
	Plot CV				**1.01**				**0.47**			**0.98**			**0.76**

Table 4 shows the CFI plot covertype distribution by stand size class for 2014 where the total number of plots was 405. Total covertype plots in aspen and red pine decreased from the last inventory period while the number of white pine and cedar plots increased. Similarly, the total number of plots in the seedling and saw-timber classes has fallen, whereas the non-stocked forests and sapling classes have increased.

Table 4. CFI covertype distribution by stand size class for 2014.

Cover Type Code	Covertype	StandSizeClass						Total
		NonStock	Seedling	Sapling	Pole	Sawtimber	All Sizes	(# of plots)
1	White pine				1	3	1	5
2	Red pine	1	5	9	31	48	5	99
3	Jack pine			6	8	2		16
4	Balsam fir			2	6	3		11
5	White spruce			2	4	2	2	10
6	Swamp conifers		1	14	13	2	2	32
7	Black spruce	1		8	11	1	4	25
8	Tamarack		1	3	7	2	3	16
9	Cedar	1			3	5	2	11
10	Scotch pine					1		1
44	Cut	10	5		1	1		17
52	Upland mixed hdwd		1	2	2		5	10
55	Black ash			2	5		2	9
60	Aspen	3	10	33	24	8	2	80
61	Paper birch		1	5	3	2	2	13
70	Grass	4		1				5
72	Lowland brush	9	7	2	1	1		20
80	Unproductive lowland	5		8				13
90	Nonforest				1	1		2
96	Marsh	6		1				7
97	Muskeg	1						1
98	Right of way	2						2
Total		43	31	98	121	82	30	405

*Size Class Specifications
Nonstocked
Seedling: Dbh <1
Sapling: Dbh ≥ 1 inch and <5 inch
Pole: Dbh ≥5 and <9 inch
Sawtimber: Dbh ≥9
All sizes: (uneven aged stand)

Summary variable changes: Figures 6 to 8 illustrate the changes in major variables on the CFC main ownership block. Summaries include number of trees, volume and biomass on a per acre basis, calculated from previous years' data. Queries, tables and past summary tables were used to summarize the graph of sampling years 1959 to 2014.

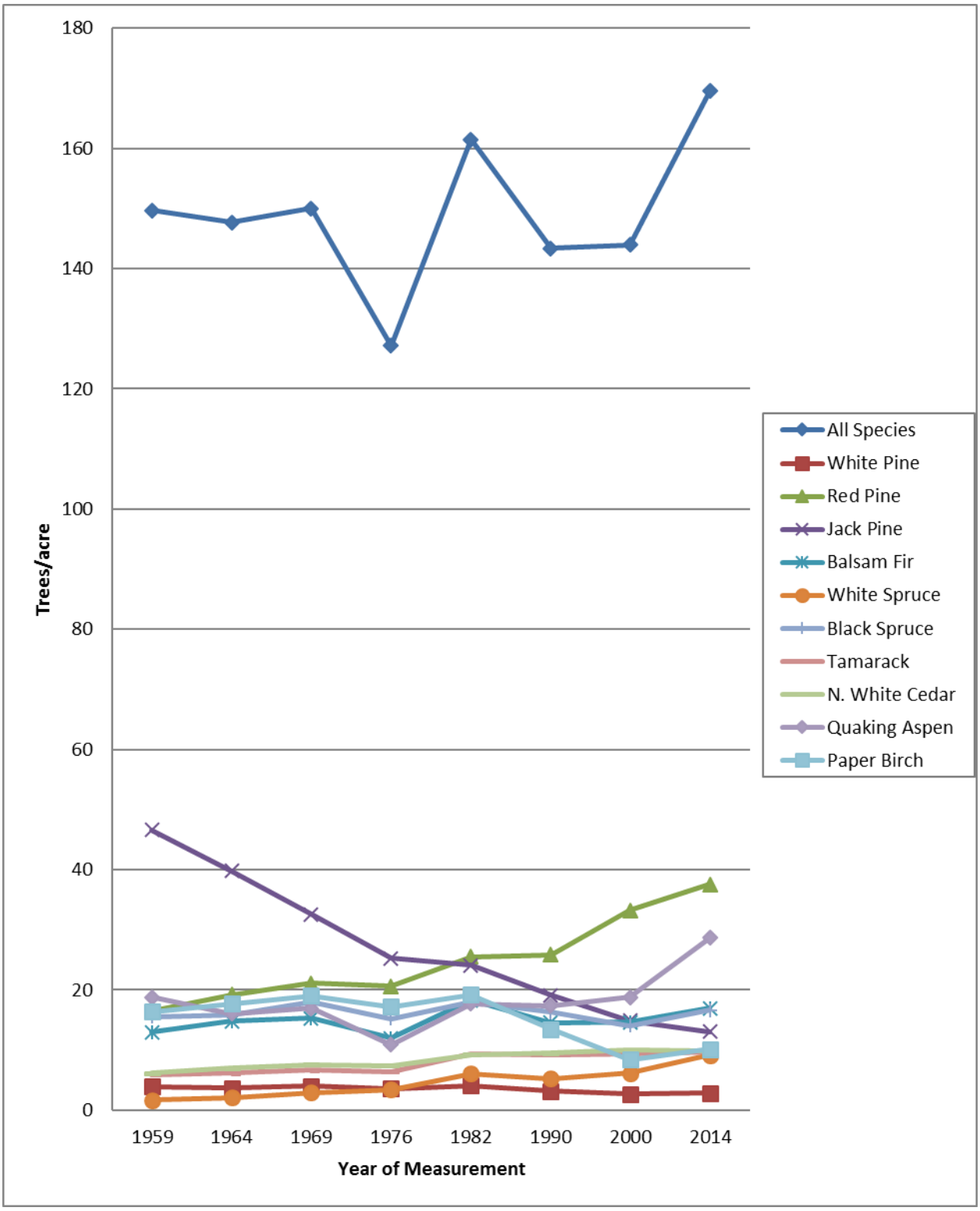

Figure 6. CFI trees per acre by species for trees with Dbh ≥ 5 for main ownership block.

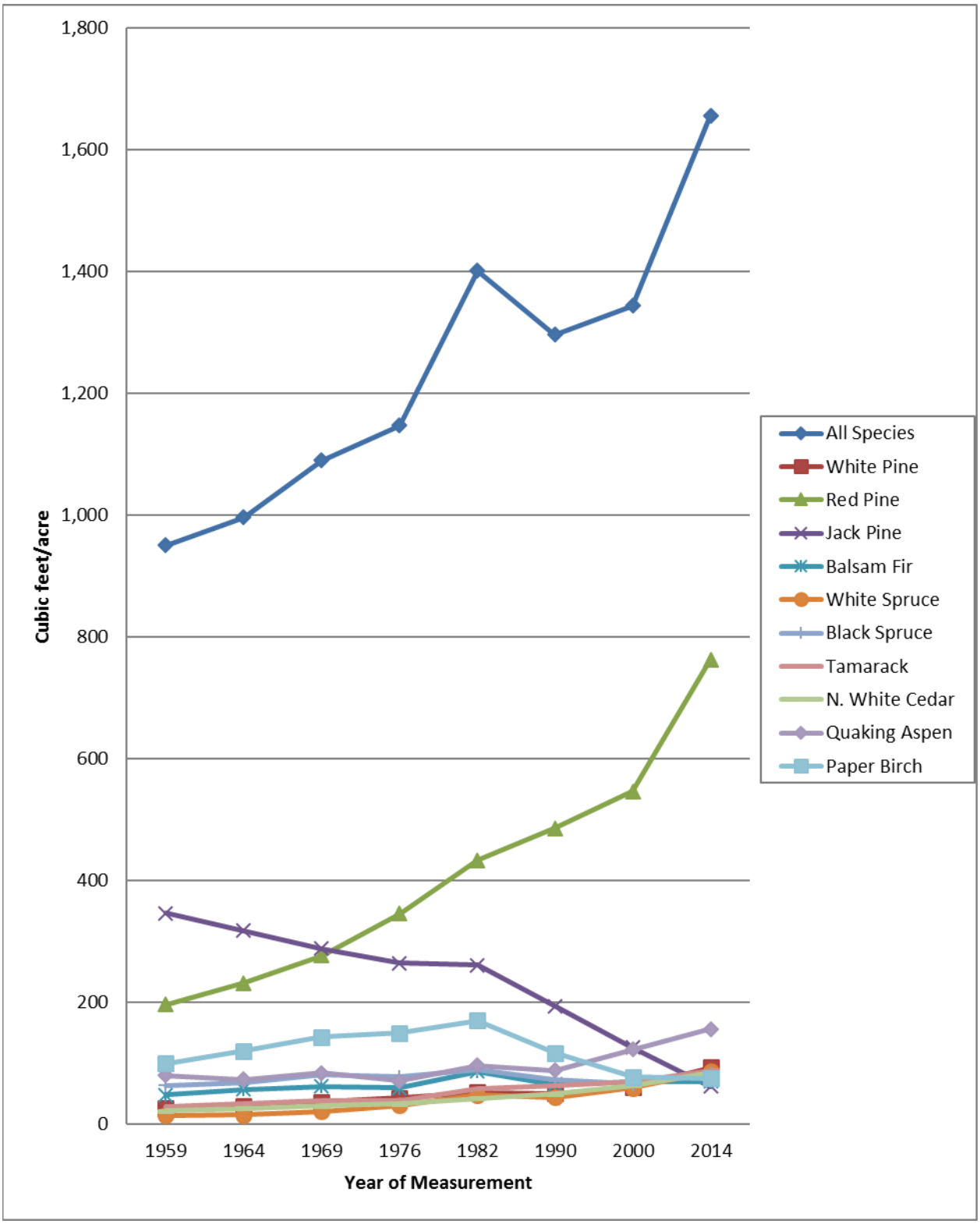

Figure 7. CFI cubic foot volume per acre by species for trees with Dbh ≥ 5 for main ownership block.

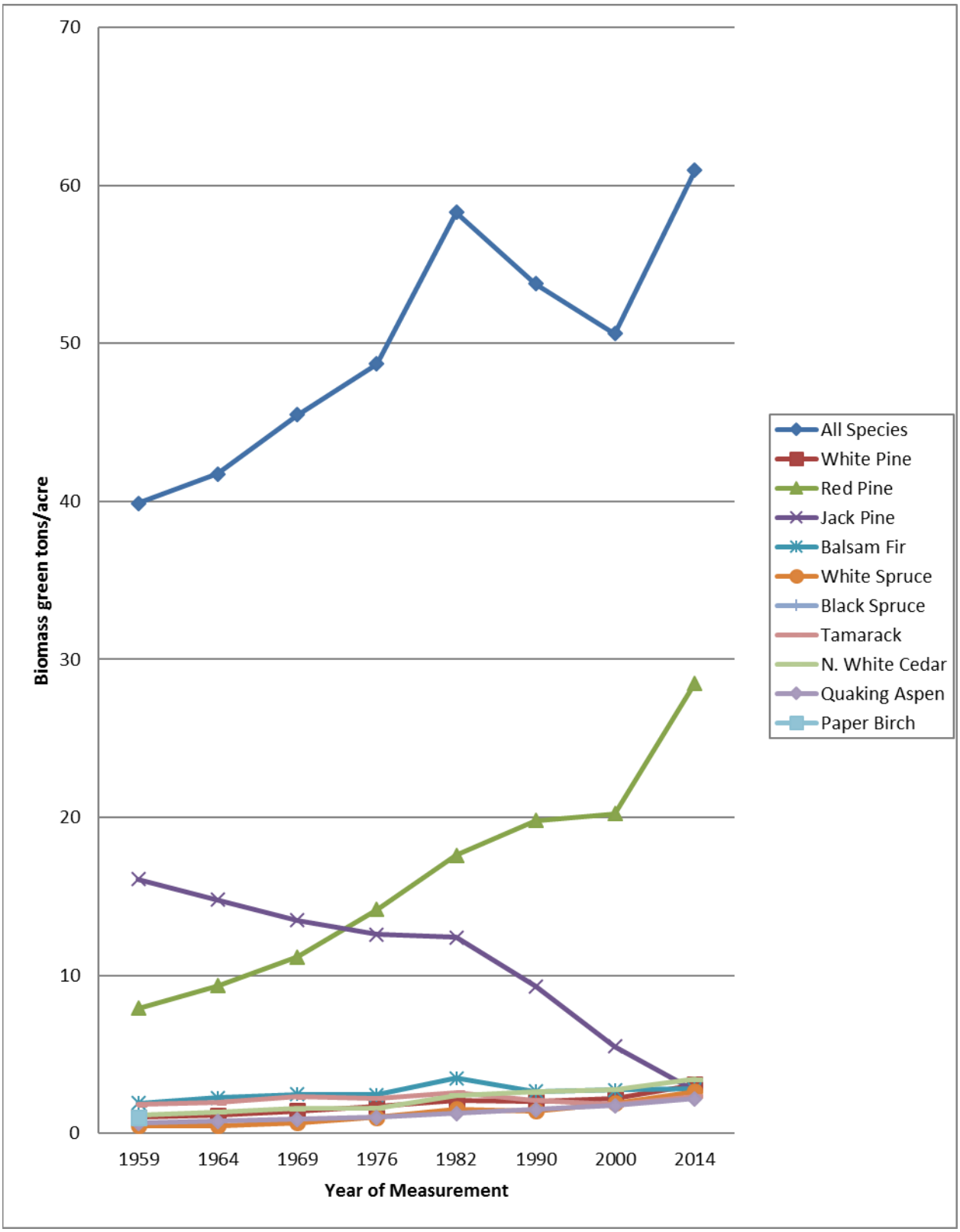

Figure 8. CFI biomass in green tons per acre by species for trees with Dbh ≥ 5 for main ownership block.

CFI DATABASE USER NOTES

CFI measurement years and plots: The CFI measurement efforts collected tree and plot level information for 350 plots in 1959, 1964, 1969 and 1976. Including some plots within unproductive covertypes and some noncontiguous blocks in Carlton County, data were collected from 448 plots in 1982 and 1990. The total number of main ownership block plots surveyed is 402 as a result of the 1982 measurement (Reber and Ek, 1982). Subsequently data was collected from 402 plots in 2000. In 2014, data were collected for 405 plots, at this time including an additional tract acquired on the east side of the Center.

Combining previous inventory data in the present format: The complete set of files and folders of the CFC CFI 2014 inventory have been saved and made available on the Interagency Information Cooperative (IIC) website (see http://iic.umn.edu). Instructions for using the Access database forms, tables and queries are included in the appendices of this report. The summary outputs for all previous CFC CFI inventory years can also be computed, i.e., by applying the calculations mentioned in the report to the data from prior measurement years in the database.

More research on coarse woody debris: The data for coarse woody debris was collected for the purpose of further research on the subject of CWD extent and distribution on the CFC and for potential monitoring of carbon sequestration. Support for such analysis of these data is now being sought.

Finally, those interested in exploring the use of these data are encouraged to contact the project leader for this study: Alan R. Ek at 612-624-3400 or email: aek@umn.edu.

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Appendix 1: Field data entry procedures with Microsoft Tablet

Inventory design, coding and procedures for the CFC CFI 2014:

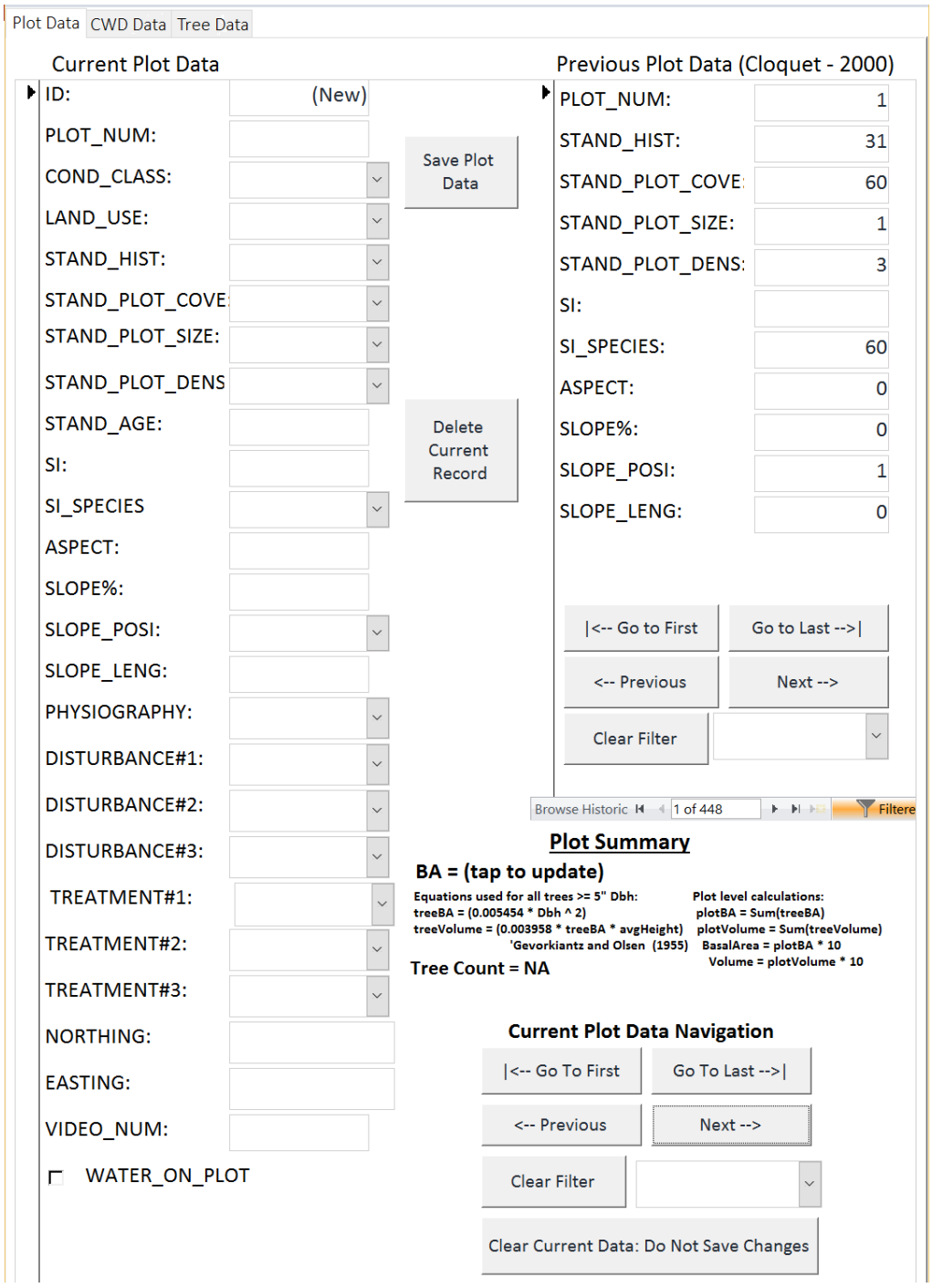
1. Azimuth and distance of each live and dead tree from the plot center was recorded.
2. Collecting data for trees with Dbh $\geq$ 0.95 and < 4.95 used a 1/100th acre circular plot.
3. Collecting data for trees with Dbh $\geq$ 4.95 used a 1/7th circular plot concentric with the 1/100th acre plot.
4. Height of each representative tree was measured using a laser clinometer.

Instructions for using CFC inventory application:

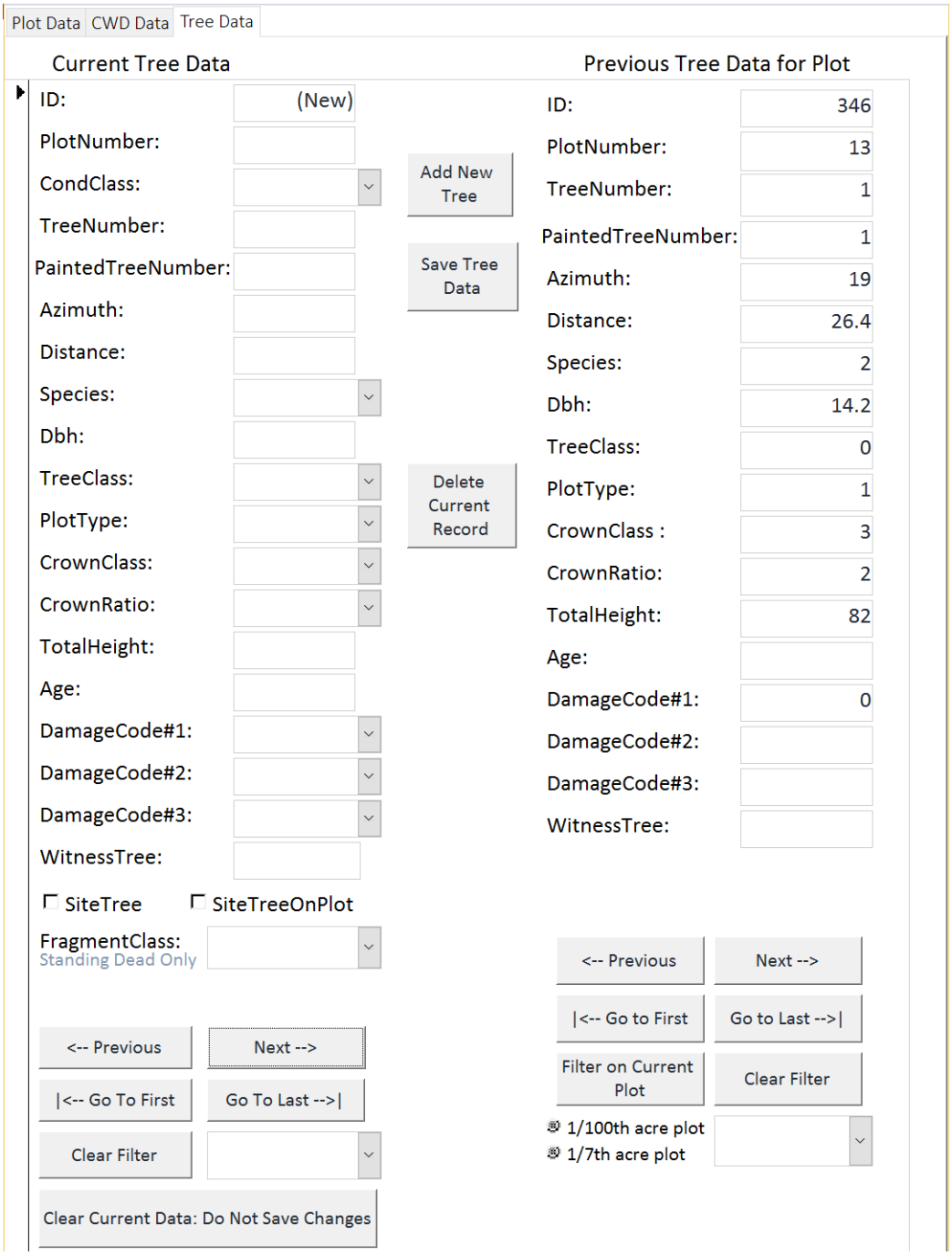
1. Open Access database
2. Go to CFCCFI data entry
3. Go to Plot Data
4. Go to 'clear filter' and select the plot number you are in
5. Click on 'Move Plot data to Current'
6. Fill any missing fields and click on 'Next' (the bottom one) to save the data
7. Go back to previous data
8. Go to Tree Data
9. Click on 'Filter on Current Plot'
10. Click on 'Move Data to Current'
11. Fill in the missing fields and hit next to save the data.
12. Click 'Next' on 'previous tree data' and move the data to current
13. Repeat steps 10 to 12 until finished with the plot
14. Go to CWD Data

Appendix 2: Access database forms

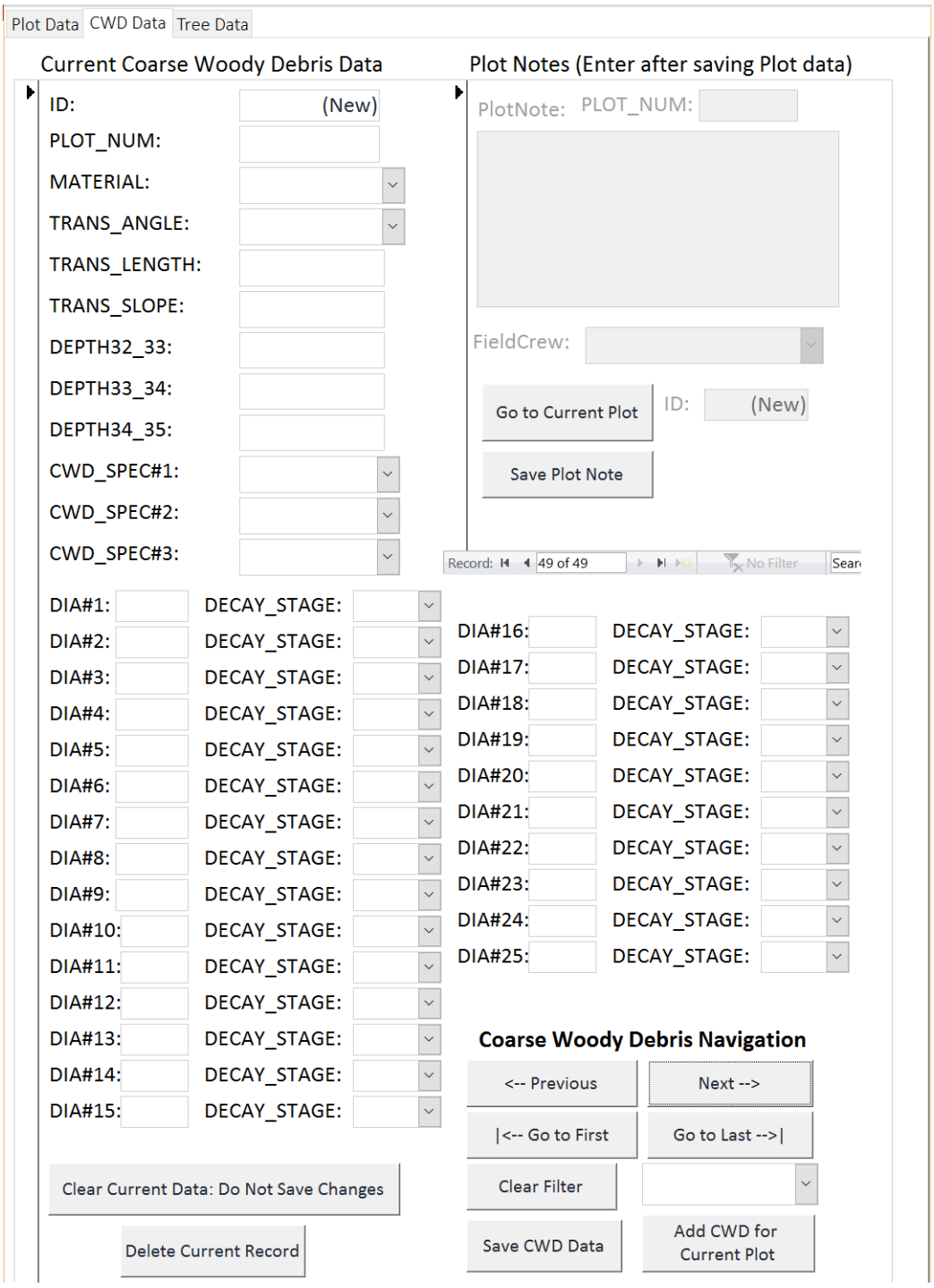
Plot data form:



Tree data form:



CWD data form:



Appendix 3: Queries and tables used in the CFC-CFI Access database

Site Index queries:

SICalcUpdate: For plots with newly collected height and age records, a new SI was calculated. The query used for SI calculation in access database was SICalcUpdate (See also UpdateSICalc; a nearly identical query).

SICalcUpdateGT110: Used to replace any calculated site index values greater than 110 (very unlikely, probably an error with early calculations) with the average site index for that covertype.

SICovertype: Used to calculate the average SI for all plots of the given covertype. This information was used to fill in SI data for some plots lacking both historic and current SI information.

SIAvgUpdate: Used to update the SIAvg field in the plot2014 table. If new SI data existed that was used first. If no new data were available, historic SI information was used. If neither historic nor new SI data existed, then the average SI for that covertype was used.

Tree_SI_Update: Used to write the best available site index data from the SIAvg column of the plot2014 table to the Plot_SI column of the tree2014 table for use in height calculations.

Height queries:

2014HeightReset: Used to clear all data from the calculated Height field in the tree2014 table.

tree2014_Height: Used to calculate the height of the trees >=5 inches Dbh.

tree2014_Height_SmallDBH: Used to calculate the height of the trees <5 inches Dbh.

AvgHeight: Used to calculate the average height for plots with total height observations on multiple trees. The average height of dominant/co-dominant trees observed on each plot was then written to the AvgHeight2014 table.

Trees Per Acre queries:

UpdateTreeTPA: Used to write the per acre expansion factor (100 for trees < 4.95 inches Dbh and 7 for trees > 4.95 inches Dbh) for each tree to the TPA field in the tree2014 table. These expanded counts were then summed for all trees on each plot to calculate the total trees per acre observed on each plot.

SumPlotTPA: Used to add the TPA for $1/100^{th}$ acre plot and $1/7^{th}$ acre plot, and write the result to the PlotTPA table.

UpdatePlotTPA: Used to write the summarized TPA data for each plot to the plot2014 table.

Basal Area queries:

BA_Update: Used to calculate the initial basal area for each tree.

Plot100_BA_Update: Query used to calculate the basal area for trees <5 Dbh.

Plot7_BA_Update: Used to calculate the basal area for trees >=5 Dbh.

Plot_BA_Update_100: Used to update the basal area for trees <5 Dbh.

Plot_BA_Update_7: Used to update the basal area for trees >=5 Dbh.

MakeTable_Plot_BA: Used to create an intermediate record set needed in the basal area summary process for each plot.
Plot2014BAUpdate: Then used to write the summarized basal area per acre values from the MakeTable_Plot_BA recordset into the plot2014 table.
Plot_BasalArea: Used to write the summarized and expanded plot basal area per acre data from the plot2014 table to each tree in the tree2014 table. This information was then used in height calculations.

Volume:

CubicFoot_Volume_SmallDBH: Used to calculate the volume of trees <5 Dbh.
CubicFoot_Volume: This query was used to calculate the volume of trees >=5 Dbh.
VolumePerAcre: Used to combine and expand all volume on each plot for trees ≥ 4.95inches Dbh to create a per acre cubic foot volume estimate in the CFVolPerAcre table.
plotCFVolAcreUpdate: Used to write the combined and expanded tree volume data for each plot into the plot2014 table from the CFVolPerAcre table.

Biomass queries:

StumpVolume: Used to calculate StumpVolume
SCF: Used to calculate Species Correction Factor.
BarkWt: Used to calculate BarkWt
BoleBiomass: Bole weight was calculated using query BoleBiomass
TopBiomass: Top biomass was calculated using query TopBiomass
TotalBiomass: Total Biomass, for trees >=5 dbh, was calculated using query TotalBiomass
SumPlotBiomass: Used to summarize the total biomass for each tree found on each plot in the PlotBiomass table.
UpdatePlotBiomass: Used to write the summarized plot biomass data from the PlotBiomass table to the Biomass column of the plot2014 table.
ResetBiomassFields: Used to reset the biomass columns to all NULL values between iterations as various approaches were used to find the correct implementation of the models.
Biomass<5: Used to calculate the total biomass of small trees in the tree2014 table.

Other important queries:

FindUniquePlots: Used to create separate tables of individual plots by covertype where trees of varying Dbh were found. The DBH parameter in this query can be changed to produce a summary of plots of different covertypes with trees of different sizes. This query produces the PlotsXCoverType table.

FindUniquePlotsByCoverType: Used to create separate tables of individual plots by covertype where trees of varying size class were found. The STAND_PLOT_SIZE parameter in this query can be changed to produce a summary of plots of different covertypes with trees of different size classes.

FindUniqueTreesBySpecies: Used to create a list of the number of trees inventoried by species and Dbh.

MakeStandPlotID: Used to create a lookup list of sample plots and their associated stands.

PC_Change: Used to create a recordset of covertype change for each inventory period from 1959-2014.

PC_Change_Crosstab_00_14: Used to create crosstab table of covertype change between 2000 and 2014.

PC_Change_Crosstab_59_14: Used to create crosstab table of covertype change between 1959 and 2014.

PlotCount: Used to create a list of plots and the number of records in the plot2014 table associated with each. This was done as a data quality check to be sure all condition classes had been considered, and none were listed twice.

PlotCountByCoverType: Used to create a list of all sampled covertypes and the number of plots associated with each.

PlotCountperSpecies: Used to create a list of the species of all trees sampled with <4.95 inches Dbh, and the unique plots on which they were found. This list is contained in the SpeciesPlotDBH table.

PlotCountperSpps5to9: Used to create a list of the species of all trees sampled between 5 and 9 inches Dbh, and the unique plots on which they were found in the SpeciesPlotDBH5to9 table.

PlotCountperSpps9andAbove: Used to create a list of the species of all trees sampled with > 9 inches Dbh, and the unique plots on which they were found in the SpeciesPlotDBH9andabove table.

SpeciesDBHPlotCount: Used to query the intermediate table SpeciesPlotDBH to create a list of the number of plots containing each species.

SpeciesDBHPlotCount5to9: Used to query the intermediate table SpeciesPlotDBH5to9 to create a list of the number of plots containing each species in the 5 to 9 inch size class.

SpeciesDBHPlotCount9andAbove: Used to query the intermediate table SpeciesPlotDBH9andabove to create a list of the number of plots containing each species in the 9 inch plus size class.

TreesWithIdenticalData: Used as a data quality check to identify any trees with identical Dbh values in both 2000 and 2014. One hundred and ten (110) out of almost

10,970 standing live trees were found to have identical measurements. These trees could have erroneous data associated with them, but also might actually have the same Dbh for successive inventories. Many of these 110 trees also had damage codes associated with them, possibly explaining poor to negligible growth between inventories.

UpdateAvgAge: Used to update the AvgAge and AvgHt columns in the plot2014 table from the StandSI working table. The AvgAge and AvgHt column references were changed manually in the query to accomplish the separate column updates.

UpdateTreePlotCoverType: Used to write the STAND_PLOT_COVE field from the plot2014 table to corresponding records for trees on each plot. This new combination of data was then used to identify which species were growing on the different covertypes.

List of tables in CFC-CFI Access database:

Plot tables:

1959-2000Plot: This table contains the cross-referenced list of plot locations used in the 1959-2000 inventories. These same locations, plus several additional plots were used for the 2014 re-inventory. Locations are given in UTM and Lat-Long formats, as well as by descriptive directions from landmarks present from 1959-2000. Stand numbers associated with each plot in 1959 and in 2000 are also provided.

CFCCFIPlots: This table contains data similar to the 1959-2000Plot table, but with the addition of the stand number associated with each plot for the 2000 re-inventory and for past re-inventories.

2000PlotLvl_FIA: This table contains FIA style inventory data for physiographic class, disturbance and treatments, as well as seedlings observed on plots during the 2000 re-inventory.

plot1959: This table contains the basic plot data recorded in the 1959 inventory.
plot1964: This table contains the basic plot data recorded in the 1964 re-inventory.
Plot1969: This table contains the basic plot data recorded in the 1969 re-inventory.
plot1976: This table contains the basic plot data recorded in the 1976 re-inventory.
plot1982: This table contains the basic plot data recorded in the 1982 re-inventory.
plot1990: This table contains the basic plot data recorded in the 1990 re-inventory.
plot2000: This table contains the basic plot data recorded in the 2000 re-inventory.
plot2014: This table contains the complete plot data recorded in the 2014 re-inventory.

PlotSI: This table contains the results of several queries used to combine observed tree height and age measurements associated with each plot where these data were collected in 2014. This table was then used as a source for information in the calculation of SICalc in the plot2014 table.

PlotSICalc: This table is an intermediate used in the calculation of Site Index for the 2014 re-inventory.

MakeTable_PlotBA: This table was created by the MakeTable_Plot_BA query as an intermediate step in writing the combined small tree and large tree basal areas for each plot to the plot2014 table.

PlotTPA: This table contains the combined trees per acre information for each plot. This estimate combines trees observed on the 1/100th acre sub-plot as well as trees observed on the 1/7th acre main plot with appropriate expansion factors used for each subset.

PlotBiomass: This table contains the calculated total biomass on each plot in tons for the 2014 re-inventory. This table was produced as an intermediate step in writing this information to the plot2014 table.

CWD2014: This table contains all observations of coarse woody debris made on a subset of plots during the 2014 re-inventory.

Tree tables:

1959-2000Tree: This table contains information on TreeNumber, Painted Tree Number (PTN), species and distance/azimuth for each tree inventoried in the 1959-2000-time period. These data were used in creating the Plot/Tree maps used by field crews in the 2014 re-inventory.
tree1959: This table contains tree observation data for the 1959 inventory.
tree1964: This table contains tree observation data for the 1964 re-inventory.
tree1969: This table contains tree observation data for the 1969 re-inventory.
tree1976: This table contains tree observation data for the 1976 re-inventory.
tree1982: This table contains tree observation data for the 1982 re-inventory.
tree1990: This table contains tree observation data for the 1990 re-inventory.
tree2000: This table contains tree observation data for the 2000 re-inventory.
tree2014: This table contains tree observation data for the 2014 re-inventory.

Stand tables:

StandCoverType: This table provides a lookup for the codes and covertype names used in the 2014 re-inventory.
StandDensity: This table provides a lookup for the codes and descriptions used to assign stand density in the 2014 re-inventory.
StandHistory: This table provides a lookup for the codes and descriptions used in the 2014 re-inventory.
StandPlotID: This table provides a list of the StandID(s) associated with each plot for the 2014 re-inventory.
StandSI: This table was used to collect the tree height and age observations for the Site Index calculation process during the 2014 re-inventory.
StandSizeClass: This table provides a lookup for the codes and descriptions used to assign stand size class in the 2014 re-inventory.

Lookup tables:

BiomassCoefficients: Contains the modeled coefficients from Hahn (1984) used in biomass calculations.

Height_Coefficients: Contains the modeled coefficients used in calculating height for each inventoried tree based on Dbh, Site Index, and plot basal area. Coefficients are taken from Ek et al. (1984).
si_data1990: Contains tree species, Dbh, and total height information for trees used in calculating Site Index for the 1990 re-inventory.
SICoef: Contains model coefficients used in calculating SICalc for the 2014 re-inventory. These coefficients are taken from Hahn and Carmean (1982).
DamageCode: Contains a lookup for the codes and descriptions used in assigning Damage Code to inventoried trees. This table is based on the FIA version of this variable.
DecayStage: Contains a lookup for the codes and descriptions used in assigning Decay Stage to standing dead trees observed in the 2014 re-inventory. This table is taken from Tyrrell and Crow (1994).
Disturbance: Contains a lookup for the codes and descriptions used in assigning Disturbance Codes to inventoried plots. This table is based on the FIA version of this variable.
CoverType: Contains a lookup for the codes and names used in assigning Covertype to plots and stands.
CrownClass: Contains a lookup for the codes and descriptions used in assigning Crown Class to inventoried trees.
CrownRatio: Contains a lookup for the codes and descriptions used in assigning Crown Ratio to inventoried trees.
PlotsXCoverType: This table provides a lookup for the plot level stand covertype associated with each plot for the 2014 re-inventory, as well as the number of trees on each plot.
LandUse: Contains a lookup for the codes and descriptions used in assigning Land Use to inventoried plots.
Physiography: Contains a lookup for the codes and descriptions used in assigning physiographic class codes to inventoried plots. This table is based on the FIA version of this variable.
Treatment: Contains a lookup for the codes and descriptions used in assigning Treatment codes to inventoried plots. This table is based on the FIA version of this variable.
TreeClass: This table provides a lookup for the codes and descriptions used to assign tree class in the 2014 and earlier re-inventory efforts.
veg2005: This table provides access to the stand level observations made during the 2005 stand delineation update effort.
PlotType: Contains a lookup for the codes and descriptions used in assigning Plot Type to inventoried trees.
SlopePosition: Contains a lookup for the codes and descriptions used in assigning Slope Position to inventoried plots.
SpeciesTable: This table provides a lookup for the codes and species names used in the 2014 re-inventory.

Intermediate Tables Used for Calculation:

AvgHeight2014: Contains the average height data for dominant/co-dominant trees observed on each plot with tree cover.

CFVolPerAcre: Contains a list of each plot and the associated volume of trees ≥ 4.95 inches Dbh.
SICoverTypesTable: Contains the average Site Index value for plots in each covertype. These data were used in calculating volume when neither historic nor current site index measurements were available for a plot.
SpeciesPlotDBH5to9: Contains a list of each plot number where a given species was found in the 5-9 inch Dbh size class.
SpeciesPlotDBH9andabove: Contains a list of each plot number where a given species was found in the ≥ 9 inch Dbh size class.

Appendix 4: Site index, tree height, volume and biomass equations

1. **Site Index Calculation:**

   $S= c_1 H^{c2} [1-e^{(c3A)}]^{c4H\^c5}$

   where

   A= tree age

   H= total tree height

   c_1 to c_5= species specific coefficients

2. **Height Calculation:**

   $H= 4.5+b_1(1-e^{(-b2Dbh)})^{b3}*S^{b4}*T^{b5}*B^{b6}$

   where

   B=stand basal area

   Dbh=diameter at breast height

   S=species site index

   T= 1.00001-d/Dbh

   b_1 to b_5 = species coefficients

3. **Volume:**

   $Volume = 3.0086*10^{-3} + S_1+ S_2 + S_3 + S_4 + S_5 + S_6 + S_7 + S_8)*79$

   where

   $S_1 = (2.0355*10^{-3}) D$

   $S_2 = (-3.0018*10^{-3}) T$

   $S_3 =(6.2381*10^{-5}) D^2$

   $S_4 = (2.5705*10^{-5}) D^2H$

   $S_5 = (-7.0090*10^{-6}) H^2$

$S_6 = (3.6708*10^{-5})\ HT^2$

$S_7 = (8.1400*10^{-10})\ D^2H^3$

$S_8 = (-1.9000*10^{-9})\ D^2H^2T$

D= diameter at breast height

T= diameter at merchantable height outside bark

H= merchantable height

4. Biomass Calculation:

Biomass for trees < 5 inches Dbh

Total biomass = $4.8900625*Dbh^{2.4323866})*0.8/2000$

Biomass for trees ≥ 5 inches Dbh

Stump Volume = Stump coefficient * Dbh^2

SCF = $(b_0+b_1*Dbh)/100$

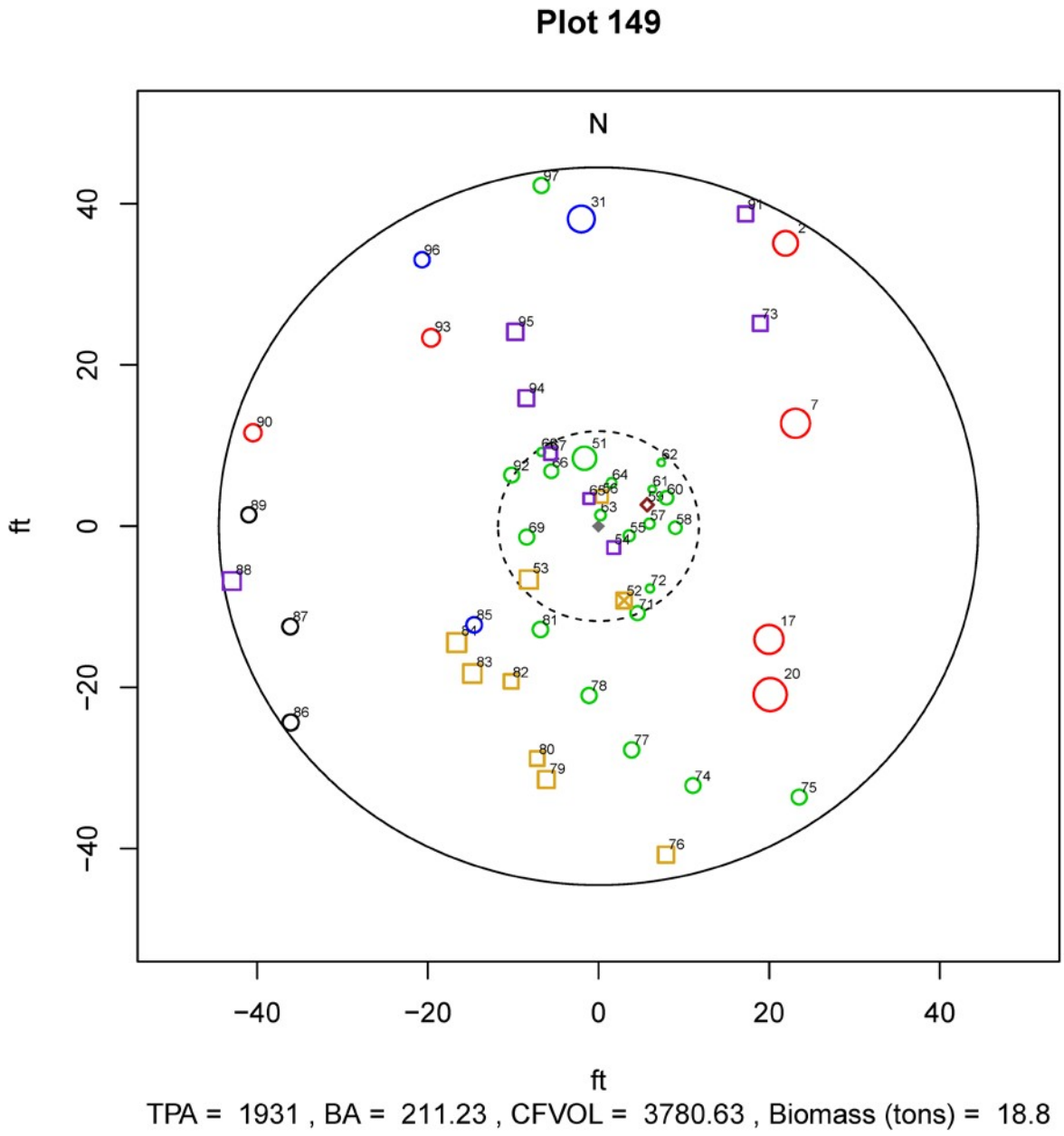
Bark = (Volume + Stump Volume)*(1.1646-SCF)*37

Bole weight = (Bark +(Volume +Stump Volume)*Biomass)/2,000

Top biomass = 0.4545*(Bark +Volume*Biomass)/2000

Total Biomass = Bole weight + Top Biomass

Appendix 5: R plot map example



Note: Circles and polygons are positioned at tree locations; painted tree numbers; species are color coded and with circle or polygon size proportional to Dbh; those containing an “x” indicate standing dead.


Plot Center
1/100th Acre Plot
1/7th Acre Plot
Pine
White Spruce
Lowland Conifer
Balsam Fir
Aspen
Paper Birch
Other
Dead
No DBH

Appendix 6: Damage codes and tree classes withheld from calculations

Damage Codes:
The damaged codes were obtained from the earlier Access database of year 2000. Few damaged codes are listed here. The trees with these damaged codes were removed before volume calculations. For biomass calculation, only damage code 900 was removed.

DamageCode		
FIADamage Code	**FIADAmCat**	**Explanation**
290	Root/Butt Rot	Removed from Calculation
710	Missing or dead top	Removed from Calculation
840	Land clearing	Removed from Calculation
900	Unknown (dead tree only)	Removed from Calculation
908	Unknown/Uncoded abnormal growth or bole form	Removed from Calculation

Tree Class:
Trees with the following codes were also excluded from volume and biomass calculations.

Code	**Class**
5	Harvested
6	Dead down
7	Missing
9	Witness tree off of plot
61	Dead standing

Appendix 7: Summary stand and stock tables

(Tables 7.1 to 7.4)

Next page:

Table 7.1: Summary of Cloquet Forestry Center historical contiguous block CFI plots, measured summer 2014

Covertype: Red Pine **Area: 814.77** **N=99 plots**

		Per Acre Results by Dbh Class (inches)													
	Tree Species	**Number of Trees**				**Basal Area ft^2**				**Merchantable Volume ft^3**			**Biomass tons**		
		0 - 5	**5-9**	**9+**	**Sum**	**0 - 5**	**5-9**	**9+**	**Sum**	**5-9**	**9+**	**Sum**	**0-5**	**5+**	**Sum**
1	White Pine	6.06	1.56	2.69	10.30	0.50	0.56	5.72	6.77	6.62	156.35	162.97	0.33	5.59	5.91
2	Red Pine	36.36	36.56	75.09	148.01	4.53	14.29	90.40	109.22	171.62	2466.74	2638.36	1.71	99.05	100.77
3	Jack Pine	2.02	5.02	2.05	9.09	0.99	3.53	2.97	7.49	27.12	37.42	64.54	0.16	2.84	3.00
4	Balsam Fir	47.47	6.65	1.06	55.18	2.24	2.10	1.24	5.58	20.65	18.79	39.45	1.28	1.58	2.86
5	White Spruce	9.09	1.41	1.70	12.20	1.43	0.40	1.94	3.77	4.60	40.01	44.61	0.49	1.36	1.85
6	Norway/Blue Spruce			0.07	0.07			0.03	0.03		0.56	0.56		0.02	0.02
7	Black Spruce		0.57	0.21	0.78	0.10	0.16	0.22	0.49	2.63	4.11	6.74		0.19	0.19
8	Tamarack		0.14	0.14	0.28	0.08	0.04	0.11	0.22	0.77	2.83	3.60		0.14	0.14
9	N. White Cedar		0.14	0.07	0.21		0.05	0.08	0.12	0.74	0.81	1.55		0.04	0.04
10	Scotch Pine		0.14	0.14	0.28		0.03	0.32	0.35	0.55	2.47	3.01		0.12	0.12
11	Frasier Fir				0.00				0.00			0.00			0.00
	Sum Softwood	**101.01**	**52.18**	**83.22**	**236.41**	**9.87**	**21.15**	**103.03**	**134.05**	**235.30**	**2730.09**	**2965.39**	**3.96**	**110.92**	**114.89**
21	Yellow Birch	1.01			1.01	0.08			0.08			0.00	0.01		0.01
51	American Elm				0.00				0.00						0.00
60	Quaking Aspen	21.21	10.18	3.82	35.21	1.74	3.73	3.37	8.84	46.26	58.29	104.55	0.55	4.37	4.92
61	Bigtooth Aspen	3.03	0.57	0.49	4.09	0.61	0.24	0.56	1.42	2.73	10.78	13.51	0.09	0.52	0.62
62	Balsam Poplar			0.07	0.07			0.04	0.04		0.96	0.96		0.04	0.04
64	Paper Birch	54.55	5.94	2.62	63.10	2.98	1.87	2.44	7.29	27.19	48.30	75.49	1.44	3.22	4.66
65	Red Maple	78.79	3.61	1.27	83.67	3.34	1.02	1.11	5.47	14.70	20.13	34.83	1.70	1.60	3.30
66	Sugar Maple		0.21		0.21	0.05	0.07		0.12	1.35		1.35		0.07	0.07
67	Black Ash				0.00				0.00			0.00			0.00
68	Red Oak		0.35	0.07	0.42		0.08	0.08	0.16	1.34	1.98	3.33		0.18	0.18
69	Other				0.00	0.01			0.01			0.00			0.00
	Sum Hardwood	**158.59**	**20.86**	**8.34**	**187.79**	**8.80**	**7.02**	**7.61**	**23.43**	**93.56**	**140.44**	**234.00**	**3.80**	**10.00**	**13.80**
73	Willow				0.00	0.02			0.02			0.00			0.00
74	Green Ash				0.00				0.00			0.00			0.00
80	Mountain Maple	2.02			2.02	0.05			0.05			0.00	0.02		0.02
81	Black Cherry				0.00	0.01			0.01			0.00			0.00
82	Choke Cherry	2.02	0.07		2.09	0.04	0.02		0.06			0.00			0.00
83	Pin Cherry	11.11	0.07		11.18	0.30	0.01		0.31			0.00			0.00
84	Service Berry	1.01			1.01	0.01			0.01			0.00			0.00
85	Mountain Ash				0.00				0.00			0.00			0.00
86	Dogwood species				0.00				0.00			0.00			0.00
90	Alder	2.02			2.02	0.09			0.09			0.00			0.00
91	Hazel				0.00	0.10			0.10			0.00			0.00
93	Hawthorne				0.00				0.00						0.00
	Sum Noncommercial	**18.18**	**0.14**	**0.00**	**18.32**	**0.62**	**0.03**	**0.00**	**0.65**	**0.00**	**0.00**	**0.00**	**0.02**	**0.00**	**0.02**
	Sum All Species	**277.78**	**73.18**	**91.57**	**442.53**	**19.29**	**28.20**	**110.64**	**158.12**	**328.87**	**2870.53**	**3199.40**	**7.79**	**120.92**	**128.71**
	Plot Mean				**442.53**				**158.12**			**3199.40**			**128.71**
	Plot Variance				**138641.54**				**3028.38**			**421.35**			**5318.45**
	Plot Standard Deviation				**372.35**				**55.03**			**20.53**			**72.93**
	Plot CV				**0.77**				**0.32**			**0.59**			**0.52**

Volume: Stem volume from 1 ft stump to merchantable top diameter per Table 6, Gevorkiantz and Olson, 1955.		Biomass: wood and bark, setm and branches per Hahn (1984).

Table 7.2: Summary of Cloquet Forestry Center historical contiguous block CFI plots, measured summer 2014

Covertype: Aspen **Area: 765.39** **N=93 plots**

		Per Acre Results by Dbh Class (inches)													
	Tree Species	**Number of Trees**				**Basal Area ft^2**				**Merchantable Volume ft^3**			**Biomass tons**		
		0 - 5	**5-9**	**9+**	**Sum**	**0 - 5**	**5-9**	**9+**	**Sum**	**5-9**	**9+**	**Sum**	**0-5**	**5+**	**Sum**
1	White Pine		0.30	0.30	0.60		0.11	0.49	0.61	1.67	11.39	13.07		0.44	0.44
2	Red Pine	8.60	4.14	4.29	17.03	1.19	1.27	6.21	8.67	17.04	161.58	178.63	0.36	6.66	7.03
3	Jack Pine	7.53	2.94	0.75	11.22	0.63	1.00	1.76	3.39	11.08	20.01	31.09	0.21	1.39	1.60
4	Balsam Fir	33.33	5.57	1.66	40.56	1.92	2.27	2.53	6.72	18.27	21.19	39.46	0.72	1.61	2.34
5	White Spruce	7.53	3.69	1.66	12.87	0.83	1.13	2.31	4.26	15.11	42.82	57.94	0.34	1.78	2.12
6	Norway/Blue Spruce	2.15	0.45	0.15	2.75	0.13	0.11	0.08	0.32	1.71	1.48	3.20	0.08	0.10	0.18
7	Black Spruce	7.53	0.75	0.15	8.43	0.53	0.26	0.19	0.98	3.19	1.28	4.47	0.28	0.13	0.41
8	Tamarack		0.30	0.30	0.60		0.17	0.20	0.37	1.26	4.38	5.64		0.22	0.22
9	N. White Cedar				0.00				0.00			0.00			0.00
10	Scotch Pine	1.08	0.08		1.15	0.01	0.04		0.04	0.28		0.28	0.00	0.01	0.01
11	Frasier Fir				0.00				0.00			0.00			0.00
	Sum Softwood	**67.74**	**18.22**	**9.26**	**95.22**	**5.23**	**6.36**	**13.77**	**25.37**	**69.64**	**264.13**	**333.77**	**2.00**	**12.36**	**14.36**
21	Yellow Birch				0.00				0.00			0.00			0.00
51	American Elm				0.00				0.00						0.00
60	Quaking Aspen	613.98	64.43	13.85	692.26	30.04	20.12	13.73	63.89	253.35	207.92	461.28	11.75	19.80	31.55
61	Bigtooth Aspen	74.19	10.39	2.03	86.61	4.25	2.57	1.62	8.44	39.18	36.84	76.02	1.98	3.31	5.28
62	Balsam Poplar		0.38		0.38		0.26		0.26	1.30		1.30		0.05	0.05
64	Paper Birch	59.14	6.47	4.29	69.90	2.69	2.01	5.65	10.35	25.97	78.19	104.16	1.32	4.87	6.19
65	Red Maple	65.59	4.67	1.88	72.14	3.13	1.26	1.54	5.93	20.15	29.91	50.05	1.76	2.23	3.99
66	Sugar Maple		0.08		0.08		0.02		0.02	0.25		0.25		0.01	0.01
67	Black Ash	1.08	0.08		1.15	0.01	0.02		0.03	0.35		0.35	0.00	0.02	0.02
68	Red Oak		0.23		0.23		0.05		0.05	0.62		0.62		0.05	0.05
69	Other				0.00	0.02			0.02			0.00			0.00
	Sum Hardwood	**813.98**	**86.71**	**22.05**	**922.74**	**40.13**	**26.31**	**22.54**	**88.98**	**341.16**	**352.86**	**694.02**	**16.81**	**30.33**	**47.14**
73	Willow	1.08			1.08	0.04			0.04			0.00	0.00		0.00
74	Green Ash				0.00				0.00			0.00			0.00
80	Mountain Maple				0.00				0.00			0.00			0.00
81	Black Cherry				0.00				0.00			0.00			0.00
82	Choke Cherry	30.11			30.11	0.57			0.57			0.00			0.00
83	Pin Cherry	8.60			8.60	0.33			0.33			0.00			0.00
84	Service Berry	8.60			8.60	0.30			0.30			0.00			0.00
85	Mountain Ash				0.00				0.00			0.00			0.00
86	Dogwood species	1.08			1.08	0.01			0.01			0.00			0.00
90	Alder	1.08			1.08	0.29			0.29			0.00			0.00
91	Hazel				0.00	0.06			0.06			0.00			0.00
93	Hawthorne				0.00				0.00						0.00
	Sum Noncommercial	**50.54**	**0.00**	**0.00**	**50.54**	**1.59**	**0.00**	**0.00**	**1.59**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	Sum All Species	**932.26**	**104.92**	**31.31**	**1068.49**	**46.96**	**32.67**	**36.32**	**115.94**	**410.80**	**616.99**	**1027.79**	**18.81**	**42.69**	**61.50**
	Plot Mean				**1068.49**				**115.94**			**1027.79**			**61.50**
	Plot Variance				**1161479.91**				**2182.56**			**1054902.64**			**1538.15**
	Plot Standar Deviation				**1077.72**				**46.72**			**1027.08**			**39.22**
	Plot CV				**0.95**				**0.38**			**0.95**			**0.60**

Volume: Stem volume from 1 ft stump to merchantable top diameter per Table 6, Gevorkiantz and Olson, 1955.

Biomass: wood and bark, setm and branches per Hahn (1984).

Table 7.3: Summary of Cloquet Forestry Center historical contiguous block CFI plots, measured summer 2014

Covertype: Hardwood **Area: 921.76** **N=112 plots**

		Per Acre Results by Dbh Class (inches)														
	Tree Species	**Number of Trees**				**Basal Area ft²**				**Merchantable Volume ft³**			**Biomass tons**			
		0 - 5	**5-9**	**9+**	**Sum**	**0 - 5**	**5-9**	**9+**	**Sum**	**5-9**	**9+**	**Sum**	**0-5**	**5+**	**Sum**	
1	White Pine		0.31	0.25	0.56		0.10	0.41	0.51	1.49	9.46	10.95		0.37	0.37	
2	Red Pine	7.14	3.81	4.06	15.02	1.05	1.17	5.67	7.89	16.00	146.81	162.80	0.30	6.08	6.38	
3	Jack Pine	6.25	2.44	0.75	9.44	0.53	0.85	1.55	2.92	9.20	18.72	27.92	0.17	1.25	1.42	
4	Balsam Fir	46.43	8.00	2.00	56.43	2.54	2.98	2.95	8.46	26.13	23.50	49.63	1.17	2.06	3.23	
5	White Spruce	6.25	3.38	1.81	11.44	0.69	1.02	2.35	4.05	13.80	43.71	57.51	0.28	1.77	2.05	
6	Norway/Blue Spruce	1.79	0.38	0.13	2.29	0.11	0.09	0.06	0.26	1.42	1.23	2.66	0.07	0.08	0.15	
7	Black Spruce	11.61	1.06	0.25	12.92	0.84	0.32	0.34	1.50	4.17	2.46	6.63	0.49	0.19	0.68	
8	Tamarack	2.68	1.38	0.50	4.55	0.18	0.42	0.55	1.15	4.91	13.51	18.41	0.12	0.71	0.83	
9	N. White Cedar		0.38	1.50	1.88		0.17	1.45	1.63	2.03	25.36	27.39		0.71	0.71	
10	Scotch Pine	0.89	0.06		0.96	0.00	0.03		0.03	0.23		0.23	0.00	0.01	0.01	
11	Frasier Fir				0.00				0.00			0.00			0.00	
	Sum Softwood	**83.04**	**21.19**	**11.25**	**115.47**	**5.94**	**7.15**	**15.32**	**28.41**	**79.39**	**284.74**	**364.13**	**2.61**	**13.24**	**15.85**	
21	Yellow Birch		0.13	0.06	0.19		0.04	0.06	0.09	0.57	0.97	1.53		0.08	0.08	
51	American Elm	0.89			0.89	0.03			0.03				0.01		0.01	
60	Quaking Aspen	513.39	55.06	11.94	580.39	25.32	17.09	11.79	54.20	215.60	180.81	396.41	9.88	16.97	26.85	
61	Bigtooth Aspen	61.61	8.75	1.88	72.23	3.63	2.17	1.44	7.24	33.30	32.79	66.10	1.64	2.86	4.50	
62	Balsam Poplar	0.89	0.75	0.31	1.96	0.01	0.35	0.23	0.59	3.18	5.27	8.45	0.01	0.31	0.32	
64	Paper Birch	58.04	6.75	4.50	69.29	2.80	2.13	5.52	10.45	26.50	82.43	108.92	1.41	5.13	6.54	
65	Red Maple	78.57	7.31	2.31	88.20	3.95	1.99	1.79	7.72	31.15	34.72	65.86	2.21	2.97	5.18	
66	Sugar Maple		0.06		0.06		0.01		0.01	0.21		0.21		0.01	0.01	
67	Black Ash	16.07	7.13	1.56	24.76	0.75	2.02	1.17	3.94	26.98	17.43	44.41	0.32	2.04	2.37	
68	Red Oak		0.19		0.19		0.04		0.04	0.51		0.51		0.04	0.04	
69	Other		0.06		0.06	0.02	0.01		0.03	0.12		0.12		0.01	0.01	
	Sum Hardwood	**729.46**	**86.19**	**22.56**	**838.21**	**36.49**	**25.86**	**21.99**	**84.34**	**338.12**	**354.41**	**692.53**	**15.48**	**30.42**	**45.90**	
73	Willow	0.89			0.89	0.05			0.05			0.00	0.00		0.00	
74	Green Ash				0.00				0.00			0.00			0.00	
80	Mountain Maple	1.79			1.79	0.01			0.01			0.00	0.01		0.01	
81	Black Cherry	0.89			0.89	0.05	0.01		0.07			0.00	0.03		0.03	
82	Choke Cherry	25.89			25.89	0.52			0.52			0.00			0.00	
83	Pin Cherry	8.93			8.93	0.36			0.36			0.00			0.00	
84	Service Berry	7.14			7.14	0.25			0.25			0.00			0.00	
85	Mountain Ash				0.00	0.02			0.02			0.00			0.00	
86	Dogwood species	0.89			0.89	0.01			0.01			0.00			0.00	
90	Alder	8.04			8.04	1.03			1.03			0.00			0.00	
91	Hazel				0.00	0.05			0.05			0.00			0.00	
93	Hawthorne				0.00				0.00						0.00	
	Sum Noncommercial	**54.46**	**0.00**	**0.00**	**54.46**	**2.36**	**0.01**	**0.00**	**2.37**	**0.00**	**0.00**	**0.00**	**0.04**	**0.00**	**0.04**	
	Sum All Species	**866.96**	**107.38**	**33.81**	**1008.15**	**44.79**	**33.02**	**37.32**	**115.12**	**417.51**	**639.15**	**1056.66**	**18.13**	**43.66**	**61.79**	
	Plot Mean				**1008.15**				**115.12**			**1056.66**			**61.79**	
	Plot Variance				**1040750.69**				**1990.17**			**945578.12**			**1357.34**	
	Plot Standar Deviation				**1020.17**				**44.61**			**972.41**			**36.84**	
	Plot CV				**0.97**				**0.37**			**0.88**			**0.57**	

Volume: Stem volume from 1 ft stump to merchantable top diameter per Table 6, Gevorkiantz and Olson, 1955. Biomass: wood and bark, setm and branches per Hahn (1984).

Table 7.4: Summary of Cloquet Forestry Center historical contiguous block CFI plots, measured summer 2014

Covertype:Softwood **Area: 1856.98** **N=226 plots**

		Per Acre Results by Dbh Class (inches)													
	Tree Species	**Number of Trees**				**Basal Area ft^2**				**Merchantable Volume ft^3**			**Biomass tons**		
		0 - 5	**5-9**	**9+**	**Sum**	**0 - 5**	**5-9**	**9+**	**Sum**	**5-9**	**9+**	**Sum**	**0-5**	**5+**	**Sum**
1	White Pine	2.65	1.21	2.76	6.62	0.22	0.43	4.69	5.34	5.19	130.48	135.68	0.14	4.64	4.79
2	Red Pine	18.58	16.51	34.16	69.26	2.11	6.47	41.67	50.24	77.70	1132.26	1209.96	0.82	45.40	46.22
3	Jack Pine	18.58	7.59	3.04	29.21	1.19	4.20	6.30	11.70	40.59	46.91	87.51	0.45	3.89	4.33
4	Balsam Fir	120.35	17.50	2.66	140.52	5.60	6.25	2.58	14.43	60.77	34.55	95.32	2.76	3.87	6.63
5	White Spruce	7.08	7.34	4.09	18.51	0.90	2.09	3.53	6.52	30.99	75.27	106.26	0.34	3.29	3.63
6	Norway/Blue Spruce		0.34	0.59	0.93		0.10	0.57	0.67	1.54	14.78	16.31		0.50	0.50
7	Black Spruce	63.72	23.66	3.13	90.51	4.20	6.60	2.36	13.16	96.36	40.88	137.24	2.11	3.97	6.07
8	Tamarack	16.81	8.95	5.98	31.74	1.04	2.64	4.62	8.31	39.65	90.41	130.06	0.53	5.40	5.93
9	N. White Cedar	4.42	9.20	7.50	21.12	0.36	2.68	6.02	9.06	35.51	100.97	136.47	0.21	3.60	3.81
10	Scotch Pine		0.09	0.22	0.31		0.02	0.38	0.40	0.30	8.17	8.46		0.32	0.32
11	Frasier Fir	0.88	0.84	0.03	1.75	0.11	0.23	0.05	0.39	3.26	1.41	4.67	0.03	0.18	0.22
	Sum Softwood	**253.10**	**93.23**	**64.15**	**410.47**	**15.73**	**31.72**	**72.77**	**120.22**	**391.85**	**1676.09**	**2067.94**	**7.38**	**75.07**	**82.44**
21	Yellow Birch	0.88	0.22	0.12	1.23	0.04	0.06	0.07	0.16	0.83	1.17	2.00	0.01	0.10	0.11
51	American Elm				0.00				0.00						0.00
60	Quaking Aspen	21.24	7.62	3.00	31.86	1.13	2.53	3.02	6.68	32.53	45.15	77.68	0.41	3.28	3.69
61	Bigtooth Aspen	1.77	0.28	0.22	2.27	0.30	0.11	0.25	0.66	1.26	4.72	5.98	0.05	0.23	0.28
62	Balsam Poplar	0.88	0.09	0.03	1.01	0.11	0.02	0.06	0.18	0.20	0.42	0.62	0.03	0.02	0.05
64	Paper Birch	41.15	7.19	2.88	51.22	2.42	2.06	2.67	7.15	28.72	47.82	76.54	1.10	3.32	4.43
65	Red Maple	43.81	2.66	0.93	47.40	1.91	0.69	0.92	3.53	9.69	15.19	24.88	0.97	1.11	2.08
66	Sugar Maple		0.09		0.09	0.04	0.04		0.07	0.59		0.59		0.03	0.03
67	Black Ash	17.26	1.12	0.34	18.71	0.54	0.32	0.28	1.14	3.77	4.19	7.96	0.22	0.40	0.62
68	Red Oak		0.15	0.03	0.19		0.04	0.04	0.07	0.59	0.87	1.46		0.08	0.08
69	Other	0.88			0.88	0.02			0.02			0.00	0.01		0.01
	Sum Hardwood	**127.88**	**19.42**	**7.56**	**154.85**	**6.52**	**5.86**	**7.29**	**19.67**	**78.19**	**119.53**	**197.72**	**2.81**	**8.57**	**11.38**
73	Willow	0.44			0.44	0.02			0.02			0.00	0.00		0.00
74	Green Ash		0.03	0.03	0.06		0.01	0.01	0.02	0.16	0.30	0.46		0.02	0.02
80	Mountain Maple	1.77			1.77	0.03			0.03			0.00	0.01		0.01
81	Black Cherry				0.00	0.00			0.00			0.00			0.00
82	Choke Cherry	0.88	0.03		0.92	0.03	0.01		0.04			0.00			0.00
83	Pin Cherry	5.75	0.03		5.78	0.23	0.01		0.23			0.00			0.00
84	Service Berry	0.44			0.44	0.01			0.01			0.00			0.00
85	Mountain Ash	4.42	0.06		4.49	0.07	0.01		0.08	0.09		0.09	0.03	0.01	0.04
86	Dogwood species				0.00				0.00			0.00			0.00
90	Alder	15.49			15.49	0.81			0.81			0.00			0.00
91	Hazel	0.88	0.03		0.92	0.17	0.00		0.17			0.00			0.00
93	Hawthorne				0.00				0.00						0.00
	Sum Noncommercial	**30.09**	**0.19**	**0.03**	**30.31**	**1.36**	**0.04**	**0.01**	**1.42**	**0.25**	**0.30**	**0.55**	**0.05**	**0.03**	**0.08**
	Sum All Species	**411.06**	**112.84**	**71.73**	**595.63**	**23.62**	**37.62**	**80.07**	**141.31**	**470.29**	**1795.92**	**2266.21**	**10.24**	**83.67**	**93.90**
	Plot Mean				**595.63**				**141.31**			**2266.21**			**93.90**
	Plot Variance				**256438.85**				**3462.46**			**3431612.06**			**4393.29**
	Plot Standar Deviation				**506.40**				**58.84**			**1852.46**			**66.28**
	Plot CV				**0.82**				**0.40**			**0.79**			**0.68**

Volume: Stem volume from 1 ft stump to merchantable top diameter per Table 6, Gevorkiantz and Olson, 1955.

Biomass: wood and bark, setm and branches per Hahn (1984).

Appendix 8: Forest covertype classification system

From Appendix 1 of Loeffelholz and Zimmerman (2011)

Covertypes: Commercial Tree Species

Symbol	Covertype	Description
A	Aspen	More than 66% of total BA aspen.
B	Paper Birch	More than 66% of total BA paper birch.
C	White Cedar	More than 66% of total BA white cedar.
D	Scotch Pine	More than 66% of total BA scotch pine.
E	Bottomland Hardwoods	Lowland site with > 66% of total BA comprised of a mix of ash, cottonwood, willow and maple. No species is greater than 66% of BA.
F	Balsam Fir	More than 66% of total BA balsam fir
H	Black Ash	More than 66% of total BA black ash.
J	Jack Pine	More than 66% of total BA jack pine.
Q	Mixed Swamp Conifers	Lowland site with > 66% of total BA comprised of a mix of spruce, cedar, balsam and tamarack. No one species is greater than 66% of BA.
UC	Upland Conifers	Upland site with > 66% of total BA comprised of a mix of red pine, white pine, jack pine, spruce and balsam.
MS	Maple	More than 66% of total BA is maple.
N	Northern Hardwoods	Upland site with > 66% of total BA comprised of a mix of birch, maple, aspen and ash. No one species is greater than 66% of BA.
NS	Norway Spruce	More than 66% of total BA Norway spruce.
O	Oak	More than 66% of total BA is oak.
HC	Mix Hardwood/Conifer	Upland site with a mix of hardwood and conifer species with no one species having > 66% of BA.
R	Red Pine	More than 66% of total BA red pine.
S	Black Spruce	More than 66% of total BA black spruce.
T	Tamarack	More than 66% of total BA tamarack.
W	White Pine	More than 66% of total BA white pine.
WS	White Spruce	More than 66% of total BA white spruce