



Environment and Natural Resources Trust Fund (ENRTF)

M.L. 2014 Work Plan Final Report Abstract

2014 Project Abstract

For the Period Ending June 30, 2016

PROJECT TITLE: Restoring Forest Inventory Data
PROJECT MANAGER: Alan R. Ek
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FUNDING SOURCE: Environment and Natural Resources Trust Fund (ENRTF) Appropriation
LEGAL CITATION: M.L. 2014, Chp. 226, Sec. 2, Subd. 05d

APPROPRIATION AMOUNT: \$100,000

Overall Project Outcome and Results

Motivation and objectives: Long-term datasets have proven invaluable for understanding changing forest conditions and implications for timber supply, wildlife habitat, insect, disease, wildfire, and climate change. This history is also important to charting future investments in forest based industry, forest management and the protection of forests resources for the role they play in water quality and retention of biodiversity. The primary objective of this project was to find and restore the first (1935), second (1953) and third (1962) statewide forest inventories of Minnesota plus other forest inventory datasets we might find. A secondary object was to develop comparisons of those inventories to present day forest conditions.

Methods: The project began with review of the published literature and available notes, letters, planning and other documents) plus direct contacts with present and former USDA Forest Service inventory staff who might recall aspects of these early inventories and especially where these data might be located. With success in locating these data, we have moved to digitize and restore them, check the accuracy of the restoration, and make comparisons with the present (the 2014) statewide forest inventory. Finally, we have sought to make these data (and metadata) publically available for other analysts and researchers.

Results: We have succeeded in restoring the 1935 statewide forest inventory in considerable detail, now described in a published project report. We have also located various summary data of the 1953 inventory. However, that effort was developed as an update of the 1935 inventory with inputs of data obtained from federal, state, county and private companies in various years. Thus it lacks the geographical and temporal specificity and completeness to be very detailed and thus useful in research. The 1962 inventory records were fully digital and are thought to be much more useful, but those records are yet to be located—thus our search is continuing.

Significance: The project publication (Flanary et al. 2016) included with this report describes the restoration of the 1935 inventory and comparisons to the present. Also, figures 8, 9 and 10 of this report describe major aspects of forest change. This report is viewed by the USDA Forest Service forestry inventory leadership as a very successful effort and a model for other states in restoration of inventories from the 1930s to the 1960s that have likewise been lost in terms of their detail. The agency is now moving to establish a nationwide effort to restore these older yet very valuable inventory datasets.

Project Results Use and Dissemination

The project data have been and are increasingly used to provide an understanding of the dramatic change in our forests since 1935. E.g., we have moved from a very young forest to an older forest with 3-4 times more standing biomass per acre that in the 1930s with important implications for forest health, wildfire, productivity and habitat. These results have been presented to the Minnesota Forest Resources Council and the Minnesota Forest Resource Partnership and been made available on the Interagency Information Cooperative website at:

<http://iic.umn.edu/project-areas/forest-inventory/historic-data/1936-usfs-survey>.

Additional presentations, publications and reports (and popular messages) are planned for the coming months.



Environment and Natural Resources Trust Fund (ENRTF) M.L. 2014 Work Plan Final Report

Date of Report: October 15, 2016
Date of Next Status Update Report: None
Date of Work Plan Approval: June 4, 2014
Project Completion Date: June 30, 2016
Does this submission include an amendment request? No

PROJECT TITLE: Restoring Forest Inventory Data

Project Manager: Alan R. Ek
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Location: Statewide

Total ENRTF Project Budget:	ENRTF Appropriation:	\$ 100,000
	Amount Spent:	\$ 100,000
	Balance:	\$ 0

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 05d

Appropriation Language:

\$100,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to obtain and restore statewide forest inventories of 1935, 1953, and 1966 to link with more recent data to improve understanding of historical forest trends and enhance long-term ecological monitoring.

I. PROJECT TITLE: Restoring Forest Inventory Data

II. PROJECT STATEMENT:

Long-term forest plot datasets have proven invaluable for understanding the changing conditions and ecology across Minnesota's 17.3 million acres of forestland. Major forest conditions, e.g., forest type and age class distributions, have changed dramatically in the last century. One dataset that has contributed enormously to our understanding of change is the statewide forest inventories reported on in 1935, 1953, 1962, 1977, 1990, 2003, 2008 and 2013. These data are from the USDA Forest Service Forest Inventory and Analysis (FIA) program and represent high quality data collection methods for their time and thousands of field plot observations for each survey. Unfortunately, only the data from 1977 to the present is available in detail; the earlier plot records have been lost. We propose to locate and restore and/or reconstruct the earlier data down to a level useful for ecoregion to local change analysis and thereby reestablish linkage to the 1977 and more recent data. We may also be able to locate the original field data in archives. With that data we will gain 40+ years of detailed forest dynamics—invaluable to climate, environment and habitat change understanding.

Additional datasets exist beyond FIA that can also be effective to extend our capability to assess and analyze long term forest change. An example is the 400 forest plot inventory on the University's 3,500 acre Cloquet Forestry Center—measured 7 times from 1959 to 2000 and with an 8th measurement scheduled for 2014. Other research or simply long-term monitoring datasets exist on a smaller scale than FIA but may have important utility regionally. This project will seek out those offering the most promise for restoration and understanding environmental change.

Research hypothesis: We recognize the increasing value of large, long-term and intensive forest inventory datasets for examining a wide range of ecological, habitat and economic issues. We anticipate that today's search, database management, scanning, digitizing, interpolation, extrapolation and imputation methodologies are sufficient to complete databases with gaps or missing data such that truly useful detail can be restored and linked to the more recent records. Further, we anticipate that informed searching of published records, internal agency reports and data archive sites can provide sufficient information and perhaps original data to allow nearly complete and highly useful dataset restoration

III. PROJECT STATUS UPDATES:

Project Status as of January 15, 2015:

A search for reports and publications describing the 1935, 1953 and 1962 FIA inventories has been conducted and results have provided all known reports in the form of work plans, working papers, analyses, special studies and summary reports. To this point the most detailed reports from 1935 consists of large format summaries of data from the six FIA survey units at that time, including all unit summaries. These have since been digitized in the form of 280 Excel spreadsheets organized by unit, covertype, 25 species, tree diameter class, timber volumes, ownership and more for each of the six survey units. These have also been checked successfully against published reports at that time. Additionally, we have been in contact with the FIA Washington Office for (1) permission to visit and search the Federal Records Center and (2) to collaborate with a project there focusing on software development to bring older FIA data into a reporting capability that will match current reporting formats, i.e., similar tables. Finally, we have made contact with former (now retired) FIA employees who have some knowledge of the 1935, 1953 and 1962 records. These contacts have helped refine our search for the FIA records and data files. We have also been making contacts to identify and assemble plot records from various forests inventories and studies dating back to the early 1900s.

Project Status as of June 30, 2015:

The 1935 FIA Forest inventory data has been restored with detail down to survey unit for tree numbers within 1-2-inch diameter classes. This breakdown is further by species by covertype by stand size class by product (cubic feet and board feet), etc. This will now allow comparison of tree species, covertype and size class composition statewide and by survey unit from 1935 to the present. These data have also been processed converted from paper to a digital database.

The 1962 FIA survey data has been more elusive. We have been working with the USDA Forest staff in FIA and the Federal Records Center staff in Kansas City to identify potentially instructive records. We anticipate an investigative visit to the Federal Records Center soon to carry this effort further. Other long-term forest plot measurement records recovered to date include the permanent forest inventory / research plots on the University of Minnesota's Cloquet Forestry Center permanent plot database. These records encompass eight measurements taken from 1959 to 2014. Additionally, recently remeasured red pine study plots from the early 1900s have been recovered from the Cloquet Forestry Center and the North Central Research and Outreach Center at Grand Rapids. More such plot measurement record findings are anticipated.

Project Status as of January 15, 2016: The 1935 FIA Forest inventory data have been incorporated in a Microsoft Access database, which is a format used today by the FIA in making their inventory data available to the public. We have also developed SQL (Structured Query Language) queries for checking the accuracy of the 1935 database and for making a range of comparisons of that inventory and forest conditions with the FIA inventory data collected since, notably from 1977 up to 2014. These comparisons are being developed and described in reports to be finalized and published later this year. We see these comparisons as being very instructive in climate change impact analysis, assessing long term carbon sequestration and in the study of biodiversity dynamics.

For the 1962 FIA inventory data, we have continued to expand our contacts with former and current FIA employees and especially staff of the Federal Records Center in Kansas City. Because of Forest Service concerns for data security, an MOU for this project with the Forest Service FIA and an associated data security plan have been developed and should allow an actual project team visit (by Alan Ek) to the Federal Records Center soon. This trip should reveal, in detail, the extent of 1962 FIA records that will be available for the project. Unfortunately, the time taken to gain official and physical access to Federal Records Center data has taken longer than expected.

In addition to FIA data, numerous smaller long-term forest inventory records have been recovered, and we have continued to search for more. We have also been compiling, quantifying and analyzing the long-term growth and change in these data. These analyses are being developed and described in draft reports...to be finalized and published later this year.

Project Status as of June 30, 2016:

After numerous communications by phone and email with the USDA Forest Service FIA and Federal Records Center administration and security processes, the project manager was able to visit the Federal Records Center in Kansas City, KS in March, 2016. This visit was a major step in finding and inspecting the contents of approximately 70 boxes of Forest Service records, largely relating to forest surveys from the 1930s to the 1960s. Given that, we finalized and published our report on the 1935 inventory restoration as a Staff Paper Report (citation below, electronic copy attached, and three copies of the report will be delivered to the LCCMR).

Flanary, M. H., B. D. Anderson, D. C. Wilson and A. R. Ek. 2016. *Restoration of the 1936 statewide forest survey of Minnesota: Data description and comparisons with 2014 forest conditions*. St. Paul, MN: University of Minnesota, Department of Forest Resources, Staff Paper Report No. 241. 30 p. plus 3 Appendices. (also available at <http://www.forestry.umn.edu/our-department/publications>)

Notable in this report is documentation that the forest age class distribution of the forest has changed dramatically since 1935—from a preponderance of young forest acreage to a predominately older forest, with 3-4 times as much standing biomass as in the 1930s.

This report has since been disseminated to the MN DNR Division of Forestry, the USDA Forest Service FIA offices in St. Paul and Washington D.C. and others. A journal article and research notes on aspects of forest change from 1935 to 2014 are also being drafted. The Staff Paper report is viewed by the Washington Office (per Brad Smith, FIA Associate National Program Leader) as the most thorough restoration of a 1930s era statewide forest inventory to date. That office has further indicated they will provide staff support for further digitizing efforts with inventory restoration efforts.

The 1935 Forest Survey report, system description, metadata and data (together with user guide and query capability) are also available to researchers and the public via the Interagency Information Cooperative (IIC) website in conjunction with the University of Minnesota Library Digital Conservancy. The direct website link is <http://iic.umn.edu/project-areas/forest-inventory/historic-data/1936-usfs-survey>

For the 1962 FIA inventory data, no data beyond published summary records were found through the Kansas City Federal Records Center visit. However, we did identify some computer tapes that will be examined for their content. Fortunately, the visit also uncovered some early and complete records of Minnesota forest surveys from the 1940s and 1950s; we and many others were unaware of their existence. These will be brought back to St. Paul. Also, a trip to the Federal Records Center in Chicago is being planned for later this year to continue the search for the 1962 FIA Inventory data.

Additionally, the University of Minnesota Cloquet Forestry Center (CFC) permanent sample plots (known as the CFC Continuous Forest Inventory (CFI)) have been assembled as a Microsoft Access database of 400+ field plots measured eight times since 1959. For this collection, we have also developed metadata plus sample queries. These data are described in a report as:

Shrestha, M., D. C. Wilson, J. M. Zobel and A. R. Ek. 2016. *Cloquet Forestry Center Continuous Forest Inventory Update for 2014*. St. Paul, MN: University of Minnesota, Department of Forest Resources, Staff Paper Report No. xxx. 22 p. plus Appendices. In review.

An additional dataset to be included is the 100 plus year observation record of the Chapman Plantation located on the University's North Central Research and Outreach Center in Grand Rapids, MN. Like the 1935 FIA forest survey documentation, the CFC and Chapman data will be made available on the Interagency Information Cooperative website in conjunction with the University of Minnesota Library Digital Conservancy. We expect to complete this step by early 2017.

Overall Project Outcomes and Results: October, 2016: Major statewide forest inventory datasets have been identified, restored and/or captured in the project, with more likely to be added soon. The smaller ones typically include but a few plots but can be very instructive locally or for specific research questions. As the Flanary et al (2016) report suggests, there is much utility in these datasets for understanding long term forest dynamics and implications. Among these implications are those for timber supply, wildlife habitat, insect, disease, fire risk and climate change. Given that, our efforts to find and fully restore the 1962 FIA Statewide forest survey of Minnesota will be continued as other funding allows.

The project has been successful in restoring the 1935 FIA Forest Survey. Its details and potential research value is now described in a published report. Additionally, in large part on the basis of our efforts, the USDA Forest Service FIA Washington Office is now seeking to create an archivist position and organization to bring back ALL

of the forest survey data from the federal records centers for local (in each of the four FIA regions nationally – Northern (includes Minnesota), Southern, Interior West and Pacific Northwest) storage and restoration of these earlier surveys. Finally, the FIA is working to establish regional centers to focus on restoration of their earlier surveys, primarily those prior to the 1970s. We (the University of Minnesota) will likely play a lead role in the Upper Great Lakes portion of the Northern Region FIA.

Restoration of the 1962 FIA forest inventory for Minnesota remains elusive. The same is true for many early forest surveys in other states. However, this project and its efforts in Minnesota have provided an example of success and motivated the FIA to expand their efforts at restoration. For the 1962 FIA Inventory, we are continuing the search for these data in paper and electronic formats. Should either be found, we will seek University, USDA Forest Service and possibly other support for their restoration.

In terms of dissemination of results, publication is underway and protocols for electronic distribution are in place and in use. The primary project report on the restoration of the 1935 forest inventory of Minnesota is already serving as a motivating example for the USDA Forest Service Forest Inventory and Analysis leadership in addressing the restoration of older (than 1970) inventories nationwide. Additional reports based on the 1935 data are also underway.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Collect, assemble and recover information on and details of the 1935, 1953 and 1966 statewide forest inventories.

Description: The 1935, 1953 and 1962 FIA data are available only in summary reports on a statewide and sometimes regions and counties. We have sought further documentation describing these data and also interviewed individuals who designed and/or executed these surveys, including past and present survey project leaders. Here we extend those efforts further to restore the subject datasets. The attached graphic suggests the geographic extent of the project.

We anticipate documentation and actual summary and field plot records exist in various federal, state, university, industry and individual survey crew or supporting scientist files in various formats. Operationally, we will further develop our contact list from currently employed and retired individuals likely to be familiar with these data. Subsequently, we will contact them to narrow the search. Questions for these contacts will seek their knowledge of the documentation of these survey designs, the location of plot records and related data and maps, and the names of other contacts who might be helpful. We will also explore library and publication archives, federal archives in Washington, D.C. and Kansas City, MO and existing research compilations, electronic and otherwise, to identify promising leads and/or key portions of the FIA records. Once located, these data would be processed per the activity steps described below to make them useable and readily available.

If we are unable to locate the full datasets in the form of detailed plot records, then various statistical approaches would be used to impute existing data to provide useful plot, survey line, section, township, county or survey unit results and associated map characterizations. Note there are 4-6 survey units in Minnesota depending upon the year of the survey.

The priority in restoration will be the 1962 and then 1935 datasets. It is possible the 1962 plot data still exists in punch card or electronic format or in a form that can be scanned and digitized. Even though the 1935 plot data and some tree data was summarized and transferred to IBM cards, it is less likely that these would still be readable or even found. The 1953 Survey was compiled from inventories conducted by federal, state, county, and industry entities and is perhaps the most problematic for reconstruction at the plot level.

Summary Budget Information for Activity 1:

ENRTF Budget: \$ 85,830

Amount Spent: \$ 85,830

Balance: \$ 0

Activity Completion Date: March 2016

Outcome	Completion Date	Budget
1. Collection and synthesis of documentation, summaries, maps and field data records from individuals, agencies, and federal archives for the subject inventories.	January 2015	\$22,000
2. Digitization, processing, and recovery of data down to survey unit, county, township and plot levels; verification of restoration by comparison with published summary reports.	January 2016	\$60,000
3. Database formatted to link for analysis with datasets for 1977 to present and reporting.	March 2016	\$4,830

Activity Status as of January 15, 2015: A search for reports and publications describing the 1935, 1953 and 1962 FIA inventories has been conducted and originals have been obtained (or copies thereof). This includes all known reports in the form of work plans, working papers, analyses, special studies and summary reports. Most of these are USDA Forest Service documents, but some are state and other documents, often in the form of grey literature. To this point the most detailed from 1935 consists of large format summaries of data from the six FIA survey units at that time, including all unit summaries. These have since been digitized in the form of 280 Excel spreadsheets organized by covertype, 25 species, tree diameter class, timber volumes, ownership and more for each of the six survey units. These have also been checked successfully against published reports indicating they represent the entire statewide inventory at that time. Additionally, we have been in contact with the FIA Washington Office for (1) permission to visit and search the Federal Records Center and (2) to collaborate with a project there focusing on software development to bring older FIA data into a reporting capability that will match current reporting formats, i.e., similar tables. However, it appears we have the most detailed records of the 1930 surveys of anywhere in the U.S. Finally, we have made contact with 5 former (now retired) FIA employees who were likely to have had direct knowledge of the 1935, 1953 and 1962 records. These contacts have helped refine our search for the subject records and data files.

Activity Status as of June 30, 2015: The 1935 FIA Forest inventory data has been restored with detail down to survey unit for tree numbers within 1-2 inch diameter classes x species x by covertype x stand size class x product (cubic feet and board feet), etc. The digitization in this effort was accomplished by transferring early handwritten records to an Excel spreadsheet format. We now have these data in the form of 100+ spreadsheets. This will now allow comparison of tree species, covertype and size class composition statewide and by survey unit from 1935 to the present. These data have also been processed to a format for developing past to present comparisons via an Access database.

The 1962 FIA survey data has been more elusive. We have been working with the USDA Forest staff in FIA Washington, D.C. and St. Paul and the Federal Records staff in Kansas City to identify potentially instructive records, if not a complete copy of this survey in some form. We anticipate a site visit to the Federal Records Center soon to carry this effort further. So far we have only summary records to various levels of detail for major variables of interest, most from FIA reports.

Activity Status as of January 15, 2016: The 1935 FIA Forest inventory data have been incorporated in a Microsoft Access database, which is a format used today by the FIA in making their inventory data available to the public. We have also developed SQL (Structured Query Language--a special-purpose programming language designed for managing data held in a relational database management system) queries for checking the accuracy of the 1935 database and for making a range of comparisons of that inventory and forest conditions

with the FIA inventory data collected since, from 1977 up to 2014. These comparisons are being developed and described in draft reports...to be finalized and published later this year.

For the 1962 FIA inventory data, we have continued to expand our contacts with former and current FIA employees and especially staff of the Federal Records Center in Kansas City. Because of Forest Service concerns for data security, an MOU for this project with the Forest Service FIA and an associated data security plan have been developed and should allow an actual project team visit (by Alan Ek) to the Federal Records Center soon. This trip should reveal, in detail, the extent of 1962 FIA records that will be available for the project.

Activity Status as of June 30, 2016: After numerous communications by phone and email with the Federal Records Center in Kansas City for identification of potentially useful records and the development of data security approval by the USDA Forest Service, permission to visit the Federal Records Center in Kansas City, KS was granted in February, 2015. The project manager visited this center in March, 2016 and inspected the contents of approximately 70 boxes of Forest Service records, largely relating to forest survey from the 1930s to the 1960s. This inspection confirmed various aspects of the 1935 inventory, but did not include the sought after field tally sheets. Given that, we finalized and published our report on this inventory restoration as a Staff Paper Report (citation below, electronic copy attached, and three copies of the report will be delivered to the LCCMR).

Flanary, M. H., B. D. Anderson, D. C. Wilson and A. R. Ek. 2016. *Restoration of the 1936 statewide forest survey of Minnesota: Data description and comparisons with 2014 forest conditions*. St. Paul, MN: University of Minnesota, Department of Forest Resources, Staff Paper Report No. 241. 30 p. plus 3 Appendices.

This report can also be found at <http://www.forestry.umn.edu/our-department/publications>.

This report has since been disseminated to the MN DNR Division of Forestry, the USDA Forest Service FIA offices in St. Paul and Washington D.C. and others. A journal article and research notes are also being drafted. The report is viewed by the Washington Office (per Brad Smith, FIA Associate National Program Leader) as the most thorough restoration of a 1930s era statewide forest inventory to date. That office has further indicated their staff support for any further digitizing efforts with these data.

The 1935 Forest Survey report, system description, metadata and data (together with user guide and query capability) are also available to researchers and the public via the Interagency Information Cooperative website in conjunction with the University of Minnesota Library Digital Conservancy. The direct website link is <http://iic.umn.edu/project-areas/forest-inventory/historic-data/1936-usfs-survey>

For the 1962 FIA inventory data, no data beyond published summary records (which we already have) were found through the Federal Records Center Visit. However, we did identify some computer tapes that are scheduled to be examined for their content. Fortunately, the visit also uncovered some early records that we and many others were unaware of their existence...including:

1. A 1946-53 Forest Survey of most Minnesota counties with apparently complete and detailed records, including field tally sheets, stand maps and aerial photos.
2. A 1950s set of permanent plots established across Northern Minnesota Counties (never remeasured) including field tally sheets.

Given the information gleaned from our study, a trip to the Federal Records Center in Chicago is now being planned for later this year to continue the search for the 1962 FIA Inventory data.

Final Report Summary: October 15, 2016: The project has been successful in restoring the 1935 FIA Forest Survey. Its details and research value is now described in a published report. Additionally, in large part on the basis of our efforts, the USDA Forest Service FIA Washington Office is now seeking to create an archivist position

and organization to bring back ALL of the forest survey data from the federal records centers for local (in each of the four FIA regions – Northern (includes Minnesota), Southern, Interior West and Pacific Northwest) storage and restoration of these earlier surveys. Finally, the FIA is working to establish regional centers to focus on restoration of their earlier surveys, primarily those prior to the 1970s. We (the University of Minnesota) will likely play a lead role in the Upper Great Lakes portion of the Northern Region FIA.

Restoration of the 1962 FIA forest inventory for Minnesota remains elusive. The same is true for many early forest surveys in other states. However, this project and its efforts in Minnesota have provided an example of success and motivated the FIA to expand their efforts at restoration. For the 1962 FIA Inventory, we are continuing the search for these data in paper and electronic formats. Should either be found, we will seek USDA Forest Service support for their restoration.

ACTIVITY 2: Identify and restore additional long-term forest plot datasets.

Description: Seek out and recover additional long-term datasets that have potential for understanding forest change. Key criteria are that these datasets (a) describe ecologically important conditions over a large area, (b) have detail for meaningful change analysis, and (3) describe timeframes in excess of 30 years. These datasets will focus on naturally occurring forest conditions, though some portion may have a history of management treatments.

These datasets will include the eighth remeasurement of the permanent forest inventory / research plots on the University of Minnesota’s Cloquet Forestry Center permanent plot database, to be conducted in the summer of 2014 with funds obtained from the University’s Office of the Vice President of Research. Earlier measurements of these 400 plots were taken in 1959, 1964, 1969, 1976, 1982, 1990, 2000. Note the initial project proposal included an activity that sought funding for the 2014 measurement of the Cloquet dataset. This measurement activity has now been deleted from the work plan as it is no longer needed. However, we have included that dataset to be treated under this revised activity.

Additionally, we will seek out and attempt to recover additional long-term datasets that have potential for understanding forest change. Key criteria are that these datasets (a) describe ecologically important conditions over a large area, (b) have detail for meaningful change analysis, and (3) describe timeframes in excess of 30 years. These datasets will focus on naturally occurring forest conditions, though some portion may have a history of management treatments. We anticipate such datasets exist in various federal, state, university, industry and individual files in various formats.

Operationally, we will develop a contact list from currently employed and retired individuals likely to be familiar with such datasets. Subsequently, we will contact them to narrow the search. We will also explore library and publication archives and existing research compilations, electronic and otherwise, to identify promising datasets that suggest they include long-term records. Once located, these datasets would be processed per the activity steps described below to make them useable and readily available.

Summary Budget Information for Activity 2:

ENRTF Budget: \$ 14,170

Amount Spent: \$ 14,170

Balance: \$ 0

Activity Completion Date: March 2016

Outcome	Completion Date	Budget
1. Identification and collection of documentation and existing field data for the subject inventories.	October 2015	\$ 4,000
2. Digitization, processing, and restoration of data with recompilation to compare and verify against official reports.	March 2016	\$ 8,000

3. Databases and data formatted for forest change analysis and reporting consistent with USDA Forest Service FIA and MN DNR data specifications.	June 2016	\$2,170
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Activity Status as of January 15, 2015: We have been making contacts to find old forest plot records and data files. To date we have identified records of 100+ year old permanent sample plots at the University of Minnesota’s Cloquet Forestry Center and the North Central Research and Outreach Center at Grand Rapids. Both of these sets are in digital format. The search for more 100 year records is continuing.

Activity Status as of June 30, 2015: Long-term forest plot measurements records recovered now include the permanent forest inventory / research plots on the University of Minnesota’s Cloquet Forestry Center permanent plot database. These records encompass eight measurements taken from 1959 to 2014. Additionally, red pine study plots from the early 1900s and recently remeasured have been recovered from the Cloquet Forestry Center and the North Central Research and Outreach Center at Grand Rapids. All of these are now in an Access database format. More such plot measurement record findings are anticipated.

Activity Status as of January 15, 2016: While the above note records have been recovered, we have continued to search for more. Additionally, we have been writing SQL queries to quantify and analyze the long-term growth and change in these data. These analyses are being developed and described in draft reports...to be finalized and published later this year.

Activity Status as of June 30, 2016: As noted above under Activity 1, Alan Ek traveled to the Federal Records Center in Kansas City, KS in March 2016 for search and inspection of USDA Forest Service records of Minnesota Forest Surveys. This led to knowledge of FIA datasets 1 and 2 described under Activity 1 above. Working with the USDA FIA unit in St. Paul, we are in the process of bringing those data back to Minnesota for further inspection and potentially full restoration.

Additionally, the University of Minnesota Cloquet Forestry Center (CFC) permanent sample plots (known as the CFC Continuous Forest Inventory (CFI)) have been assembled as a Microsoft Access database of 400 plots measured 8 times since 1959. For this collection, we have also developed metadata plus sample queries. These data are described in a report as:

Shrestha, M., D. C. Wilson, J. M. Zobel and A. R. Ek. 2016. *Cloquet Forestry Center Continuous Forest Inventory Update for 2014*. St. Paul, MN: University of Minnesota, Department of Forest Resources, Staff Paper Report No. xxx. 22 p. plus Appendices. In review.

An additional small dataset to be included is the 100 plus year observation record of the Chapman Plantation located on the University’s North Central Research and Outreach Center in Grand Rapids, MN. Like the 1935 FIA forest survey documentation, the CFC and Chapman data will be made available on the Interagency Information Cooperative website in conjunction with the University of Minnesota Library Digital Conservancy. We expect to complete this step by early 2017.

Final Report Summary: October 15, 2016: Major datasets have been identified, restored and/or captured in the project, with several more possibly added soon. The smaller ones typically include but a few plots on small areas but can be locally very instructive. As the Flanary et al (2016) report suggests, there is much utility in these datasets for understanding long term forest dynamics and implications. Among these implications are those for timber supply, wildlife habitat, insect, disease, fire risk and climate change. Given that, our efforts to find and fully restore the 1962 FIA Statewide forest survey of Minnesota will be continued as other funding may allow.

V. DISSEMINATION:

Description: The project plans to provide restored databases in electronic formats together with data descriptions for other users. These results and dataset restoration methodology will also be described in paper and electronic reports to be made available to ecologists, inventory specialists, and resource analysts through publications and web access (via the Department of Forest Resources and the Forest Resources Interagency Information Cooperative (IIC) websites). Additionally, we are planning on technical journal articles and webinars to describe the datasets and restoration methodology for potential use by those in other regions. The data is intended to in convenient data formats including those compatible with current statewide forest inventory data. These datasets will be employed as soon as they become available for examination of long-term forest change, specifically for their implications for climate change (resilience, adaptation), for understanding long-term carbon sequestration in forests statewide, and for habitat change, e.g., for ruffed grouse, moose and forest health and biodiversity implications as well. We anticipate our own (other) projects in these subject areas will provide the funding for using these data further. We also see these data as an important and publicly available datasets to be made available for applications by others within and beyond the University and Minnesota on funding they may have available.

Activity Status as of January 15, 2015: This activity is slated largely for the second year of the project, however, we are adapting the Interagency Information Cooperative website for this effort as well as working with the University of Minnesota Library for the possibilities for data archiving and access available in that repository.

Activity Status as of June 30, 2015: This effort is now in development in terms of computing basic “restoration methodology” and “past versus present” comparison reports to highlight the data availability and potential usage. This includes making the data available in electronic formats with appropriate metadata. We are also seeking funding to extend this work as further research on the issues that the data now allow us to address.

Activity Status as of January 15, 2016: The activities described for June 30, 2015 are continuing.

Activity Status as of June 30, 2016: The activities described above are continued with protocols for communication and data access now well developed.

Final Report Summary: October 15, 2016: The documentation and communications efforts and data access are now in place for several historic datasets and are being extended to include additional datasets as they become available and are restored. The project has achieved national level recognition with but modest communications so far.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	\$ Amount	Explanation
Personnel:	\$ 96,800	<p>Research Support: <u>Research Associate</u> John Zobel @ 25% time for one year to assist project team in developing statistical approaches for restoring data sets, notably to address gaps in data, as necessary. Total: \$17,000.</p> <p><u>Research Fellow</u> David Wilson@ 65% time for two years to assist project team in the collection and synthesis of the subject long-term forest inventory plot datasets. Total \$79,800.</p>
Travel Expenses in MN:	\$1200	To dataset and or archive sites outstate

Other: Travel expenses beyond MN	\$2,000	To federal archives in Washington D.C. and Kansas City, MO.
TOTAL ENRTF BUDGET:	\$100,000	

Explanation of Use of Classified Staff: NA

Explanation of Capital Expenditures Greater Than \$5,000: NA

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 1.6

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: NA

B. Other Funds:

Source of Funds	\$ Amount Proposed	\$ Amount Spent	Use of Other Funds
Non-state			
	\$	\$	
State	\$		
University of Minnesota In-kind Services During Project Period: Project manager (Ek) will contribute 1% time to the project; other University co-PI (Burk) will contribute 1% time to working with project employees.	\$6,594	\$6,594	Project manager faculty time providing project research leadership
University of Minnesota Unrecovered indirect costs @ 52% of modified total direct cost base of \$100,000	\$52,000	\$52,000	
TOTAL OTHER FUNDS:	\$58,594	\$58,564	

VII. PROJECT STRATEGY:

A. Project Partners: The University of Minnesota will receive the funding and also contribute substantial faculty time and effort to the project. Project team members (PIs) are from the University's Department of Forest Resources and include Professors Alan Ek and Thomas Burk, Research Associate John Zobel and Research Fellow David Wilson. A key cooperater is the USDA Forest Service Northern Research Station Forest Inventory and Analysis unit in St. Paul and related Federal Archive sites (in Washington, D.C. and Kansas City, MO), plus the MN DNR Division of Forestry and other individuals that have been involved with collection of MN FIA and other data in the past.

B. Project Impact and Long-term Strategy: A two-year project length is needed to be able to identify, locate and restore existing datasets. This includes the development of statistical imputation methodology as needed, and to digitize and make the datasets available for improving the analysis of forest change for ecological, habitat and economic interests.

C. Spending History: The project manager and his research teams have been using long-term forest datasets in research for several decades. However, we have only recently sought to improve on the data available through the restoration of “lost” forest inventory records. However, no ENRTF and MRRF funds have been used in those efforts.

Funding Source	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12-13	M.L. 2013 or FY14

VIII. ACQUISITION/RESTORATION LIST: NA

IX. VISUAL ELEMENT or MAP(S): To be developed from the datasets restored in the course of this project

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: NA

XI. RESEARCH ADDENDUM:

XII. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 15, 2015, June 30, 2015, January 15, 2016, and June 30, 2016. A final report and associated products will be submitted between June 30 and August 15, 2014.

GRAPHIC: History of Statewide Forest Inventories in Minnesota from 1935 to 2013.

- **2013:** The figure below describes the location of the latest Forest Inventory and Analysis (FIA) field plots in Minnesota (6,139 plots, each consisting of four 1/24th acre subplots) and examples of data collected.

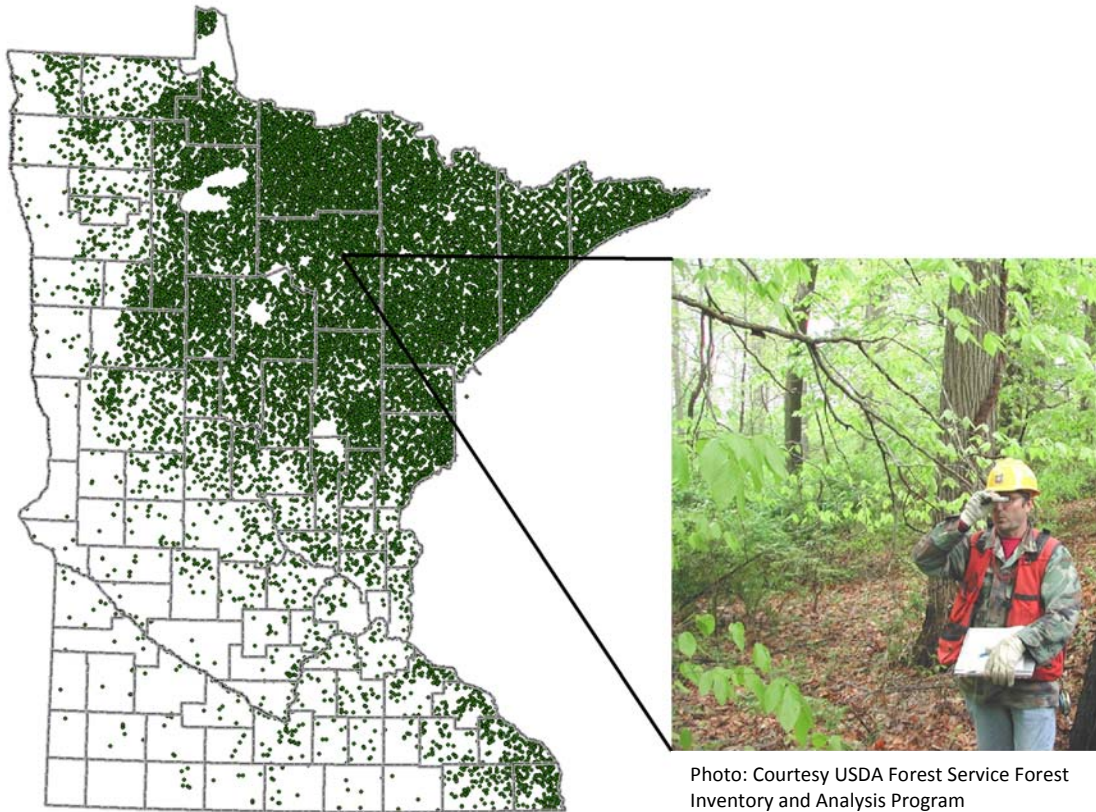



Figure 1: FIA plots in Minnesota in 2013. The plots were measured over a 5 year period (2009-2013) and provide estimates of forest area, ownership, cover type, stand tree and site description, numerous ecological descriptors, habitat indicators, and numerous other measures.

- **2008:** Same sample plot grid layout and measurement as 2013
- **2003:** Same sample plot grid layout and measurement as 2008
- **1999:** Same sample plot grid layout and measurement as 2003
- **1990:** Similar sample plot grid layout and measurement as 1999
- **1977:** Same sample plot grid layout and measurement as 2013
- **1966:** Data lost...
- **1953:** Data lost...
- **1935:** Data lost...

Project Activity: Locate, collect and restore the lost inventory data and compilations.

Results: Extension of forest and related ecological monitoring data and compilations for 40+ years, thus greatly strengthening historic detail on forest dynamics—invaluable to climate, environment and habitat change understanding.

Environment and Natural Resources Trust Fund								
M.L. 2014 Project Budget								
Project Title: Restoring Forest Inventory Data								
Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 05d								
Project Manager: Alan R. Ek								
Organization: University of Minnesota								
M.L. 2014 ENRTF Appropriation: \$ 100,000.								
Project Length and Completion Date: 2 years, June 30, 2016								
Date of Report: October 15, 2016								
								
ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET								
	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	<i>Collect, assemble and recover information...</i>			<i>Identify and restore additional...datasets</i>				
Personnel (Wages and Benefits)	\$83,130	\$83,130	\$0	\$13,670	\$13,670	\$0	\$96,800	\$0
John Zobel, Research Associate: \$17,000. (66.4% salary, 33.6% benefits); 25% FTE for one year. Work: To assist project team in developing statistical approaches for restoring data sets, notably to address gaps in data, as necessary.								
David Wilson, Research Fellow: \$79,800. (66.4% salary, 33.6% benefits); 65% FTE for two years. Work: to assist project team in the collection and synthesis of the subject long-term forest inventory plot datasets.								
Travel expenses in Minnesota	\$700	\$700	\$0	\$500	\$500	\$0	\$1,200	\$0
<i>Mileage, lodging and meals to locate and collect restorable datasets in Minnesota</i>								
Other	\$2,000	\$2,000	\$0	\$0	\$0	\$0	\$2,000	\$0
<i>Air fare, lodging, and meals to locate and collect restorable datasets from federal archives in Washington, DC and Kansas City, MO.</i>								
COLUMN TOTAL	\$85,830	\$85,830	\$0	\$14,170	\$14,170	\$0	\$100,000	\$0

**Restoration of the 1936 statewide forest survey of
Minnesota: Data description and comparisons with
2014 forest conditions.**

by

Merril H. Flanary, Brian D. Anderson, David C. Wilson and Alan R. Ek

August 18, 2016

Staff Paper Series No. 241

Department of Forest Resources

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The University of Minnesota is committed to the policy that all persons shall have equal access to its programs, facilities, and employment without regard to race, color, creed, religion, national origin, sex, age, marital status, disability, public assistance status, veteran status, or sexual orientation.

Acknowledgements

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative–Citizen Commission on Minnesota Resources and the University of Minnesota’s College of Food, Agricultural and Natural Resources Sciences Department of Forest Resources and the Minnesota Agricultural Experiment Station under Project MIN 42-019. The authors also wish to thank the USDA Forest Service Northern Research Station staff for their generous support in identifying and seeking historic records through the Federal Records Center System, notably Northern Research Station staff of the Forest Inventory and Analysis (FIA) Program Dr. Mark H. Hansen, Patrick D. Miles, Peggy SB. Castillo and FIA Program Manager Dennis M. May. Advice on locating historic records by W. Brad Smith, Associate National Program Leader, FIA was also greatly appreciated.

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ABSTRACT

Long-term forest plot datasets have proven invaluable for understanding the changing conditions and ecology across Minnesota's 17.3 million acres of forestland. Data from past and present USDA Forest Service (USFS) Forest Inventory and Analysis (FIA) program efforts are of high quality and are informed by thousands of field plot observations for each survey. Unfortunately, only the data from 1977 to the present is available in electronic format with full detail; the earlier plot records have been lost. The aim of this study was to locate historic forest records for Minnesota, identify useful data, and develop methodologies for digitizing and restoring data to a usable format. Over 300 stand and stock tables and summary of volume tables for Minnesota were restored from the first FIA Lake States forest survey conducted between 1930 and 1938. The level of detail of the data varied, but included area of forest cover types and stand size classes, and number of trees and volumes per acre by individual species. This report is primarily intended as a reference for describing how the data was located, restored, digitized and compared with current FIA data, including overcoming limitations in the available data.

Included with this documentation is a set of comparisons of various forest conditions over an eighty-year period using the restored dataset and FIA data for Minnesota from 1977 and 2014 inventories. The results showed that overall statewide comparisons using the historic data were most complete and more dependable than comparisons made at survey unit and per-acre scales. Total forest area in Minnesota increased by 1.8 million acres during the eighty-year period, much of that due to the recovery of lands categorized as brush lands in the 1930s. The stand size class distribution in the 1930s was also dominated by an abundance of young stands, and pine forests were more common than hardwood stands across the state. Today the situation is somewhat reversed, with older forest common over large areas, less conifer acreage and much increased standing volume and hence biomass. Both merchantable volume and total cubic volume have increased three-fold since 1936. Additionally, ownership has shifted by nearly five-million acres to more public ownership today than eighty years ago. Historic volume summary tables have provided sufficient detail to develop meaningful comparisons with current FIA data, establishing linkage to the 1977 and more recent reports.

1. INTRODUCTION

The effects of environmental and human induced change on forest ecosystems is difficult to assess over short time scales. Long-term datasets subsume such short-term complexity and allow better understanding of changes in forest composition, structure and biodiversity over time (Dornelas et al. 2014; Groffman et al. 2012). For forests in Minnesota and the Great Lakes region, land use change, fire suppression and periods of heavy extraction over the past century have caused dramatic change in forest composition and structure. These changes have been explored using long-term datasets (Fei and Steiner 2007; Friedman and Reich 2005; Friedman et al. 2001; Rhemtulla 2009; Schulte et al. 2007; White and Host, 2008), but detailed statewide forest inventory data has not been available beyond the past forty years. Recovering historic forest inventory data offers a potentially powerful tool for addressing the impacts of climate change and land use change on Minnesota's 17.3 million acres of forest land.

One forest inventory data source that has contributed enormously to our understanding of our forest resources is the statewide forest inventories reported in 1936, 1953, 1962, 1977, 1990, 2003, 2008 and 2014. These data are from the USDA Forest Service (USFS) Forest Inventory and Analysis (FIA) program and represent high quality data collection methods and thousands of field plot observations for each survey. Unfortunately, only the data from 1977 to the present is available in detail; the earlier plot records have been lost. For this study we proposed to locate data from the first USFS inventory in the Lake States, conducted in the 1930s, to explore the feasibility of restoring and reconstructing such data for Minnesota. Specifically, we have focused on a level of detail useful for analysis of change from a local to ecoregion scale, and thereby reestablishing linkage to the 1977 and more recent data.

The USFS was authorized to develop the first nationwide forest survey as part of the McSweeney-McNary Forest Research Act of 1928 (Smith 2002). The purpose of the survey was to statistically quantify forest area and timber volume following a period of heavy extraction of forest resources across the nation. Eight experiment stations located throughout the U.S. were tasked with developing and implementing regionally-specific forest inventory designs. This effort also fostered a burgeoning period for what would become the national FIA program (LaBau 2007). Minnesota, Wisconsin and Michigan were included in the Lake States survey.

The Lake States survey was carried out from 1930 to 1938 under the guidance of R.M. Cunningham and Suren R. Gevorkiantz at the Lake States Forest Experiment Station in St Paul, Minnesota. Field work began in Minnesota in 1934 and continued for two years (Chase 1964; Gafvert 1938). In the years following the survey, USFS publications referred to the original survey as the '1936 Lake States survey' (Guilkey et al. 1954), referring to the year field work was completed and office work commenced. Field crews worked during harsh winter months in Minnesota to make crossing lakes and swamps more feasible (Gafvert 1938). In all, 15,600 miles of survey lines were run, 125,000 plots were sampled, and over 100 million acres were inventoried (Chase 1964).

Few publications are available describing the specific methods, preliminary calculations and final results of the 1936 USFS Lake States survey. A series of Economic Notes published from 1935-1938 provide summary reports of the final figures including total area, volume, ownership, etc., for the region and each state (USFS 1938). An unpublished Work Plan (USFS 1935)

provides detailed instructions for the field and office work portions of the survey. However, this documentation apparently has not been noted or utilized in any data restoration activities until the current study. The Land Economic Survey (MnDNR 1935), a statewide program to quantify forest resources by county, was developed around the same time using similar methodologies. However, this program was short-lived in Minnesota and data was only available for Hubbard County (Chase 1964). As such, data on Minnesota forests during this critical period of recovery following intensive logging is not readily available. Thus our understanding of how various changes (natural and anthropogenic) may have impacted successional processes in Minnesota's forests is limited.

A primary goal of this study was to make data from the 1936 forest survey available and useable for forestry research. Original records from the first Lake States survey have been stored in St Paul and at national archives throughout the U.S. Until now these forest survey records had not been revisited to determine if they provide truly usable data. The study focused on survey records from Minnesota, and asked two research questions. First, is it possible to locate and interpret eighty-year-old forest inventory records to obtain usable data? Second, are there ways to reconstruct the data so that it is compatible with current FIA data? In addressing these questions, we located many historic forest survey records, identified useful data, and developed methodologies for digitizing and restoring these recovered data to a usable format. This study serves as a reference for the restored data with explanations of methodologies, and definitions for terminology used in the original survey.

2. METHODS

Methods sections 2.1-2.3, and Appendix 1 and 2, provide detailed summaries of the methodologies, terminology and calculations used in the 1936 USFS Lake States forest survey. The purpose was to provide enough detail on the original survey and the digitized data that future applications could be developed using the restored and related database tables.

Methods sections 2.4 and Appendix 3 illustrate several applications of the data, including how we developed methods for making the 1936 data compatible with current FIA data. The database queries developed for these applications include the necessary SQL language.

2.1. Data sources

Original field tally sheets for the 1936 USFS Lake States forest survey (hereafter Survey) were not available, but searches in federal archives throughout the country are ongoing. The records utilized for the study were recovered by one of the authors (Ek) from a St. Paul storage facility (see full list of records in Appendix 1) (Ek 2014). Included was a set of six large (3'x 2'), hard-bound Survey summary books (see Figure 1). Each book contained summary data for one of the six geographic Survey units in Minnesota. Each book in turn contained two sets of tables: (1) Stand and stock tables (Figure 2) that contained average per-acre volume and tree counts, and (2) Summary of volume tables (Figure 3) that contained total volume and area in a unit by cover type, stand size class, and ownership type. In the absence of original plot-level data for Minnesota, the 296 summary tables served as the main source of data. An additional overall summary book was also included and used as a check on the data from the six unit books.

The Survey Work Plan (USFS 1935) provided detailed instructions for both the field and office work components of the Survey. The Work Plan was an unpublished, hard-bound book (approximately 2" thick) likely compiled after the Survey was completed. The Work Plan consists of instructions, correspondence, and special notes regarding various aspects of the Survey in all three states. The Work Plan contained detailed instructions, but the book lacked chapters and page numbers making it difficult to reference. Considerable effort was made to closely read the Work Plan and organize useful information in a more user-friendly format. As part of the study, the Work Plan was digitized using Digital Library Services at the University of Minnesota Libraries.

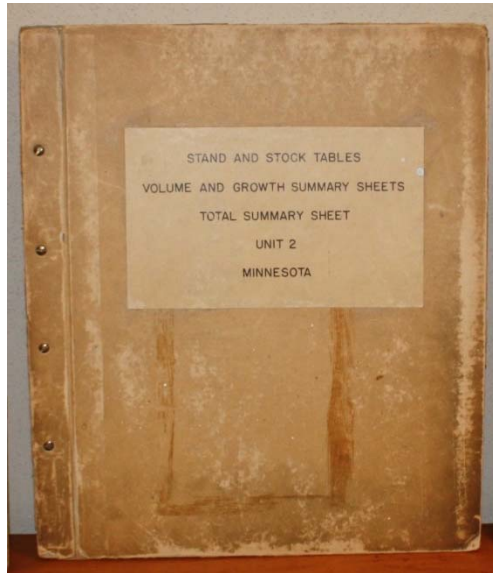


Figure 1. Summary of volume book from 1936 Lake States Survey.

STAND AND STOCK TABLE
UNIT One

LAND TYPE _____ COVER TYPE f SIZE CLASS 0-5

SPECIES	NUMBER OF TREES AND VOLUME PER ACRE (BY SPECIES)								TOTALS	CULL	ANNUAL GROWTH PER ACRE				
	AIP	BLSP	V.P	WP	PB	YO	TO	WP			GROSS FACTOR	GROSS DD FT	GROSS CU FT	NET FACTOR	NET DD FT
KEES	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
KEES	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
T. S.															
KEES	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
T.															
T. S.															
CU FT.															
KEES	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
T.															
T. S.															
CU FT.															
KEES	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
T.															
T. S.															
CU FT.															
KEES	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
T.															
T. S.															
CU FT.															

Figure 2. Example of summary and volume table from 1936 Lake States Survey.

Figure 3. Example of summary and volume table from 1936 Lake States Survey.

2.2. Review of 1936 Lake States Survey methods

2.2.1. Early FIA Survey units and cover types in Minnesota

The Survey was designed to inventory all forested lands in Michigan, Wisconsin and Minnesota. Data was collected by survey units instead of by individual counties. Each state was divided into survey units of four to fifteen million acres. A sketch of the original Survey units was available (USFS 1938) and used in conjunction with county boundaries in Minnesota and ArcMap to provide an instructive map (see Figure 4). Unlike current FIA units, the 1936 survey unit boundaries did not always coincide with county lines. Portions of Aitkin, St. Louis, and Lake counties were split across two or more Survey units. There was no clear explanation as to the reason certain counties were split; it was assumed regions of St. Louis and Lake counties fell within the Superior National Forest in Unit 4.

Unit 4 (Superior) and Unit 6 (Prairie) were not surveyed as part of the Lake States Survey. A separate survey was carried out by the Superior National Forest; final summary data was reconstructed to match the Lake States Survey data. Therefore, per-acre data was not available for unit 4. Unit 6 lacked enough forestland to warrant the resources necessary to carry out a survey in the prairie region. Thus data for unit 6 was based on reconnaissance from unit 5. Although per-acre data was available for unit 6, ownership data was not.

In total, 19,701,700 acres of forestland were surveyed in Minnesota, including 17 forest cover types. Five of those cover types were classified as non-forested: Brush land (2,589,600 acres), grass land (667,700 acres), wooded pasture (565,800 acres), marsh land (300,000 acres) and shelterbelt (86,300 acres), and accounted for 4,209,400 acres across Minnesota. Non-forest cover types were not included in this study. Instead, focus was placed on the remaining 15,492,300 acres of forestland cover types.

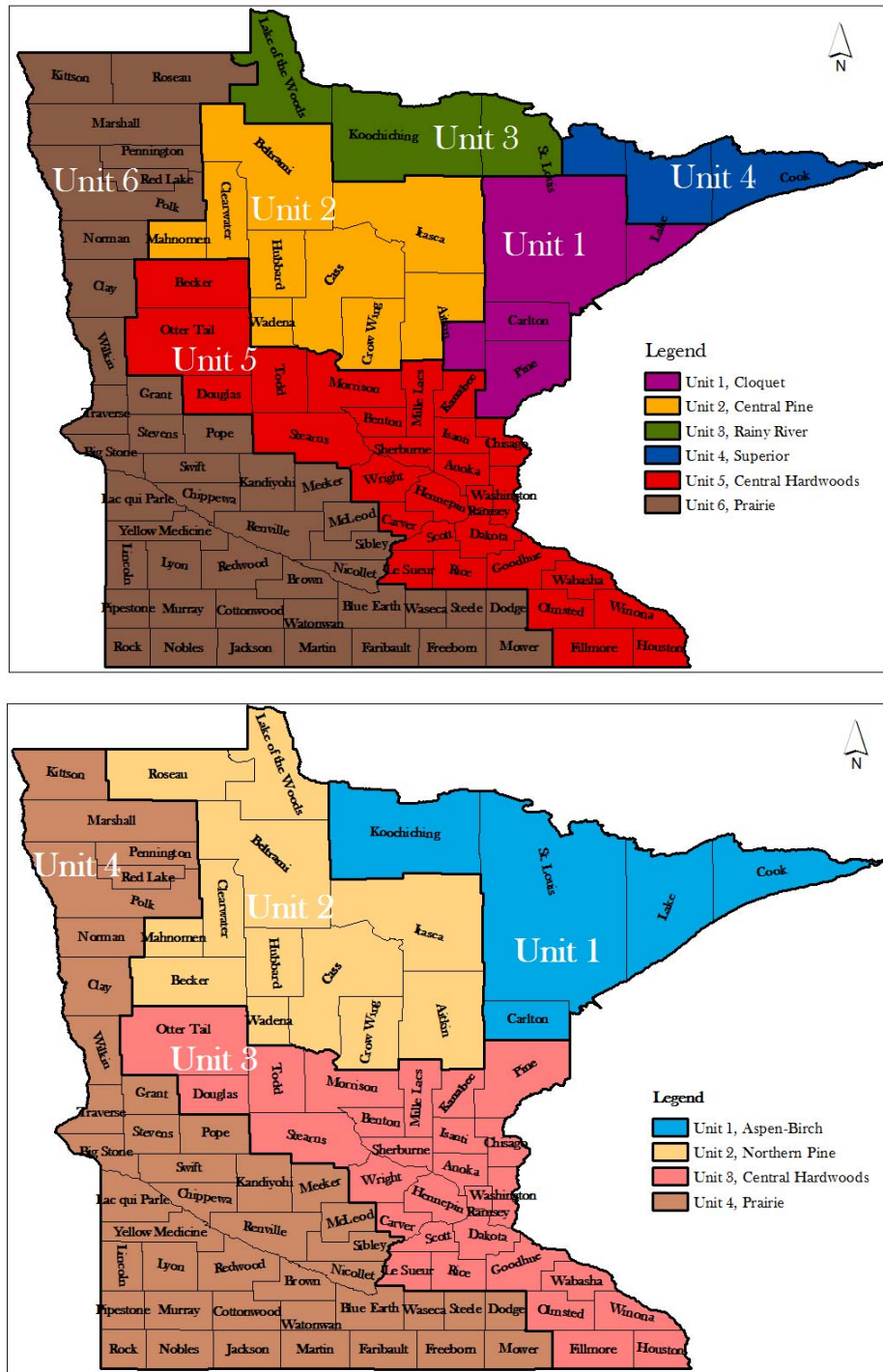


Figure 4. FIA Survey unit and county boundaries for 1936 (top) and 2014 (bottom).

2.2.2. Survey design and field work summary

Survey sample plots consisted of three circular concentric plots totaling 1/5th-acre (see Figure 5). Sample plots were placed at ten chain intervals along east-west transect lines (see Figure 6). The inventory was intended to sample all forested areas in the three states. Trees greater than one-inch diameter were tallied by species and two-inch diameter classes. Plot classifications such as cover type, stand size class, and ownership were designated. For each well-stocked plot, a sample tree of average diameter and species was measured for DBH and height. Table 1 provides a quick reference and example of each field measurement, including Appendices where more detail is provided. In all, measurements were collected for twenty species, thirteen forest cover types, four non-forest cover types, four stand size classes, and six ownership types.

Table 1. Summary of field measurements.

	Field measurements	Definition	Example measurement	Appendix
individual tree	DBH	2-inch DBH classes	2" = 1.0-2.9" DBH 4" = 3.0-4.9" DBH etc.	A1.2
	species	20 species	aspen jack pine etc.	A1.3
plot	cover type	13 forest; 4 non-forest	aspen cover (forest) grassland cover (non-forest) etc.	A1.4
	stand size class	4 size classes	new growth (2-4" DBH) pole size (6-8" DBH) etc.	A1.5
	sample tree volume	1 tree per plot of average diameter and species	DBH height etc.	A1.6
	ownership	6 groups	small private large private etc.	A1.7

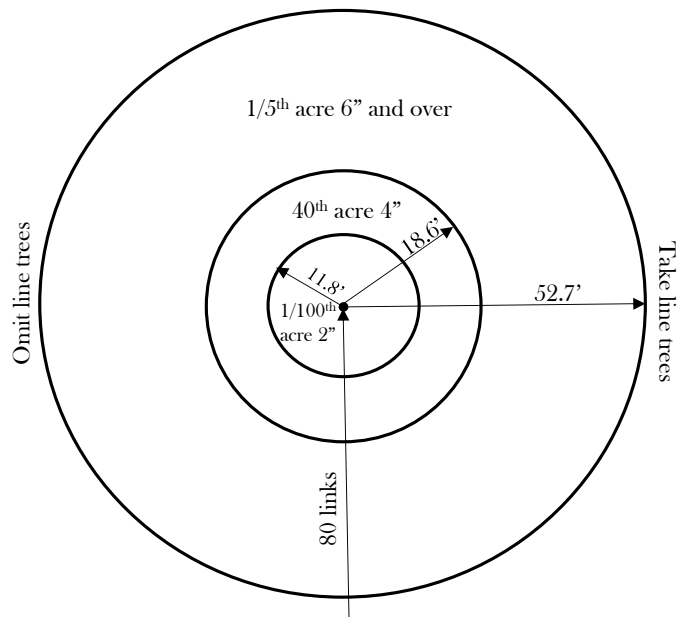


Figure 5. Sample plot design for 1936 Lake States Survey; adapted from Survey Work Plan (USFS, 1935).

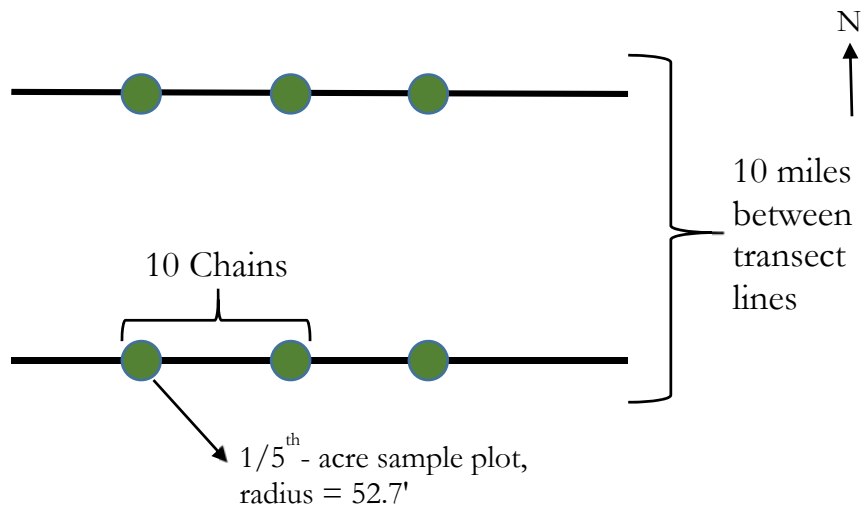


Figure 6. Lake States Survey strip survey design for 1936; adapted from Survey Work Plan and (LaBau, 2007).

2.2.3. Volume of summary books and office work summary

Stand and Stock tables—per acre estimates

A separate stand and stock table for each forest cover type and stand size class combination in a unit provided per-acre estimates for number of trees and volume for each species and diameter class¹. Stand and stock tables were available for units 1, 2, 3, 5, 6. As mentioned previously, stand and stock tables did not exist for unit 4 because of alternative survey methods. In total, 176 stand and stock tables were available. See Appendix A1.8 for an example table.

Calculating trees per acre

Average trees per acre was a preliminary calculation whereby the total number of trees from plot tally sheets in each species, DBH, cover type and size class combination were reduced to per-acre values using an acreage reduction factor.

Calculating volume per acre

According to the Work Plan, estimating volume of each tally tree was not feasible. Instead, local volume tables were generated using sample tree measurements for board foot, pulpwood cubic foot, and total cubic foot of all sample trees. Local volume tables provided net volume for an average tree in each unit, size class, species and DBH class. See Appendix A1.7 for more details on generating volume tables.

Local volume table figures were multiplied by trees per acre (from the stand and stock tables) to generate average net volumes per acre. Board foot volume per acre was calculated using Scribner log scale for merchantable-sized trees (i.e. trees greater than 9.0" DBH). Pulpwood cubic foot volume per acre was calculated for six species (black spruce, white spruce, balsam fir, jack pine, tamarack, aspen) for pulpwood-grade trees greater than 6" DBH. Cubic foot volume per acre was calculated for all trees greater than 5.0" DBH.

Summary of Volume tables—total volume, area and ownership estimates

The second set of tables in each summary book contained volume summary tables with total volume for each species and product type, and total area in a unit for each cover type and size class. Area and volume by ownership type was also included. One-hundred-twenty summary tables were available across six survey units. See Appendix A1.8 for examples of the following calculations.

Calculating area

Forestland area was determined during Survey office work by dividing net land area of each unit between forest cover types and size classes in proportion to the distribution of sample plots for each. Data on number of plots was not available, so area represented by each plot could not be determined. Forestland areas for each cover type and size class combination were entered into the summary of volume table. Ownership area was also based on the distribution of sample plots for each ownership group in a given unit and cover type.

¹ Summary tables contained additional data not included in this report, such as cedar volume, volume by ownership type, and annual per-acre gross volume growth estimates. These data have been digitized and are available.

Calculating total volume

Stand and stock tables and summary of volume tables were interrelated. Per-acre volume totals from the stand and stock tables were multiplied by area totals in the volume tables; the product was total volume. Unit volume totals were available for board foot of merchantable trees, cubic foot volume of all trees, and cordwood volume² for six pulpwood species.

2.3. Digitizing summary tables and quality control

Microsoft Excel spreadsheet templates were designed to closely mimic the original format of the 1936 tables. Data were entered manually by three personnel, and spreadsheets were then reformatted for querying in Microsoft Access. Queries were developed using SQL language. Databases were subsequently uploaded to an online resource for public use.

Quality control

See Appendix 2.1 for comparisons of digitized data with published figures found in *Economic Notes* (USFS 1938). The purpose of comparing the figures was to determine whether the digitized data was representative of the final Survey results. In most cases, the digitized data closely matched published figures (within 1%). In the case of board foot volume, published figures were based on International 1/4-inch log rule. Saw timber volume in summary books was based on Scribner log rule, underestimating published totals by 18.60%. According to a note in the *Economic Notes 10* (USFS 1938, p.52), figures were converted to International 1/4-inch volumes for publishing—about 18% higher than Scribner—because it more closely reflected output from sawmills.

2.4. Applications of 1936 Survey data

A main objective of the study was to determine whether historic data could be made compatible with recent FIA data. Given that objective, three applications using the historic data were attempted (see sections 2.4.1, 2.4.2 and 2.4.3). As a first step for statewide resolution, using totals from the summary of volume tables, compatibility between historic and current FIA conventions was accomplished by re-naming and re-categorizing attributes. At a statewide resolution, using per-acre totals from the stand and stock tables, total forest area for the state was recalculated to omit areas made up by units 4 and 6 for both historic and current surveys. At finer detail, such as at the survey unit level, historic data had to be re-summarized or re-distributed to match current conventions. This step introduced the most opportunity for error.

Where available, statewide data for 1936, 1977, and 2014 were compared. FIA data for 1977 and 2014 were queried using *EVALIDator 1.6.0.03* (Miles 2014; O'Connell et al. 2014). Appendix 3 provides a full list of tables and attributes used to generate queries. Digitized data from the 1936 Survey was queried using SQL searches in Microsoft Access.

² Pulpwood volume was expressed in cubic foot for the stand and stock tables and then converted to total cubic foot volume in the summary of volume tables. In addition, pulpwood cubic foot volume was converted to cordwood in the volume summary tables. The cordwood conversion was likely 78.3 cubic feet per cord of 16' logs in 4"+ diameter classes. The precise conversion was not mentioned in the Work Plan, but was mentioned in a USFS publication around the time of the survey for balsam fir (Zon, 1914).

2.4.1. Total statewide comparisons using multiple inventory years

Statewide comparisons by area of cover type

To compare cover type area for the three inventory years, cover types were re-organized. For 2014 and 1977 inventories, Minnesota Department of Natural Resources Cooperative Stand Assessment cover types (MnDNR 2006) were selected as the forest type attribute in *EVALIDator*. In some cases, cover types for more recent inventories had to be combined to match conventions in 1936, and *visa versa*. Table 2 provides a list of cover type combinations across the three inventory years. For instance, aspen, birch, and balsam poplar stands were designated as aspen-birch cover in 1936 (see description in Table A1.5). These three forest types were combined for 1977 and 2014.

Table 2. Forest cover types across inventory years.

2014 and 1977 Forest Types MnDNR	1936 Cover Type
Jack pine	Jack pine
Red pine	Norway pine
Eastern white pine	Eastern white pine
Balsam fir	Spruce-fir
White spruce	
Black spruce	Black spruce
Tamarack	Tamarack
Northern white-cedar	Northern White Cedar
Oak	Oak
	Scrub oak
Northern hardwoods	Northern hardwoods
Lowland hardwoods	Bottomland and swamp hardwoods
Aspen	Aspen
Birch	
Balsam poplar	
Other/non-stocked:	
Eastern red cedar	Non-productive swamp
Other softwoods	
Cottonwood/willow	
Other	
Non-forest (not included):	
	Grassland
	Brush land
	Marsh or Bog
	Wooded pasture
	Shelterbelt

Statewide comparisons by total area of stand size class

Stand size classes were re-categorized to three classes to match 2014 conventions (see Table 3). Old-growth and second-growth size classes from the 1936 Survey were combined to into one size class for large trees.

Table 3. Stand size class designation across forest inventory years.

1936			2014	
Code	Name	Diameter range	Name	Diameter range
15+	Old-growth	Trees >15.0"	Large	Trees >11"
9-15	Second-growth	Trees 9.0-14.9"		
3-9	Pole size	Trees 5.0-8.9"	Medium	Trees 5-10.9"
0-5	New growth	Trees 1-4.9"	Small	Trees 1-4.9"

Statewide comparisons of total board foot volume

Total board foot comparisons were made for merchantable-sized trees in 1936 and 2014. Although a merchantable log was defined as 16' in length in both surveys, sawlog diameters differed. For instance, in 1936, a merchantable log had a minimum DBH of 9" inches and a minimum top dib of 8" for hardwoods. FIA protocol in 2014 considered any hardwood tree greater than 11" DBH and 9" dib to be merchantable. Inconsistencies across the two years also existed for softwoods (see Table 4). Overcoming sawlog diameter discrepancies was not possible as volumes were totaled across two-inch diameter classes in the 1936 Survey.

In 1936, saw log volume estimates were based on Scribner log rule, but 2014 FIA volume data was based on the International 1/4-inch rule. Using the modal percent difference from the six units reported in *Economic Notes 10* (USFS 1938), Scribner volume data for 1936 was converted to International 1/4-inch volume estimates using a conversion factor of 18.6% for all species (see Appendix A2.3).

Table 4. Saw log definitions across forest inventory years.

Species	1936		2014	
	Minimum DBH	Minimum top DIB	Minimum DBH	Minimum top DIA
hardwood	9"	8"	11"	9"
conifer	9"	6"	9"	7"

Total cordwood volume of pulpwood

Total cordwood volume of six major pulpwood species was calculated for the 1936 Survey. The six pulpwood species were aspen, balsam fir, black spruce, jack pine, tamarack and white spruce. See Appendix A1.7 for the definition of a cord of wood in 1936. Later FIA inventories did not collect pulpwood volume estimates; therefore, comparisons were not possible for pulpwood between inventory years.

Total cubic foot volume comparisons

In 1936, total forest volume, including board foot and pulpwood, was estimated in cubic foot for all trees greater than 5" DBH. This convention was similar for more recent FIA inventories. Data for cubic foot volume for all trees greater than 5" DBH was available for the 2014 FIA inventory.

Statewide ownership comparisons

The 1936 Survey categorized ownership type into eight categories (see Appendix A1.6), but there were only four categories in the 2014 FIA data. The four ownership groups for 2014 were federal, state, county and private. The 1936 totals were re-categorized into these four groups by combining reserved and unreserved public lands, and small and large private ownership into one group. Unit 6 ownership data was not available from 1936. Since unit 6 was predominately prairie land, it was assumed the 1,416,800 acres of forestland in unit 6 were either privately or county owned. Using 0.17% (the percentage of the remainder of land in county and municipal ownership in the state), unit 4 forestland area was split into county ownership (2,478 acre) and the remainder in private ownership (1,414,322 acres).

Table 5. Ownership groups across forest inventory years.

2014 Ownership Group	1936 Ownership Group
Federal	Federal reserved
	Federal unreserved
	Indian
State	State reserved
	State unreserved
County and municipal	County and municipal
Private	Small private
	Large private

2.4.2. Per-acre statewide comparisons

Statewide totals for average trees-per-acre were compared for 1936 and 2014 inventories by size class and cover type. Due to missing per-acre tree and volume data for unit 4 and much of unit 6, the comparison required recalculating total forest area for both inventory years to exclude the area comprised by unit 4. The total forested area for unit 4 in 1936—1,951,500 acres—was subtracted from the state total. Forested area in Minnesota in 1936 went from 15,492,300 acres to 13,540,800 acres.

For the 2014 inventory, trees-per-acre was calculated using total tree counts divided by area of each size class and cover type combination, less an area and tree count representative of 1936 unit 4. From a sketch of 1936 Survey units (USFS 1938), it was estimated that about 25% of St. Louis, 66% of Lake, and 100% of Cook Counties fell within unit 4 boundaries (see Table 6). Data for 2014 was adjusted by these county percentages. For instance, tree counts and forested area in Cook County were excluded altogether, and data for St. Louis and Lake Counties were partially excluded.

Per-acre estimates were originally calculated for each size class and cover type combination at the unit scale. For statewide comparisons, it was necessary to recalculate the 1936 Survey for trees per acre using total number of trees and total area of each size class and cover type combination. This was similar to how trees-per-acre was calculated using the 2014 data above.

Table 6. County areas in Survey unit 4 for 1936.

County	% of County in 1936 unit 4	% of County data included in 2014 per-acre calculations
Cook	100	0
Lake	66	34
St. Louis	20	80

Trees-per-acre was also compared at the statewide level for white pine stands, including species and DBH. The white pine cover type was chosen based on the assumption that this cover type was assigned similarly across both inventory years, thus minimizing type definition differences. The four most common species in white pine cover in 1936 were aspen, balsam fir, paper birch, and white pine. The two-inch DBH classes were grouped into three DBH ranges (see Table 7).

Table 7. Diameter range classes for summarizing trees-per-acre by species.

Diameter class	Diameter range label
small	2-8"
medium	10-14"
large	>16"

2.4.3. Redistributing historic data across current FIA unit boundaries and quality control

In some instances, complex changes were necessary to make data compatible, most notably for the issue of unit boundaries. Data from the 1936 Survey was organized by six geographic units as opposed to four units in 2014 (see Figure 4). This required a redefinition of boundaries from six units to four. The procedure required several steps and assumptions. A first step involved the development of methods for evenly re-proportioning area of forestland in a unit by *all* the counties making up the unit. The following is an example:

The total area of Mille Lacs County is about 336,000 acres of total land (both forested and non-forested), which is equivalent to about 3% of the 11,800,000 acres of total land making up 1936 unit 5. It was assumed that 3.0% of the 2,300,000 acres of forestland in unit 5, or about 71,000 acres, existed in Mille Lacs County.

To generate the proportions of a unit represented by each county, it was then assumed that 1) all forests were evenly distributed across the unit, and 2) all forests were evenly distributed across the counties in which they were proportioned. This was a crude assumption due to the variability of forest cover and area within any given unit. However, with no additional information, proportionate distribution of the forest was the only reasonable assumption.

Counties were assigned both 1936 and 2014 FIA units. Once units were re-proportioned to individual counties, they were reorganized using the 2014 FIA unit id, and new 2014 unit totals

were calculated using 1936 data. For instance, Lake Mille Lacs County moved from unit 5 in 1936 to unit 3 in 2014.

Quality control

The 1935 Land Economic Survey (MnDNR 1935) provided a means of comparing re-proportioned county totals described above with Hubbard County to determine how the assumptions and methods compared to actual county totals. Appendix A2.2 provides a comparison of total forest area by four stand size classes between the two surveys. In all but the old-growth size class, the re-proportioned county data using USFS data underestimated the Land Economic Survey county totals between 22-25%. The old-growth totals overestimated the Land Economic Survey by 11%. The total forested area of Hubbard County in the re-proportioned data was 13% less than the Land Economic Survey. This is an indication of the error involved with the assumption of proportionate distribution of forest area across counties.

3. RESULTS

3.1. Total statewide comparisons for multiple inventory years

3.1.1. Comparison: Total forest cover type area

Figures 7a and b provide comparisons of area by forest cover types (with and without aspen, respectively) for 1936, 1977, and 2014 FIA inventories. Table 8 provides acres of forest types and total acres for each inventory year. The overall forest area for the three inventories was 15,492,300 acres in 1936, 16,537,380 acres in 1977, and 17,260,177 acres in 2014.

Aspen dominated forest area in all three inventory years, with approximately 7 million acres, roughly 40% of the total forestland area, in all three years. Black spruce was also a common forest type in all three years. Jack pine cover dwindled across the three periods, while oak, Northern hardwoods, and red pine, among others, all increased.

3.1.2. Comparison: Total stand size class area

Comparisons of stand size class for 1936 and 2014 are shown in Figure 8; area by stand size class is listed in Table 9. The most common stand size class in 1936 was small diameter stands, with 9,366,900 acres across the state, followed by 4,558,900 acres of pole-size stands and 1,566,500 acres of stands dominated by large-diameter trees. In 2014, area by three size classes were fairly evenly distributed. Small, medium and large size classes were 6,114,147 acres, 6,191,578 acres, and 4,954,453 acres, respectively.

3.1.3. Comparison: Total volume—board foot, cubic foot, pulpwood cords

The shift in size class distributions between 1936 and 2014 was also reflected in volume estimates for the two inventories. Board foot volume (Figure 9) of merchantable timber in 2014 was over three times greater than in 1936, with totals of 12.4 and 45.3 billion board feet, respectively. The volume of softwood species was slightly greater than hardwoods in 1936; in 2014, volume of hardwood species was greatest, with 27 billion board feet statewide.

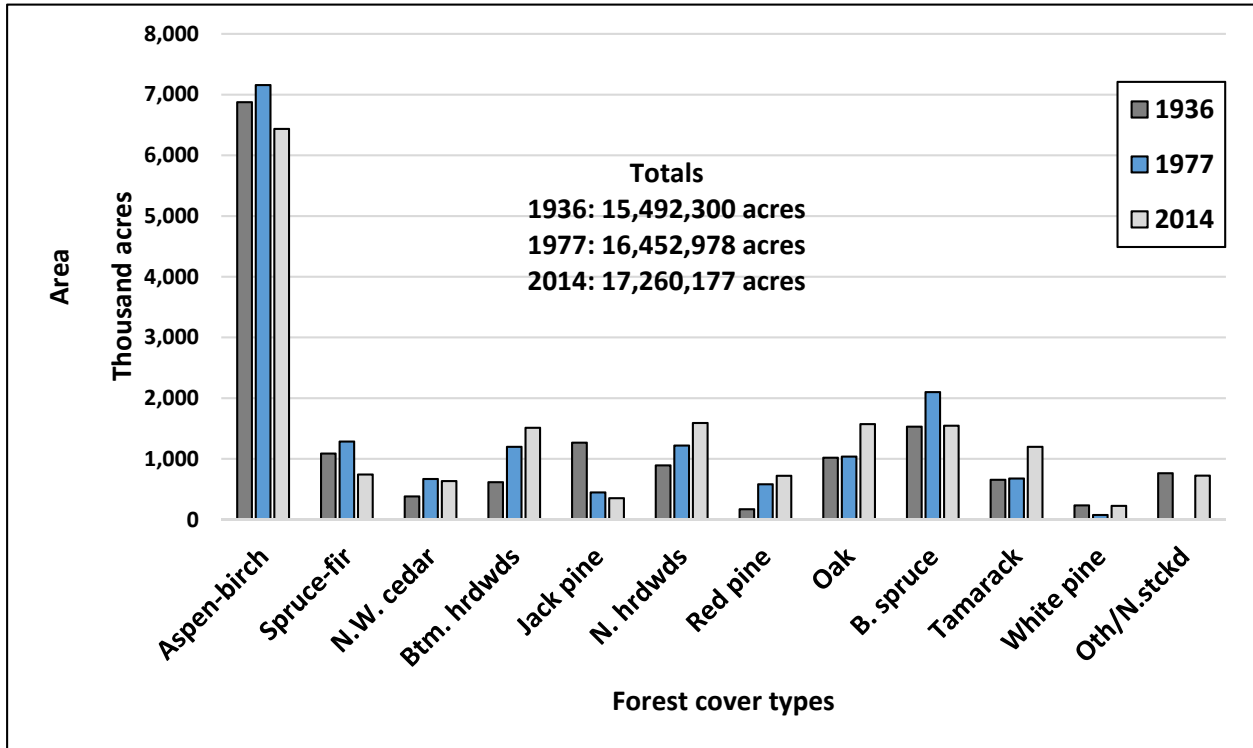


Figure 7a. Area of forestland by forest cover type.

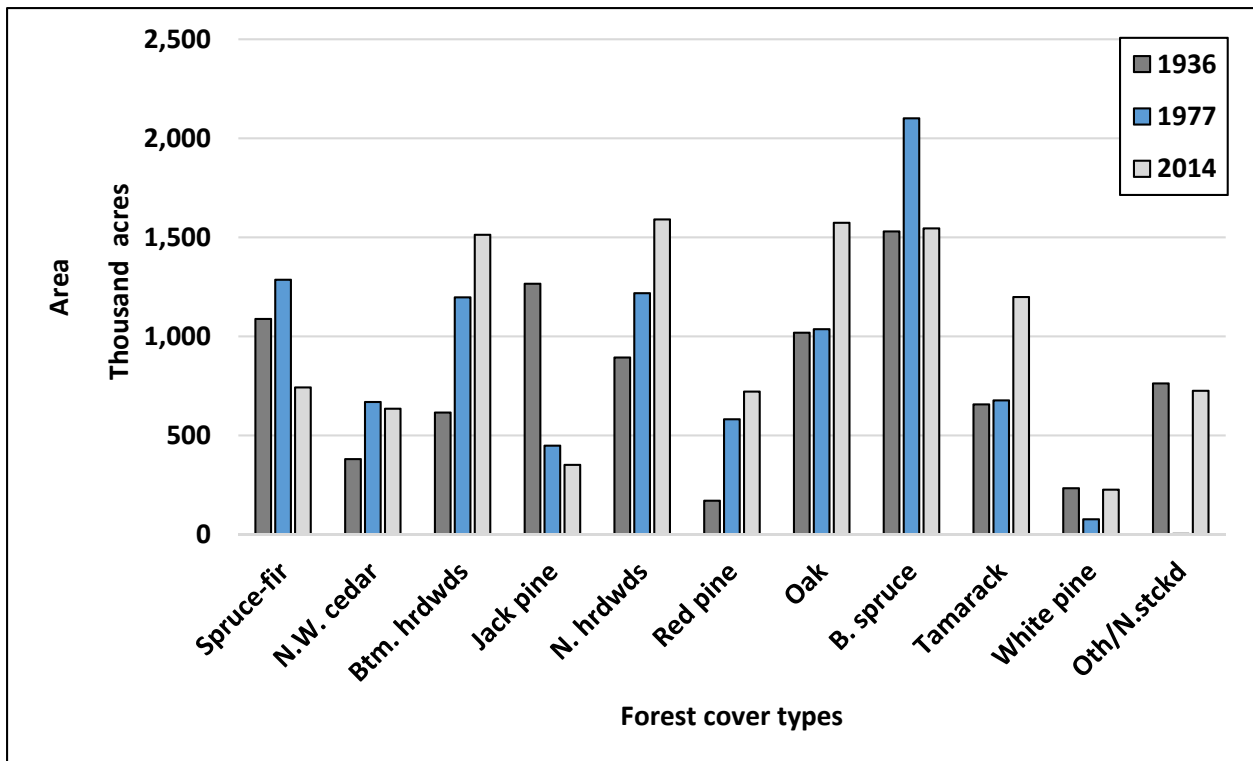


Figure 7b. Area of forestland by forest cover type, excluding aspen.

3.1.3. Comparison: Total volume—board foot, cubic foot, pulpwood cords

The shift in size class distributions between 1936 and 2014 was also reflected in volume estimates for the two inventories. Board foot volume (Figure 9) of merchantable timber in 2014 was over three times greater than volume totals in 1936, with totals equaling 12.4 and 45.3 billion board feet, respectively. Volume of softwood species was slightly greater than hardwoods in 1936; in 2014, volume of hardwood species was greatest, with 27 billion board feet statewide.

Total cubic foot volume by species was also compared between two inventory years (Figure 10); cubic foot by cover type is listed in Table 10. Cubic foot volume of aspen species was greatest in both years, but much greater in 2014 than 1936, with totals around 4.4 billion and 1.6 billion cubic feet, respectively. Similar to cover type area, the volume of oaks and other hardwoods increased greatly between the two years, along with red pine. Jack pine volume decreased, but all other species increased in volume from 1936 to 2014.

The total cordwood volume of six major species used for pulpwood (aspen, balsam fir, black spruce, jack pine, tamarack, and white spruce) is shown in Figure 11. In 1936, the Superior National Forest (unit 4) contained the most pulpwood, over 7 million cords. The other three northern units (units 1, 2, and 3) comprised the second-most pulpwood volume, with units 5 and 6 contributing but a small proportion of total pulpwood. Table 11 lists cordwood volume totals by species and unit. In 1936, jack pine and aspen species provided the highest volume of cordwood; 5.4 and 4.2 million cords, respectively. In total, there were 18.25 million cords of pulpwood in 1936.

Table 8. Area of forestland by forest type across multiple inventory years.

Forest Type	1936	1977	2014
	(acres)		
Aspen-birch	6,875,300	7,157,014	6,434,322
Spruce-fir	1,088,300	1,286,046	742,952
Northern white cedar	380,600	668,720	635,336
Bottomland hardwoods	616,100	1,197,491	1,513,483
Jack pine	1,266,000	448,675	351,962
Northern hardwoods	893,600	1,218,646	1,591,054
Red pine	170,500	581,449	721,609
Oak	1,018,400	1,036,569	1,573,699
B. spruce	1,529,800	2,100,800	1,545,309
Tamarack	656,900	677,057	1,198,742
White pine	233,700	76,711	226,313
Other/Non-stocked	763,100	3,800	725,396
Total	15,492,300	16,452,978	17,260,177

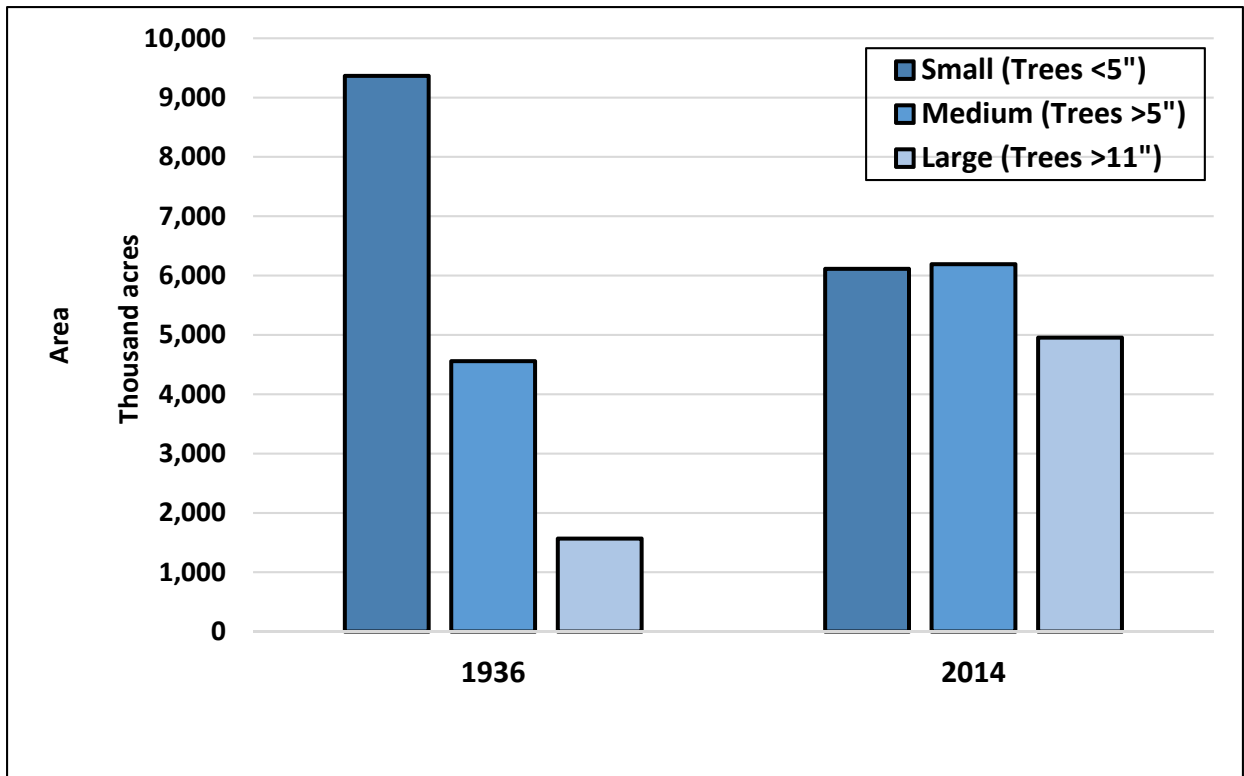


Figure 8. Area by stand size class distribution across two inventory years.

Table 9. Area of stand size class distribution across two inventory years.

Stand Size Class (DBH range)	1936	2014
	(acres)	
Small (Trees <5")	9,366,900	6,114,147
Medium (Trees >5")	4,558,900	6,191,578
Large (Trees >11")	1,566,500	4,954,453
Total	15,492,300	17,260,178

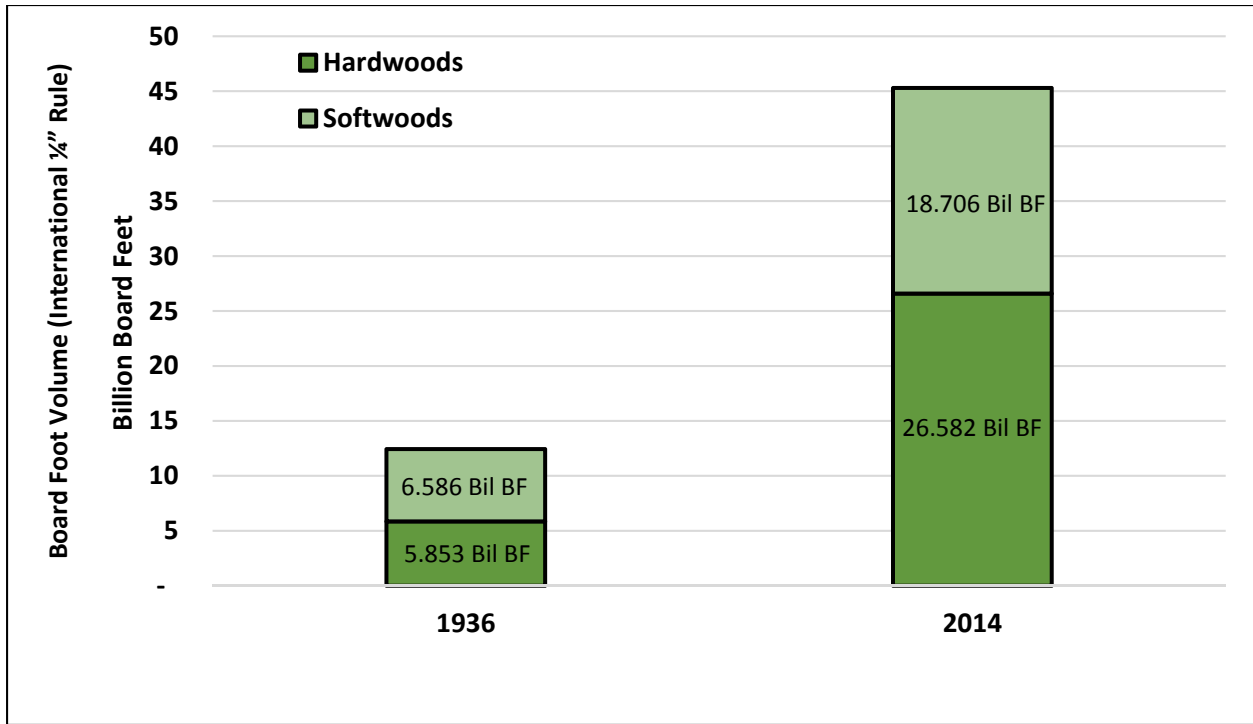


Figure 9. Merchantable volume for hardwood and softwood types, 1936 vs 2014.

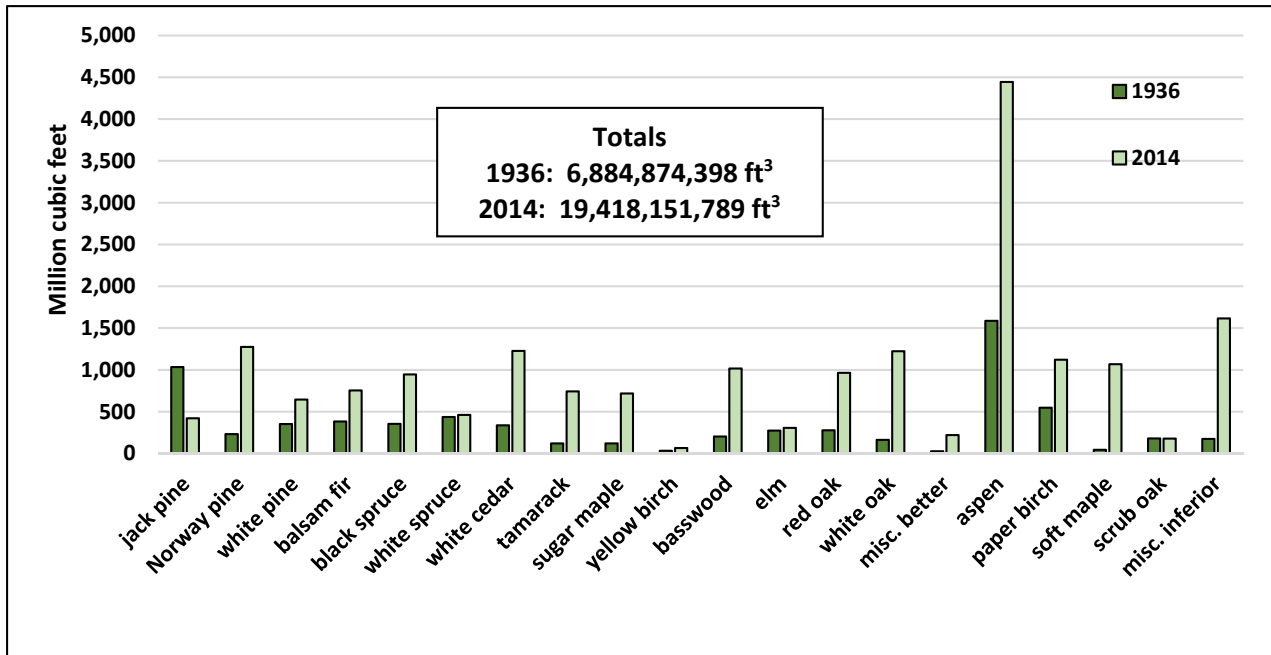


Figure 10. Total cubic foot volume by species across two inventory years.

Table 10. Volume of total cubic volume by species across two inventory years.

Species group	1936	2014	Species group	1936	2014
	cubic foot			cubic foot	
jack pine	1,034,451,369	421,167,044	red oak	277,401,400	964,869,729
Norway pine	231,301,281	1,274,498,584	white oak	162,292,500	1,222,871,787
white pine	352,165,791	645,694,579	misc. better hardwoods	26,390,200	221,538,587
balsam fir	383,523,000	754,772,678	aspen	1,587,602,880	4,445,148,582
black spruce	355,538,020	946,200,441	paper birch	547,287,200	1,122,273,281
white spruce	436,743,135	461,018,030	soft maple	44,717,000	1,068,041,276
white cedar	336,563,700	1,226,671,184	scrub oak	180,740,900	177,683,429
tamarack	121,000,636	742,619,459	misc. inferior hardwoods	175,325,100	1,614,850,280
sugar maple	121,263,508	719,113,502			
yellow birch	33,340,700	65,770,543	Total	6,884,874,398	19,418,151,789
basswood	202,867,278	1,016,940,837			
elm	274,358,800	306,407,957			

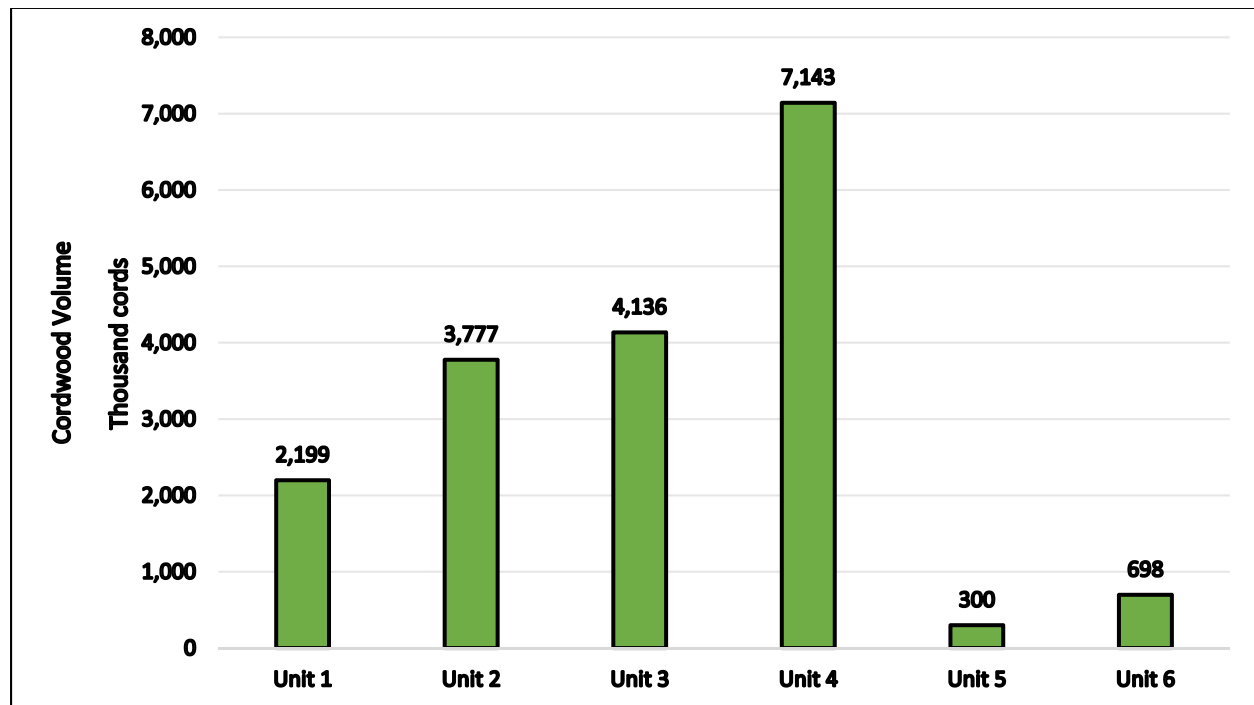


Figure 11. Cordwood volume for six pulpwood species in 1936 survey units.

Table 11. Cordwood volume for six species in 1936 survey units.

Species	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Total
Aspen	593,000	1,567,000	650,588	738,000	197,049	476,540	4,222,178
Balsam fir	751,061	574,000	694,157	484,000	22,441	25,581	2,551,240
Black spruce	216,911	292,000	1,748,401	0	14,605	142,159	2,414,075
Jack pine	546,737	1,144,000	441,607	3,259,000	2,255	11,876	5,405,476
Tamarack	3,563	95,000	436,837	9,000	61,296	34,646	640,343
White spruce	87,753	105,000	164,451	2,653,000	2,425	6,980	3,019,609
Total	2,199,025	3,777,000	4,136,042	7,143,000	300,070	697,783	18,252,920

3.1.4. Comparison: Area by ownership type

Figure 12 compares ownership groups between 1936 and 2014; Table 12 lists area by ownership group for both inventory years. Public ownership, most notably municipal and county-owned land, increased from a total of 24,100 acres in 1936 to 2.6 million acres in 2014. We note the 1930s were a period of considerable tax forfeiture of private land. Private ownership decreased from 11,184,500 acres in 1936 to 7,806,457 acres in 2014.

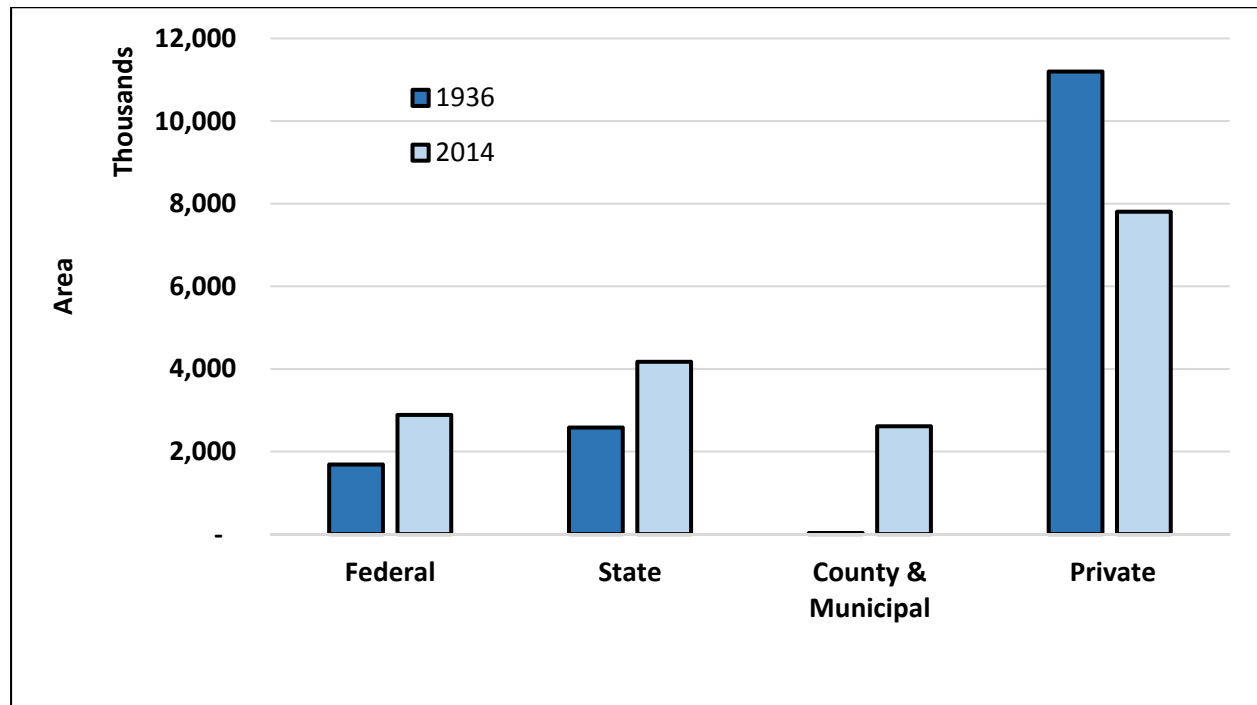


Figure 12. Forestland area by ownership group across two inventory years.

Table 12. Forestland area by ownership group across two inventory years³.

Ownership Group	1936	2014
	(acres)	
Federal	1,684,500	2,885,441
State	2,582,400	4,174,438
County and Municipal	26,578	2,610,977
Private	11,198,822	7,806,457
Total	15,492,300	17,477,313

³ Ownership data was not available for the prairieland region (Unit 6 in 1936). The 1,416,800 acres of forestland in unit 6 was split between county and private ownership. From unit 6 forestland area, 2,478 acres were added to the county and municipal ownership type based on the statewide percentage of land in county ownership (0.17%). The remainder of unit 6 forestland, 1,414,322 acres, were added to the private ownership group.

3.2. Per-acre statewide comparisons

Trees-per-acre estimates by forest cover type were compared across two inventory years (see Figure 13). In 1936, stands rarely exceeded 750 trees-per-acre (all species), except in the large diameter stand size class. Trees-per-acre in aspen stands in 1936 were among the lowest in the state in small and medium size classes. Overall, trees-per-acre in 1936 were higher in pine species than hardwoods, but forests were relatively poorly stocked throughout the state. In 2014, cedar was an important species across all three size classes. However, the high per acre count for cedar includes all tree species—a majority of which were small balsam fir. In addition, trees-per-acre in 2014 were highest in aspen and black spruce cover types.

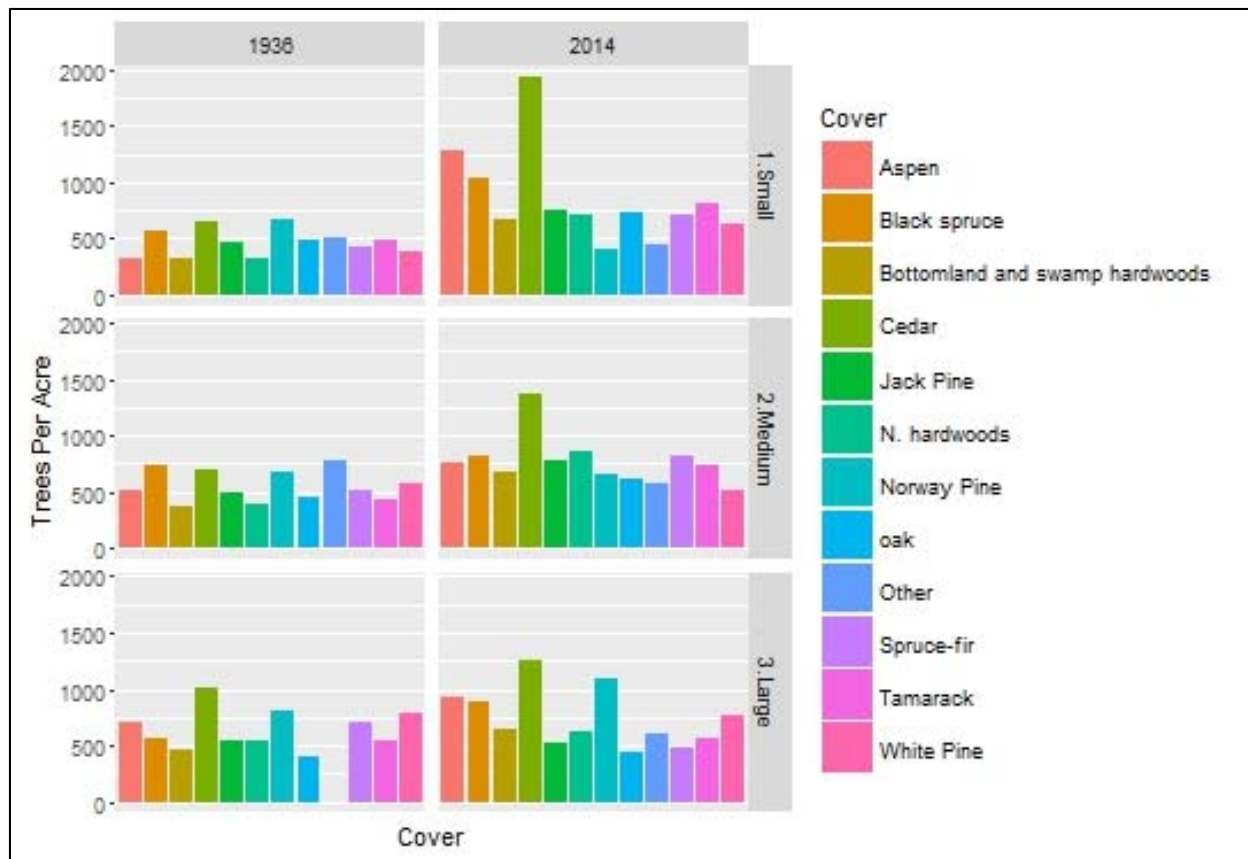


Figure 13. Trees per acre by cover type and stand size classes for 1936 vs 2014.⁴

Trees per acre estimates were also compared for four important species in white pine stands across three diameter classes and three size classes (see Figure 14). Species and diameter composition shifted across the three size classes. Very few large trees existed in small and medium size classes, with white pine, aspen and paper birch dominating species type. In the large size class, white pine made up most of the larger diameter trees, but balsam fir became most common in the small diameter range in the larger size class.

⁴ Excludes 2 million acres of forested land in 1936 unit 4. Total adjusted forested area for 1936 and 2014 inventories were 13,540,800 and 15,308,677 acres, respectively

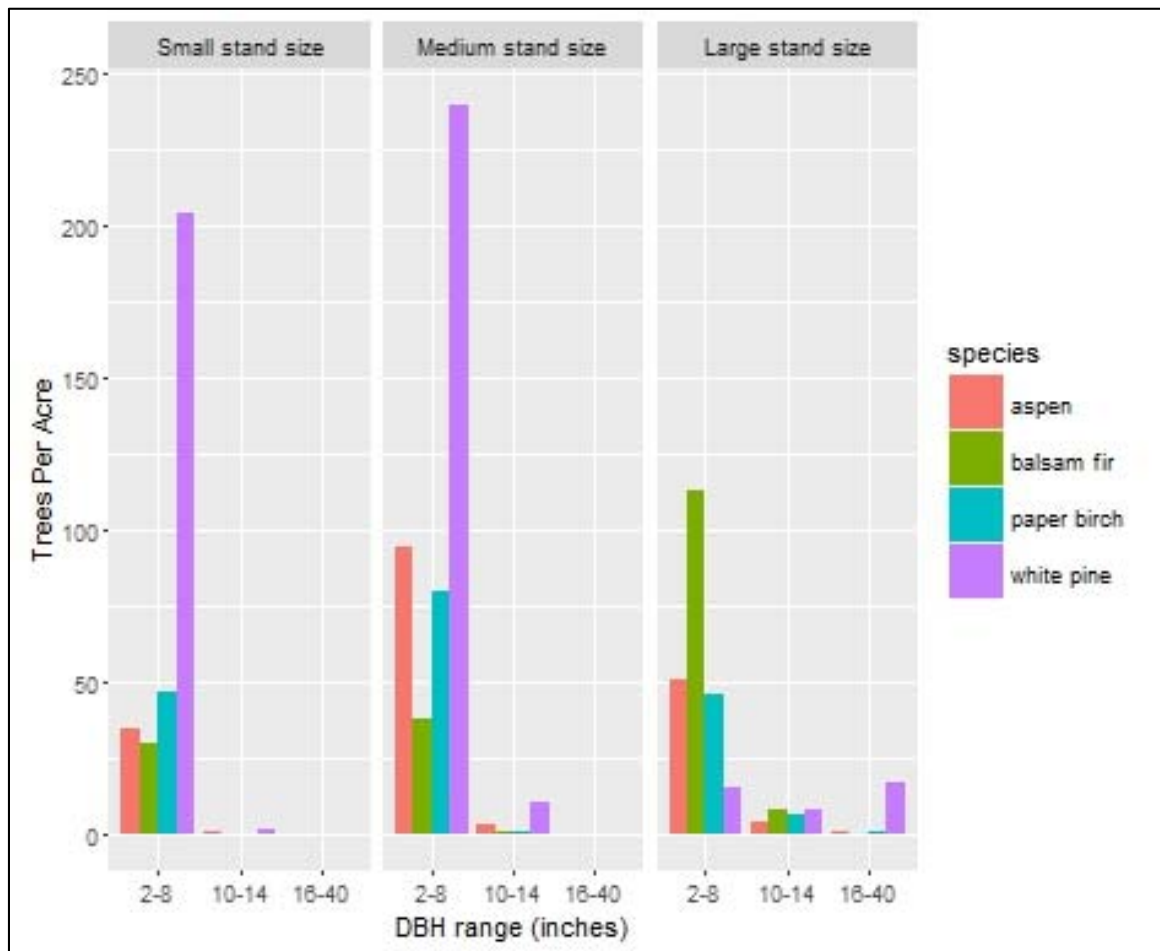


Figure 14. Trees per acre by species, DBH and stand size class in white pine stands.⁵

⁵ Excludes 2 million acres of forested land in 1936 unit 4. Total adjusted forested area for 1936 and 2014 inventories were 13,540,800 and 15,308,677 acres, respectively

3.3. Unit comparisons using redistributed FIA unit boundaries

Figure 15 provides a comparison of total forest area across two inventory years with re-proportioned unit totals so that both inventory years are represented by four survey units. Total area of forestland from 1936 to 2014 increased in units 1, 2, and 3. Unit 4 forestland decreased from 1936 to 2014.

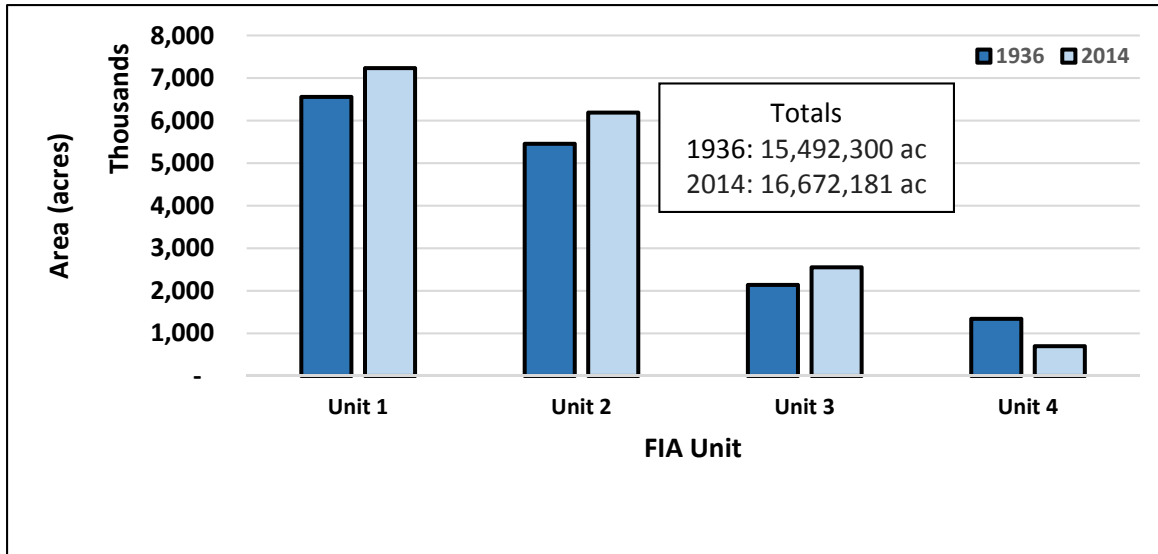


Figure 15. Forest area by adjusted unit boundaries.

4. DISCUSSION

It was possible to restore historic data from the 1936 Survey using available summary books. However, restored data was most complete and compatible with current FIA data when compared statewide. Restored data closely matched final figures published at the time of the survey for area of size class, cover, and volume in each unit (USFS 1938). This conclusion was despite likely differences in naming conventions and other survey methodologies across inventory years.

At smaller scales, limitations in the data made meaningful comparisons more difficult. Without number of plots and thus the area represented by each plot, it was not feasible to accurately deduce per acre estimates for unit 4 using per acre volume and tree counts from nearby units. Furthermore, without number of sample plots it was not possible to determine the measure of variability of the dataset within Survey units.

When county boundaries were redistributed from 1936 FIA units to 2014 FIA units and data was re-proportioned, restored data was less accurate than at the unit level due to assumptions that cover types, size classes, and species locations were evenly distributed across each respective FIA unit. When compared to final figures from a county survey at the time, restored data both underestimated and overestimated published figures by more than 10% (MnDNR 1935).

Despite its limitations, the dataset offers a meaningful resource: a large systematic sample of the entire forested regions of Minnesota following a period of high extraction and preceding an era of rapid forest growth. Not only does the dataset offer insight into the conditions of forests over eighty years ago, but it provides opportunity for observing shifts in species composition and forest dynamics.

4.1. Total statewide comparisons

Comparisons generated in the study demonstrated the types of summary comparisons that could be made using the restored data. Statewide total comparisons across two or three inventory years showed clear changes in forest conditions during an eighty-year period. Firstly, total forest area expanded by 2 million acres. It was important to note that over four-million acres of lands inventoried in the Survey consisted of then non-forested covers such as brush land and grass land that were omitted from the analysis. This seemed compatible with current FIA protocol, which also omits such non-forested cover from “forest types”

Minnesota forests in 1936 were highly cut-over, with little mature and older stands remaining. The state was dominated by large areas of newly developing forests leading to the often noted “wall of wood” coming forward over the subsequent decades. On a whole, the state resembled a largely even-aged forest, with three distinct age classes descending in acreage from large areas dominated by young stands to much smaller areas of mature and old-growth forest. Today, our forests are much older, on average, with similar acreage in the small, medium and large stand size classes.

Minnesota’s forests have also shifted from a balance between hardwoods and softwoods (if not a slight dominance by softwoods), to being dominated by hardwoods. In 1936, a slight majority of cubic foot volume of wood in Minnesota’s forests was softwoods. While both hardwoods and softwoods volumes have increased, hardwoods contribute substantially more cubic foot volume than softwoods in 2014. Fire suppression has also favored the less fire-dependent hardwood species like oak and other hardwoods instead of pines. Red pine, however, increased substantially in both volume and acreage likely due to its popularity as a merchantable timber species for sawlogs, pulpwood and utility poles, and a focus on red pine for reforestation efforts over the last century years. Adding to the decline in pine species is the increasingly important role that aspen has played in Minnesota’s forests and forest industry over the last 4-5 decades.

In addition to changes in forest structure and composition, forest ownership has also shifted. Public ownership increased while private ownership decreased between 1936 and 2014. Land ownership held by municipalities and counties increased dramatically, which is a reflection of high land tax delinquency during the Great Depression (MACLC, 2006).

4.2. Per-acre statewide comparisons

Trees per acre comparisons across early and more recent inventories provided a means of comparing stocking of stands across forest types. Overall, the results mimic other statewide comparisons. Forests in 1936 were highly cut over and poorly stocked; pine species were more dominant than hardwoods. Trees per acre in aspen cover was much lower than expected, but is likely a testament to the low stocking at the time. According to published figures, over half of the aspen stands in Minnesota were poorly stocked in the 1936 Survey (USFS 1938).

In 2014, per acre stocking was generally much higher than in 1936. Cedar cover showed a surprisingly high result, but likely due in part to the small area of cedar in the state and high number of stems greater than 1". Over half of the seven million trees in cedar cover were 1-3" DBH, most of which were balsam fir.

Summarizing trees per acre for species types and diameter class ranges for a cover type was an example of the most nuanced use of the historic data. In white pine stands, trees shifted in both size and species across stand size classes. Small aspen and white pine dominated young stands that shifted to an overstory of white pine in older stands with small balsam fir replacing aspen. Despite lacking data for unit 4, the restored data provide instructive detail on forest composition.

4.3. Unit comparisons

Summaries of the 1936 data using re-proportioned unit boundaries methodology were less accurate, but may provide an opportunity to compare regional trends over time at the unit level. Proportions used to generate forestland area for each of the four present day FIA units could also be used to re-proportion cover type area, volume, and tree counts per acre. However, any results using this methodology should be interpreted with caution.

4.4. Limitations of the data

Discrepancies in methodologies and naming conventions from different FIA inventories made it difficult in some instances to accurately compare data across the inventory years. Forest cover types and size class designation were made in the field in 1936. Today, FIA forest types and size classes are determined from stocking algorithms. In both cases, and for any single forest cover type or size class, there exists a variety of species and DBH classes. Therefore, changes in forest cover area should be interpreted with caution. A similar conclusion was made by Jaakko Pöyry Consulting, Inc. (1992) and Guilkey et al. (1954), when comparing forest cover change in Minnesota using different FIA inventories. In some cases, it is clear that definition and procedural changes limit the accuracy of data. An example is the black spruce cover type. It is unlikely that a large influx of black spruce forest area occurred in 1977 (see Figure 7b) and that it returned to 1936 levels by 2014. Kilgore et al. (2005) discuss such problems in interpretation with recent FIA inventories.

Several attempts were made to impute unit 4 and some cover types for unit 6 per-acre estimates based on ratios of volume to DBH distribution in neighboring units. It was postulated that if volume was distributed across DBH classes similarly, it could be assumed the number of trees in each DBH class would also be similar. However, when compared, volume of species across size

classes and cover types in each unit were inconsistent, making it difficult to assume any relationship between DBH distribution and volume in a size class and cover type. Without number of plots and thus the area represented by each plot, it was impossible to accurately estimate per acre values for unit 4 using per acre volume and tree counts from nearby units.

The 1936 restored data, as sourced from summary of volume tables, provides only summaries of data, not individual observations. This limits statistical analysis of data, namely assessing sampling errors. Furthermore, the data lacks common forest site quality measures such as site index that can help characterize and compare across differing forest conditions.

4.5. Access to the Study Data

These data are now available on the Interagency Information Cooperative (IIC) website under the heading “IIC Study Areas and Projects.” The URL to access these data is:

<http://iic.umn.edu/project-areas/forest-inventory/historic-data/1936-usfs-survey/>.

These data are stored in Microsoft Access and sample queries are provided.

5. CONCLUSIONS

This study has provided insight on important details of forest change over a long time period. The general changes from 1936 to the present have been known to experts in the field, but have not been well documented and understood by broader audiences, including many professionals.

Opportunities for further research utilizing the restored data are considerable and extend within and beyond forest summaries at the state and unit level. Examples are examination of long term changes in species composition including shifts among units and linkages to changing environmental conditions. The potential of such analyses using the restored data is enhanced by the usability of trees per acre data when unit 4 area is removed, as demonstrated in section 4.2. Understanding tree species composition change can also help in understanding and managing forest resources in the natural and anthropogenic stressors, singly or in combination.

Further research may also provide insight into the impacts forest resources and land use change have had on society. Ownership changes from private to public; size class distribution from young to older forests; and changes in species composition provide potential insight into the way forest management objectives in the state have shifted over the past eighty years. Historic and recent trends may also be useful in predicting future forest management trends. In brief, this dataset provides considerable missing detail on the history of forest use and management in Minnesota.

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APPENDIX 1: 1936 USDA Forest Service Lake States survey data descriptions with notes.

Table A1.1. Historic records from the 1936 USFS Lake States survey.

Summary of volume books

State	Unit Books	Other books
Minnesota	1-6	All Units Combined; original sheets for units 1-6
Michigan	1-4	
Wisconsin	8-9 (missing 7)	

File boxes stored in Room 305, Green Hall, University of Minnesota, St. Paul Campus

Container Number	Description
Series Title: <i>Special Growth and Yield Data Study 1936</i>	
5	field and office work plans, memoranda, and preliminary data compiled from field data (e.g. stand age, annual growth, and volume)
6	growth and yield calculations for Michigan and Wisconsin
7	the original field tally sheets described above
8	growth and yield calculations for Minnesota and Michigan
47	Age and Growth Sample Trees, Michigan and Wisconsin
Series Title: <i>RE-LS [Research Lake States] FOREST SURVEY—Michigan, 1936</i>	
13	area calculations, plot summary, and stand tables for Michigan Forest Survey
14	log grades, volume tables, and sample tree summaries
22	calculations for volume tables
Series Title: <i>RE-LS FOREST SURVEY—Wisconsin, 1936</i>	
16	area calculations, inventory volume summaries, and stand
Illegible	volume calculations, farm woodland survey study
Series Title: No official label	
None	Minnesota Survey 1959: In the front of this container is a file of USFS documents from the 1930s that mostly deal with land classification and local communities in northern Minnesota. The remaining contents are not well organized; some volume calculations and ownership information for Minnesota from the 1966 Forest Survey

Table A1.2. Two-inch diameter class ranges.

DBH Class	Minimum Diameter	Maximum Diameter	DBH Class	Minimum Diameter	Maximum Diameter
2	1.0	2.9	24	23.0	24.9
4	3.0	4.9	26	25.0	26.9
6	5.0	6.9	28	27.0	28.9
8	7.0	8.9	30	29.0	30.9
10	9.0	10.9	32	31.0	32.9
12	11.0	12.9	34	33.0	34.9
14	13.0	14.9	36	35.0	36.9
16	15.0	16.9	38	37.0	38.9
18	17.0	18.9	40	39.0	40.9
20	19.0	20.9			

Table A1.3. Species common and botanic names.

Second grouping	Species grouping	Species group code	Included species common name	Included species botanic name
Pine	jack pine	JP	jack pine	<i>Pinus banksiana</i>
	Norway pine	NP	Norway pine	<i>Pinus resinosa</i>
	white pine	WP	white pine	<i>Pinus strobus</i>
Other conifers	hemlock	Hem	hemlock	<i>Tsuga canadensis</i>
	balsam fir	Bal	balsam fir	<i>Abies balsamea</i>
	black spruce	Bsp	black spruce	<i>Picea mariana</i>
	white spruce	Wsp	white spruce	<i>Picea canadensis</i>
	white cedar	Ced	white cedar	<i>Thuja occidentalis</i>
	tamarack	Tam	tamarack	<i>Larix laricina</i>
	sugar maple	SM	sugar maple	<i>Acer saccharum</i>
yellow birch	YB	yellow birch, black birch	<i>Betula lutea, Betula lenta</i>	
basswood	BW	basswood	<i>Tilia glabra</i>	
Better hardwoods	elm	Elm	American elm, rock elm, slippery elm	<i>Ulmus americana, Ulmus racemosa, Ulmus fulva</i>
	red oak	RO	N. red oak, black oak	<i>Quercus borealis, Quercus velutina</i>
	white oak	WO	white oak, burr oak	<i>Quercus alba, Quercus macrocarpa</i>
	beech	Be	beech	<i>Fagus grandifolia</i>
	miscellaneous better hardwoods	Ms	b.nut, bl. walnut, bl. cherry, hickory spp., w. ash, h.berry, bl. locust, O. buckeye, sycamore, Ky. coffeetree, h. locust, A. chestnut	<i>J. cinerea, J. nigra, P. serotina, Hicoria spp., F. americana, C. occidentalis, R. pseudoacacia, A. glabra, L. tulipifera, P. occidentalis, G. triacanthos, C. dentate</i>
Inferior hardwoods	poplar (aspen)	Asp	quaking aspen, big tooth aspen, balm of Gilead, cottonwood	<i>Populus tremuloides, Populus grandidentata, Populus balsamifera, Populus deltoides,</i>
	paper birch	PB	paper birch	<i>Betula papyrifera</i>
	soft maple	RM	red maple, silver maple, box elder	<i>Acer rubra, Acer saccharinum, Acer negundo</i>
	scrub oak	SO	scrub oak	<i>Quercus ellipsoidalis, Quercus spp. poor form</i>
	miscellaneous inferior hardwoods	MsI	black ash, green ash, ironwood, willow	<i>Fraxinus nigra, Fraxinus lanceolate, Ostrya virginiana, Salix nigra</i>

Table A1.4. Descriptions of forest and non-forest cover types.

Code	Name	Forest Cover Type Description
j	Jack Pine	Stands in which pine predominates, jack pine is most prominent
n	Norway Pine	Stands in which pine predominates, Norway pine is most prominent
w	White Pine	Stands in which pine predominates, white pine is most prominent
e	Bottomland and Swamp Hardwoods	Shallow swamps, overflow land or second bottoms. The characteristic species of this type are black ash, American elm and soft maples. They may occur in different proportions but together they predominate over other species which occur in the mixture. Associates include balsam poplar, yellow birch, green ash, black willow hackberry, black walnut, butternut, silver maple, swamp white oak, white pine, tamarack, cedar hemlock, spruce and occasional other hardwood species. On alluvial bottoms in the southern part of the region, the associated species are black walnut, butternut, black willow, green ash, hackberry, balsam poplar and swamp white oak
m	Northern Hardwoods	Principal species: sugar maple, hemlock, yellow birch, basswood and beech. Associated species: These occur in less proportion. They are white pine, red oak, white ash, balsam fir, spruce, paper birch and ironwood, elm and cedar.
a	Aspen	Areas on which aspen and paper birch make up 60% or more of the stand.
o	Oak	Central Hardwoods. Includes stands in which white, red and burr oak are the chief species in association with maple, basswood and other hardwoods. Occurs chiefly in the southern part of the region.
so	Scrub Oak	The predominating species is jack oak, white oak, burr oak, black oak, scarlet oak and red oak of very poor form.
b	Spruce-Fir	White spruce and balsam fir are the key species, although neither may alone predominate. White cedar, aspen and paper birch are common associates, while black spruce, black ash, yellow birch and hemlock, white pine or even jack pine may occur in the mixture. The type occurs on upland soils and on swamp borders.
s	Black Spruce Swamp	This type is closely confined to acid peat bogs with poor drainage and may thus be distinguished from the spruce-fir type which grows on upland soils. Black spruce may occur in pure stands or mixed with balsam-fir, tamarack and cedar.
t	Tamarack Swamp	This type is very similar to the black spruce type in characteristic associates and site, but tamarack predominates.
c	Cedar Swamp	This type usually occurs on shallow peat. Swamp species including black spruce, balsam fir, tamarack, paper birch are usually associated with it and not infrequently yellow birch, black ash, red maple, white pine, and balsam fir.
s	Non-productive Swamp	Scrubby spruce or tamarack on deep poorly drained peat, usually less than 5" DBH at 100 years.
m(h)	Hemlock	This will be used to designate stands in which hemlock clearly predominate.
Non-Forest Cover Type Description		
wp	Wooded Pasture	Some trees but not enough for forest classification
gr	Grass or Light Brush	Deforested plantable areas--grass, bracken, sweet fern and light bush.
br	Brush	Deforested brush or slash areas which cannot readily be planted, including temporarily deforested land
ms	Marsh or Bog	Includes areas in rushes, sedge or brush such as alder, willow, leatherleaf or Labrador tea

Table A1.5. Stand size class definitions.

Name	Stand size class	Description and diameter range
15+	Old-growth	Old-growth; plots with at least 400 BF; majority of trees >16" (15.0")
9-15	Second-growth	Second-growth; Plots with at least 400 BF; majority of trees 10-14" (9.0-14.9")
3-9	Pole size	Plots with less than 400 BF but at least 0.6 cords of wood; 6-8" (5.0-8.9")
0-5	New growth	Plots with less than above but at least 20 trees 2-4" (1-4.9")

Table A1.6. Volume table data descriptions.*Sample trees and local volume tables.*⁶

Sample trees	Sample tree measurements for DBH, height, and merchantability were taken in each well-stocked plot for a tree of average size and species. Sample trees were diagrammed on plot tally sheets to calculate volume per section of tree. Each sample tree was measured for board foot, total cubic foot, and pulpwood cubic foot volume.
Local volume tables	Sample tree measurements were used to generate local volume tables for net volume for an average tree in each species, DBH class, unit, and in two size classes (saw timber-sized trees in 9-15 & 15+ size classes, and small growth 0-5 & 3-9 size classes).
Merchantable board foot	Local board foot volume tables were generated from sample trees of merchantable size using Scribner log scale, curved ($0.79D^2/4$), and Girard form class composite taper tables developed for the region. Volume per tree was based on 16' logs, adjusted for taper, that were at least 9.0" DBH and greater than 8.0" dib in hardwoods and 6.0" dib in softwoods (see Table below).
Total cubic foot	Local volume tables for net cubic foot were generated from all sample trees greater than 5.0" DBH. This included saw log trees, culled saw log trees, pulpwood species and all other species, with the exception of volume of tops and branches of all trees above 4" dib.
Pulpwood cubic foot	Pulpwood volume tables were based on high-grade pulpwood calculated for black spruce, white spruce, balsam fir, jack pine, tamarack, aspen greater than 6" DBH class. Eight-foot lengths occurring in saw timber trees above the merchantable saw log height (6" dib), and trees less than saw timber sized that contained at least two 8-foot sticks of minimum top diameter or larger, were indicated as pulpwood.

⁶ Local volume tables for Minnesota were not recovered, but were available for Wisconsin and Michigan. A portion of the hard-bound survey summary books were also available for Wisconsin and Michigan. A calculation of the local tree volume tables multiplied by trees per acre accurately returned the reported tree volumes in the summary books, providing evidence that per-acre volume estimates were based on local volume tables.

Table A1.7. Ownership group descriptions.

Group name	Description
Federal (reserved and unreserved)	All National Forests in Public Domain (e.g. Superior National Forest and Mesaba National Forest); all unreserved and un-allotted Public Domain; all military reservations, wildlife refuges, water level control
State (reserved and unreserved)	Unsold grant lands; delinquency lands (interest not paid on loans); Rural Credits lands acquired by foreclosure of loans by Rural Credits Department; State Forest, game refuge or park lands (only in Kabetogama State Forest in MN); reforestation and Flood Control Lands; delinquency lands (property tax not paid)
Indian	Lands held in trust for the Indians by Interior Department or reservation lands
County & Municipal	Lands belonging to cities, towns or counties
Small Private	Private owners having less than 1800 acres
Large Private	Private owners having 1800 or more acres of land

Table A1.8. Example of stand and stock and summary of volume tables and calculations.

Example of stand and stock table for unit 1, cover type aspen, pole-sized stand, aspen species

Unit	Cover	Stand Size Class	Species	Average per acre				
				D.B.H.	Trees	Board foot	Cubic foot	Pulpwood cubic foot
1, Cloquet	aspen	3-9 (pole size)	aspen	2"	32.26	0	0	0
				4"	41.50	0	0	0
				6"	47.08	0	112.00	20.00
				8"	28.24	0	147.06	78.00
				10"	8.89	151.00	91.00	10.00
				12"	1.89	85.00	29.00	2.00
				14"	0.26	20.00	6.00	0
				16"	0.06	6.00	2.00	0
				18"	0.02	4.00	1.00	0
Total				160.20	266.00	388.06	110.00	

Example of summary of volume table for unit 1, cover type aspen, pole-sized stand, aspen species

Unit	Cover	Stand Size Class	Species	Unit Totals				
				Area (acres)	Sawtimber (Scribner board foot)	Total volume (cubic foot)	Pulpwood (cubic foot)	Pulpwood (cords)
1, Cloquet	aspen	3-9 (pole size)	aspen	208,000	50,900,000	80,716,480	22,880,000	292,177.6

Example of how total unit volume and per-acre volumes were calculated

Unit	Cover	Size Class	Species	Cubic foot volume
1, Cloquet	aspen	3-9 (pole size)	aspen	388.06 cf/acre * 208,000 acres = 80,716,480 total cf
				80,716,480 total cf / 208,000 acres = 388.06 cf/acre

Example of how total unit number of trees and per-acre trees were calculated

Unit	Cover	Size Class	Species	Number of Trees
1, Cloquet	aspen	3-9 (pole size)	aspen	160.2 trees/acre * 208,000 acres = 33,321,600 total trees
				33,321,600 total trees / 208,000 acres = 160.2 trees/acre

APPENDIX 2: Comparisons of digitized data with published figures from 1936.

Table A2.1. Comparisons of statewide totals with USFS Economic Notes Number 10, 1938.

Comparison: Area by stand size class.

Size Class	Summary of Volume Tables		Economic Notes 10
	(all units)		
	Area (acres)		
15+	343,100		343,100
9-15	1,223,400		1,223,400
3-9	4,558,900		4,558,900
0-5	9,366,900		9,366,900
Non-forest	4,123,100		4,123,100
Total	19,615,400		19,615,400

Comparison: Cubic foot volumes by units.

Unit	Summary of Volume Tables		Economic Notes 10
	Total Volume		
	Thousand Cubic Feet		
1	775,590		775,590
2	1,611,190		1,611,190
3	1,323,570		1,323,570
4	1,789,570		1,789,570
5	939,120		939,120
6	464,370		464,370
Total	6,903,410		6,903,410

Comparison: Saw Timber volumes by units. ⁷

Unit	Summary of Volume Tables		Economic Notes 10	
	Volume Saw Timber			
	Scribner Thousand BF	International ¼" Thousand BF	% Under	
1	886,580	1,052,210	18.68%	
2	2,477,730	2,941,560	18.72%	
3	1,979,030	2,347,130	18.60%	
4	3,379,350	4,008,030	18.60%	
5	1,286,582	1,525,920	18.60%	
6	478,730	597,890	24.89%	
Total	10,488,002	12,454,740	18.75%	

⁷ Volume totals were converted from Scribner to International ¼" log rule for publication; modal difference of 18.60% (USFS 1938, p.52)

Table A2.1 Continued.*Comparison: Pulpwood volumes by units.*

Unit	Summary of Volume Tables	Economic Notes 10	% over
	Volume High-Grade Pulpwood	Cordwood	
1	2,142,920.23	2,199,000	0.00%
2	3,777,000.00	3,773,000	0.11%
3	4,136,041.69	4,131,000	0.12%
4	7,143,000.00	7,143,000	0.00%
5	300,070.39	300,000	0.02%
6	697,783.06	694,000	0.55%
Total	18,252,920	18,240,000	0.07%

Table A2.2. Comparison of re-proportioned county data and 1935 MnDNR Land Economic Survey for Hubbard County.

Size Class	Re-growth	Pole stand	Second growth	Old growth	Total
Land Economic Survey (acres)	276,348.00	130,233.00	35,132.00	4,419.00	446,132.00
USFS (acres)	207,813.00	83,397.00	27,468.00	4,904.00	389,181.00
Difference	-25%	-36%	-22%	11%	-13%

APPENDIX 3: Links for 1936 survey attributes to 2014 FIA Database User Guide.

Table A3.1. *EVALIDator* reference tables and attributes.

1936 Name	2014 Name	Reference table from FIA Database User Guide	Attribute/Name/Number	Notes
Area of forestland	Area of forest land, in acres	9.1.3. Reference Population Attribute Table	2	
Stand size class	Stand size class	2.4.20.Stand-size class code	STDSZCD	Designated based on algorithm
Cover type	Forest type	9.3. Reference Forest Type Table		MnDNR Forest groups
Species	Tree Species	3.1.16. Species Code	SPCD	
Number of trees	Number of live trees (at least 1 inch d.b.h.), in trees, on forest land	9.1.3. Reference Population Attribute Table	4	
Cubic feet volume	Net volume of live trees (at least 5 inches DBH), in cubic feet, on forest land	9.1.3. Reference Population Attribute Table	14	
Board feet volume	Net volume of sawtimber trees, in board feet (International ¼-inch rule), on forestland	9.1.3. Reference Population Attribute Table	20	
Ownership group	Owner Group Code	2.4.13. Owner group code		Four categories