2013 Project Abstract
For the Period Ending September 23, 2015

PROJECT TITLE: Improved Rapid Forest Ecosystem and Habitat Inventory

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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2013, Chp. 52, Sec. 2, Subd. 03g
APPROPRIATION AMOUNT: $262,000

Overall Project Outcomes and Results

Forests cover one-third of Minnesota and contain 15.9 million acres of timberland managed in large part by county, state and federal agencies and private landowners. Of this, 53% is public. DNR forest stand inventory records alone include nearly 200,000 stands. Stand inventories are central to the management of these lands. But forests change rapidly (e.g., 14% of field plots change covertype within 5 years) and stands can shift from sapling to old forest stage in 2-4 score years. Thus inventories need updating, but such efforts have fallen far behind. Why? They are costly (say $6 per acre, $3 for field plots, $3 for mapping) and can total millions of dollars statewide. Consequently these data are typically insufficient and out of date.

The project questioned existing inventories and explored new ideas, methodology and tools to dramatically reduce costs and to expand ecological and habitat detail. The findings below will foster inventories with greater frequency, timeliness and detail:
1) A major use of inventories is in forest planning (harvest scheduling), but results indicate such analyses do not require large numbers of field plots.
2) Forest yield estimates, essential to planning, likewise do not require large numbers of field plots—nearby and past inventories can satisfy much of this data need.
3) Data mining analyses indicate numerous ecological variables can be imputed to inventory stands from data already available such as physiographic class, soil maps, location, and tree species present. Results show moderate to high accuracy for native plant community class (NPC) estimation.
4) Habitat suitability models have been refined and packaged for PC use. This enables local to large area habitat characterization for 150+ wildlife species across past, present and projected inventories.
5) Based on the above findings, cost effective alternative inventory designs are now available to fit diverse situations. These can reduce field plot costs to half or less.

Project Results Use and Dissemination

1) Workshops, training, software tools and publications are already underway to foster implementation among DNR and county participants and other landowners. Some these will be offered through the Sustainable Forests Education Cooperative (SFEC) from the University's Cloquet Forestry Center. These workshops will cover developing local yield tables, the use of efficient judgment (located) plots, and choosing your inventory design from among alternatives. Lidar workshops have already been held. We are also making the data mining and habitat imputation capability available as software for PCs. Further details on project findings and tools and their implementation will be made available as University of Minnesota Forestry Research Notes at www.forestry.umn.edu and on the Interagency Information Cooperative website at iic.umn.edu.
2) The project manager and staff have presented project progress and various results at several meetings of participating professionals and agencies (e.g., the Minnesota Forest Resources Partnership). These

communications have focused on inventory design. This includes advising on the development of a DNR Forestry led implementation proposal directed to the LCCMR. Staff has also been working with DNR Forestry on the implementation of ecological imputation findings. A report on parts of this work has been accepted for presentation at the 2015 National Convention of the Society of American Foresters in Baton Rouge, LA in November.
3) Combinations of Lidar, spectral imagery and automated covertype mapping software explored in the project are are coming soon and will likely reduce mapping costs to half or less.
4) It is anticipated that these project findings will be examined and implemented by most project participants.
5) The subject of this LCCMR project is an increasingly common and internationally important topic. Many states and countries are faced with similar inventory cost and effectiveness problems. Thus publications and methods developed from this project will likely spur further study by others well beyond Minnesota.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2013 Final Report

Date of Status Update Report: September 23, 2015

Date of Next Status Update Report: Final Report

Date of Work Plan Approval: June 11, 2013

Project Completion Date: June 30, 2015 **Is this an amendment request?** no

PROJECT TITLE: Improved Rapid Forest Ecosystem and Habitat Inventory

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Location: Statewide

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$262,000**
	Amount Spent:	**$260,523**
	Balance:	**$ 1477**

Legal Citation: M.L. 2013, Chp. 52, Sec. 2, Subd. 03g

Appropriation Language:
$262,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to evaluate a new approach to forest inventory, based on statewide forest inventory and analysis (FIA) data.

I. PROJECT TITLE: Rapid Forest Ecosystem and Habitat Inventory by Imputation

II. PROJECT STATEMENT: Minnesota has 15.9 million acres of timberland managed in large part by county, state and federal agencies and private landowners. The breakdown of this ownership per the 2011 USDA Forest Service Forest Inventory and Analysis (FIA) reporting is:

County & Municipal	2,649,098
State	3,683,398
National Forest	1,841,155
Other Federal	205,137
Other local government	6,837
Private including forest industry	7,543,346
Total	15,928,971 acres

Additionally, 12.5 million acres of this timberland lies in northern Minnesota. Further, most of the private acreage is in small private ownerships; forest industry timberland acreage comprises approximately 5% of the total timberland acres.

Forest inventory is a major concern of all of these ownerships with the county, state and national forest and forest industry ownerships actively involved with using these data. Additionally, there is increasing interest in inventory data for small private ownerships. This project addresses these forest inventory interests with emphasis on county and state lands. However, the methodology will be applicable to and benefit all ownerships as the project databases are developed and the methodology adopted.

Why the emphasis on forest inventory? Forest management is for diverse purposes including timber, wildlife habitat, and ecological considerations. Yet much of the forest inventory data for management is too far out of date for efficient operations and effective planning for sustainability. Why? Because forests are continually changing through natural and human processes such as succession, growth, mortality and harvesting.

For most agency users, the typical once per decade cost and time of inventory efforts have become prohibitive and effectively precluded regular attention to such data collection, despite their importance to forest management. This project examines and develops a new approach to forest inventory to dramatically reduce costs, speed updates and improve usability. The primary benefits of the project will be a savings of approximately one-half of the typical inventory effort, capability for rapid inventory updates to current conditions, increased data detail and commonality in describing forest conditions, and improved projection capability and planning (for future decades).

Three types of forest inventory efforts are common in practice:
(1) Statewide strategic inventories—such as the US Forest Service Forest Inventory and Analysis (FIA) program which has established and re-measures a large number of permanent field plots on an annual basis across each state annually. In Minnesota the FIA program has 6,139 such plots with $1/5^{th}$ remeasured annually. Further, this data is readily available and free. FIA describes overall forest conditions and FIA plots are the gold standard for field data. However, the FIA sample size does not provide for localized map detail.

(2) Map based inventories—MnDNR and county inventories map each forest stand (a polygon) and describe them by covertype, site quality, age or size class, ecological conditions plus timber characterizations, as determined by several to many field plot measurements in most if not all stands. These inventories provide the operational detail needed for ownership wide forest management for sustainability and diverse other purposes. However, it has become increasingly difficult for agencies to fund such efforts.

(3) *Timber sale appraisals*—typically intensive examinations of specific mature forest stands or sale units. These are precise and detailed assessments of stand conditions and sale quantities for establishing and administering a sale. In any one year, there may be many such sales in similar forest conditions, e.g., 45-50 year old aspen stands.

Because of their large size and considerable tree, stand and ecological detail, FIA field measurement costs are typically $200-$300+ per plot. While individual map based inventory field plots are smaller and cost much less ($30-$60 each), each agency may employ thousands of these plots at rates of 1-10 per stand. This reality has slowed the frequency of updates for map based inventories. Appraisals utilize numerous plots in each stand or sale or may record data on each tree and the conditions affecting harvesting operations and follow up.

Research hypothesis:
This project recognizes that the map based inventories can be broken into two parts: (1) updating maps and (2) measurements on field plots. Further, we *hypothesize* the latter, the most expensive part, can largely be replaced using FIA data correlated with stand map classifications by covertype, site quality, age or size class, etc. Here we assume state of the art and practice remote sensing and GIS inputs. In fact, FIA data provide stand classifications in much the same way that map based inventories classify stands. Thus the detailed measurement data from FIA plots may be imputed to "similar" stands classified and mapped on specific ownerships. Additional sources of data for imputation are past inventory stand classifications and timber sale appraisals. Such imputation is possible because per acre averages for many covertype, site quality, and stand age groupings (classifications) will not change appreciably with time. The key question is the precision and accuracy of the imputation for various management and planning purposes.

Should these study results prove truly useful, the savings in field data collection efforts would dramatically reduce map based inventory costs and time and allow for much more frequent inventory updates—and increased usage of such data in operations and planning. The attached graphic illustrates the concept. Additionally, forest covertype and size class are often key predictors of forest habitat values and ecological conditions. Thus imputation based on existing data could add considerably to the description of habitat and ecological considerations for many stands and ultimately over large areas. Finally, the focus on FIA and other precisely measured plot and stand data provides the opportunity to employ high quality, standardized and detailed information at very low cost.

III. PROJECT STATUS UPDATES:

Project Status as of *(January 15, 2014)*: The project activities are on track with respect to time and budget. In terms of Activity 1, collecting and organizing the data, the response to requests for forest inventory data from the USDA Forest Service FIA, Minnesota counties and the MN DNR Division of Forestry has been speedy and very generous of their time and data. The resulting study dataset has been documented, verified, and organized in a study appropriate database. The data requirements for the study are essentially complete and sufficient to accomplish project activities. Additionally, preliminary effort on Activity 2 has indicated the imputation of various ecological characterizations will be quite feasible for certain variables of interest to forest management. Under Activity 3, we have designed the statistical and economic trials to assess the gains from imputation for inventories and forest planning. Finally, we have developed formal and informal communications with project participants (USDA Forest Service FIA, counties and the MN DNR Division of forestry, including the development of a project website.

Amendment Request (*January 31, 2014***)**
Amendment is requested to rebudget funds ($12,560) from D) Undergraduate students to Research Fellow/Research Associate to recognize (a) that one of our research fellows (J. Zobel) has finished his PhD and is now a research associate, (b) that project Activities require more advanced expert support from J. Zobel, and (c) to recognize that funding from the University's Office of the Vice President of Research has been made available to assist with data verification tasks at the Cloquet Forestry Center, thus that student employee expense is no longer required.

Project Status as of *(September 15, 2014)***:** The project activities are on track with respect to time and budget. In terms of Activity 1, the extent of data now available for the project exceeds that originally anticipated. The data requirements for the study are essentially complete and sufficient to accomplish project activities. Additionally, efforts on Activity 2 have indicated the imputation of various ecological information will be quite feasible for essentially all variables of interest contemplated for the study. The anticipated level of imputation for native plant community characteristics is the NPC Class, with finer detail possibly available through association of particular forest types, physiography, and soil characteristic combinations with NPC field data as available for stands in the

Minnesota DNR Cooperative Stand Assessment (CSA) inventory data. Under Activity 3, the statistical and economic trials to assess the gains from imputation for inventories and forest planning are well underway. Finally, our formal and informal communications with project participants continues with plans for expansion in the last year of the project.

Project Status as of *(March 15, 2015)***:** The project activities are on track with respect to time and budget. Activity 1 has been completed. Activity 2 has successfully demonstrated the utility of a wide range of existing data sources for imputation of economic and ecological variables. This imputation appears to provide very substantial time and inventory cost savings. We are now extending that demonstration and implementation to forest areas of priority interest to the DNR Division of Forestry and county land departments. Activity 3 has successfully demonstrated that forest inventory for planning purposes can be developed with greatly reduced sample sizes with little loss of precision in timber volume and value estimates. Finally, a range of inventory designs and imputation tools have been developed for user consideration and implementation.

Amendment Request *(March 15, 2015)*
Amendment is requested to rebudget funds ($6,500) from Travel Expenses in Minnesota to Personnel B. Research Fellow/Research Associate to recognize that one of our research fellows (D. Wilson) is needed more than planned on the project for his expertise in imputation. At the same time we have substantially reduced our travel expenses by electronic communications and meetings in St. Paul, rather that outstate. Specifically, this amendment requests (a) Under Activity 1, moving $2500 in Travel to Activity 3 Personnel; (b) Under activity 2, moving $500 in travel to Activity 3 Personnnel; and (c) under Activity 3, moving 3500 in Travel to Activity 3 Personnel. Amendment approved by LCCMR March 24, 2015

Project Status Final Project Report Summary *(September 23, 2015)***:** The project activities have been completed. However, broad utility and interest in the project and possibilities for further refinement will mean further efforts (by the project manager and perhaps many others) through other funding sources. The findings below provide a brief synthesis of results from the project activities.

As a preface to this report, forest management inventories provide key information for resource management, yet they are typically very time consuming and expensive. Additionally, forest conditions can change quickly, even within 5 years. The resulting outdated information in turn hinders the ability to plan and execute plans effectively. This project sought to find ways to dramatically reduce inventory costs and to add more ecological detail. The results will foster inventories with greater frequency, timeliness and detail. The seven major findings and results are described below and in more detail under the three Project Activities. Incorporating these findings in future inventories will constitute a major paradigm shift in cost, detail and effectiveness.

Finding 1. We are taking far too many field plots. There are two primary uses for plot information. The first is to describe the forest age class distribution (e.g., yields) for input to harvest scheduling. The second is "finding those stands" indicated for harvesting in the above schedule. Our harvest scheduling analyses indicate that very few plots are needed, provided key covertype and age variables are observe--and enough plot data to describe the mean yields of each age class is present. We also found a single subjectively located sample plot to be very cost effective for stand description.

Finding 2. Forest yield data is readily available. Recent inventory sample plots are always useful. However, much of the ability to estimate forest stand yields for each age class is also available in the form of previous and nearby inventories. However, this usage does require careful archiving and sharing of data, whatever its age.

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Finding 3. Numerous ecological variables can be imputed from readily available data. One can also develop an effective understanding of the ecological information that you might need or seek before going to the field. Available data especially helpful to imputation are physiographic class, soil maps, location, site index and tree species present. Project algorithms now allow prediction of Native Plant Communities (NPCs) and other ECS characterizations with a moderate to high level of certainty.

Finding 4. Habitat description capability is now available. Habitat values for individual stands and across a large forest can now be estimated—as well as changes in habitat values overall—from a PC packaging of location, covertype and habitat suitability.

Finding 5. Alternative inventory designs are available to fit diverse circumstances. The results of the project will be made available in the form of alternative designs for user consideration and choosing. It is expected that the field plot costs of future forest inventories can be reduced dramatically, perhaps to half or less of present costs.

Finding 6. Major changes in remote sensing/GIS capabilities are coming soon. The project has examined the use of lidar imagery, spectral imagery from satellites and automated type mapping (E-cognition software). Used together these tools may realistically reduce forest type mapping costs from the typical $3 per acre to half or less of present costs within a few years.

Finding 7. Workshops and training are an important next step in implementation and success. The project has described these findings to the MN DNR and counties and will be offering workshops for participants later this year to introduce these ideas in operational detail. Lidar workshops have already been held. Details on these findings and results and their implementation will be made available as University of Minnesota Forestry Research Notes at www.forestry.umn.edu and on the Interagency Information Cooperative website at iic.umn.edu.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Assemble data--map based forest stand inventory data from cooperating agencies and FIA data statewide, including timber, habit and ecosystem data.

Description: FIA data will be assembled for use in imputation trials. These data will include all FIA plot data statewide from inventory dates encompassing 1977, 1990, 2003, 2008 and 2012. Past and recent forest inventory (plot and/or stand data) data from cooperating agencies will also be assembled for at least a large county (St. Louis), a small county (Carlton) and MnDNR Forestry state lands in northern Minnesota. We anticipate the MnDNR will be able to provide an old and a recent inventory for some parts of the state. We further anticipate such data being available from at least three additional counties. In at least two counties data will be available from an old and a recent inventory. We expect the MnDNR and these counties will also be able to provide recent timber sale appraisal data. Data from additional counties will also be assembled as available and time permits. As an added test of methodology, 1959, 1964, 1976, 1982, 1990 and 2000 permanent plot inventory data from the University of Minnesota Cloquet Forestry Center (CFC) will be included. We also anticipate the data assembled here will have descriptions and formats sufficient to allow analysis as described in Activity 2. However, we expect to visit and/or otherwise contact these sources to ensure the understanding of data descriptions and formats. Ultimately, we seek to create one large database for the entire project, specifically to speed trials as described in Activity 2 and 3.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$ 58,500**
Amount Spent:	**$ 58,500**
Balance:	**$ 0**

Activity Completion Date:

Outcome	Completion Date	Budget
1. *Collection of FIA, county, state and university data files for inventories and appraisals, etc. for the subject study areas and dates.*	November 2013	$ 31,000
2. *Verification, data processing/organization and preparation of these data for subsequent trials.*	January 2014	$ 27,500

Activity Status as of *(January, 2014)*: **1.** USDA Forest Service FIA data has been updated and assembled in a MS Access database together with coding refinements that allow easy generation of forest attribute x age class tables. Additionally, the permanent research plot inventory data of the U of MN Cloquet Forestry Center has been added to project files. Recent and in some cases past inventory data has been requested and collected from 12 forested counties including Aitkin, Becker, Beltrami, Carlton, Cass, Clearwater, Crow Wing, Hubbard, Koochiching,

Lake, Pine, and St. Louis. Cook, Itasca and Lake of the Woods counties are included in the study framework, but have little forest land or have not been able to provide the requested data. Most of these data have come in the form of shapefiles with detailed stand information, some including ECS and NPC data. Several counties were also able to provide the requested timber sale appraisal data. Similarly, the MN DNR Division of Forestry has been asked to provide such data and that has since been added to the study database. In fact, the DNR data covers agency lands statewide. **2.** These above noted data have been processed, organized in MS Access formats and prepared for subsequent analysis and trials. However, some formatting refinement to subsets of the data will be made later to facilitate subsequent activities.

Activity Status as of *(September 2014)***:** We have acquired some additional ecological classification data from the MN DNR Division of Forestry, notably point and map data describing ecological classifications and native plant community determinations. Additionally, we have succeeded in linking some of these data with FIA plot locations. This step will improve our capability for imputation of these variables to other locations, the subject of Activity 2. Additionally we have been able to add data from the 7th remeasurement of 400+ permanent field plots on the University of Minnesota's Cloquet Forestry Center. This includes measurements from 1959, 1964, 1976, 1982, 1990, 2000 and now 2014. The latest remeasurement was provided by funding from the University's Grant-In-Aid program. Finally, we have retained a small portion of the Activity 1 budget to meet anticipated needs for reformatting and further verification for statistical and cost analyses as they develop.

Activity Status as of *(February 2015)***:** Data reformatting and verification for statistical and cost analyses has been completed. Activity 1 is now complete.

Activity Status Final Report Summary *(September 23, 2015):* Activity 1 is complete. We have acquired and processed substantial forest and ecological classification data from the MN DNR Division of Forestry and most Minnesota counties. This includes point and map (polygon) data describing forest stands and ecological classifications and native plant community determinations. Additionally, we have linking some of these data with FIA plot locations. This step will improve our capability for imputation of these variables to other locations, the subject of Activity 2. Additionally we have been able to add data from the 7th remeasurement of 400+ permanent field plots on the University of Minnesota's Cloquet Forestry Center. This includes measurements from 1959, 1964, 1976, 1982, 1990, 2000 and now 2014. These data are deemed more than sufficient for project purposes.

ACTIVITY 2: Evaluate the precision and accuracy--of imputation for forest ecosystem and habitat description, including additional map attributes that may improve imputation.

Description: Imputation trials will be conducted to test the statistical precision and accuracy of imputation of FIA data, past and recent inventory data, appraisal data, and other data sources to estimate key attributes of the mapped polygons on county and state lands. Precision and accuracy will be developed for actual field plot data and imputation results for the subject polygons for a range of measurements or observations that might be desired as part of the field data. To the extent that imputation provides useful precision and increased detail and at a much reduced cost for forest covertype by age by site class estimates, the methodology will be successful and widely adopted. Results will be developed separately for FIA data, past and recent inventory data, and timber appraisal data. With FIA and perhaps other data, we will also examine the utility of imputing habitat and ecological classification data. A last step will be evaluation of existing map and remote sensing data that may further improve imputation.

Summary Budget Information for Activity 2:

ENRTF Budget: $ 90,500
Amount Spent: $ 90,000
Balance: $ 500

Activity Completion Date:

Outcome	Completion Date	Budget
1. *Trials of imputation from FIA to map based inventories.*	June 2014	$ 35,000
2. *Incorporation of appraisal, past inventory data, etc. to further improve imputation.*	September 2014	$ 32,000

3. *Evaluation of existing and potential map data that can improve imputation ((including remote sensing (e.g., lidar) and thematic map inputs).*	February 2015	$ 23,500

Activity Status as of *(January 2014)*: The data collection efforts in Activity 1 also allowed for the collection of map and geographical data including that for forest soils, ecological classifications (ECS) and native plant community (NPC) data from several counties, the MN DNR and research efforts. Together with FIA physiographic class data, we have been able to determine that imputation of ecological characterizations will be quite feasible for several variables of interest to forest management. Subsequent efforts will develop those imputation capabilities in user friendly detail.

Activity Status as of *(September 2014)***:** The above data has been analyzed in a number of ways with emphasis on developing imputation capability, first through statistical analysis of relationships and more recently by the development and testing of software to provide widespread and straightforward estimation of ecological information that has been neglected in forest inventory data collection due to cost (time and availability of expertise). Information to be imputed includes habitat, physiography, soils, ecological classification and native plant community data. While analysis and refinements continue, it appears most of this information can be imputed with very usable precision. One report to date describes a computerized framework for estimating wildlife habitat suitability indices from the stand level to statewide (see Zobel J. M. and A. R. Ek. 2104. *The wildlife habitat indicator for native genera and species (WHINGS): Methodology and application*. Staff Paper Series No. 231. St. Pal, MN: University of Minnesota, Department of Forest Resources at http://www.forestry.umn.edu/Publications/StaffPaperSeries/index.htm). Stand description and forest growth and yield are also improved by using data from past inventories and that from nearby counties and FIA or other ownership data with a county. Specifically, this result suggests considerable savings in inventory by sharing data among agencies.

Activity Status as of *(March 2015)***:** The imputation potentials considered in this activity have been coded in software for testing and to provide the software for user applications, notably for stand growth and yield and native plant community (NPC) estimation. Estimation of stand growth and yield is measurably improved using past, nearby (state or county or FIA) inventory data. We have not been able to link well with appraisal (timber sale) data as these are often not well linked to specific stand inventory data because sale boundaries often cross stand boundaries. We are now in the process of demonstrating the imputation capability for each county. Most important is that we have found it feasible to estimate native plant community designations from a combination of common forest inventory and existing point and thematic data sets, e.g., using existing NPC data linked to FIA, DNR Forestry, county, County Biological Survey and thematic data (e.g., for region, soils and physiographic class). This suggests great savings are possible in developing NPC classifications for the vast majority of public forest lands not yet visited in the field for NPC classification (overall 89% accuracy). Reports and publications describing this imputation capability and associated software tools are in preparation and we are in discussions with the DNR Division of Forestry on their application in the coming year. Finally, remote sensing data and LiDAR trials for automating and speeding forest type mapping are under development

Activity Status Final Report Summary *(September 23, 2015)***:** Activity since the previous Activity Status report has concentrated on refinement and synthesis. This has included presentation of key findings to state and county participants and discussions of implementation interests. Also included are software and algorithm refinements and report/manuscript drafting. Relevant findings are detailed below in the Final Report Summary. This activity is now complete. Results are summarized below.

Typical inventories have cost about $6 per acre, with the cost split 50:50 between (a) field plot data collection and (b) stand mapping involving remote sensing and GIS data development. With these costs, such inventories are updated infrequently, typically after 10-20 years. Yet forest conditions can change quickly, e.g., 10-15% of stands change type in 5 years, excluding those that are harvested. The high costs and outdated information in turn limit the collection of ecological detail and the ability to plan and execute plans effectively. Given this situation, study findings are:

We have been taking far too many field plots. There are two primary uses for plot information. The first is to describe the forest age class distribution (e.g., yields) for input to harvest scheduling. The second is "finding those stands" indicated for harvesting in the above schedule. The first requires information on stand age and site index (and perhaps other descriptors); the second requires information that can help find those stands for execution of the planned schedule. Fortunately, our harvest scheduling analyses suggest that very few plots (perhaps one or none per stand) are needed, provided one obtains precise information on covertype, age and site index) and overall you collect enough plot data to describe the mean yields of each age and site class present (and perhaps density). We also found a subjectively located Bitterlich point sample plot to be effective—essentially unbiased and more precise than randomly located plots.

The ability to estimate stand yields for each age class is already available in the form of previous inventory nearby and FIA plots. Thus a large current inventory is not very crucial to developing such kind of information. This does suggest archiving and using previous and nearby county, state and federal inventory data effectively. However, experience with archiving and effective use of older data is not widespread in practices. It will need to be encouraged.

Major changes in mapping costs are coming soon due to improving remote sensing/GIS capabilities. The project has examined the use of lidar imagery together with spectral imagery from satellites together with automated type mapping (E-cognition software). These capabilities may realistically reduce forest type mapping costs from the typical $6 per acre to half or less within a few years. Achieving this will likely require investment in training and a large area trial.

Numerous economic and ecological variables can be estimated by imputation from available data. Results for stand growth and yield are described in the above March 2015 report. Results for the ecological variables have come more recently from the data mining components of the study. One can now develop a useful understanding of the typical ecological information sought before going to the field. Examples of available data for imputation are physiographic class (especially FIA physiographic class), soils, ecological subsection, and site index. Given these, it is possible to predict likely Native Plant Communities (NPCs) and other ECS characterizations with a moderate to high level of certainty. For example, combining the DNR database for native plant communities with forest inventory data has allowed us to predict likely NPCs from their association with the above variables; particularly physiographic class, soils and current cover type (some with 100% certainty and others to within a small cluster of 3-5 related NPCs). How can this be? The presence of forest types and native plant communities is strongly associated with physiographic class, soils, and several other variables that are readily available. For example, few cover types are found on more than two physiographic classes. Likewise site indices are similar in those situations, while stand growth (tree size, etc.) is related to successional stage. The project has produced a data mining algorithm which provides for imputation of NPCs given stand location, common inventory variables, and readily available auxiliary data.

ACTIVITY 3: Evaluate the practical utility--and savings of imputed inventory data.

Description: This analysis will examine results for forest inventory and planning across the subject county and state areas, e.g., for a MnDNR Sustainable Forest Resource Management Planning (SFRMP) area. Additionally, we would include an examination for the smaller but intensively measured Cloquet Forestry Center. Comparisons would be made for inventory and planning results with actual field data for subject polygons and alternatively with imputed data. In this effort we would examine costs and benefits of imputation and, for each application, whether imputation provided truly useful and cost effective results. These evaluations would involve participating agency staff evaluations of relevant costs, practical feasibility, and utility for various inventory and planning needs. Trials would also include examination of the utility of imputation for habitat description using a recently developed forest wildlife habitat model for native Minnesota species. Reporting would include a range of

inventory designs and types and extent of imputation such that users could ultimately choose the type and extent of imputation for their own choice of inventory approach.

Summary Budget Information for Activity 3:

ENRTF Budget: $ 113,000
Amount Spent: $ 63,250
Balance: $ 977

Activity Completion Date:

Outcome	Completion Date	Budget
1. *Identification of cost savings and practical utility of imputation for inventory.*	February 2015	$ 30,000
2. *Identification of cost savings and practical utility of imputation for planning.*	April 2015	$ 58,000
3. *Final report submitted, development of further outreach and technology transfer.*	June 2015	$ 25,000

Activity Status as of *(January 2014)*: Effort in this activity has considered how to design meaningful trials to answer the questions about cost savings in forest inventory and forest planning. These trials will have both statistical and economic considerations. Designs for these trials are now set and will be implemented over the coming months

Amendment Request (September 8, 2014): This request is to transfer some of the funding (approximately $12.000) for **Activity 3 Outcome 1.** From the **C) Graduate Students** category to employ two recently graduated U of MN forestry students (with a B.S. degree, but not enrolled as graduate students) to conduct short trials to demonstrate field aspects of actual imputation methodologies for inventory. These students (Kylee Berger and Paul Swanson) are employed as Civil Service Bargaining Unit employees. This request does not change planned activities or Activity budgets. This change is described further in V1. Project Budget Summary as part D) added under Personnel with a small related change to Part C). Amendment Approved by LCCMR 10-03-2014.

Activity Status as of *(September 2014)***:** The trials of cost savings in inventory and planning are underway with emphasis on the tradeoffs between the cost of the number of field plots used in forest planning vs the cost in terms of losses in precision for planning results as the number of plots is reduced. At the same time we are also considering imputation to substitute for actual field plots. In doing so, we are using a harvest scheduling model and simulation of planning results (for a large forest area) in terms of revenue and timber supply. Additionally, we are looking at alternatives to usual forest stand inventories, such as remote sensing, to address data needs such as identifying actual harvestable stands given the desired overall harvest level specified in planning--a very practical need. Finally, we have acquired and tested and conducted field trials of essentially all of the equipment considered important to cost savings in inventory practice.

Activity Status as of *(February 2015)***:** This activity has clarified the project implications for the two major uses of forest inventory data: (1) for planning to manage the forest age class distribution and (2) to identify the stands for harvest and management for execution of the plan. For (1), planning model trials have indicated the necessary field plot sample size for effective planning is substantially less that in current inventories, i.e., there is little loss of revenue and volume estimates in planning when sample size is reduced and the loss is in part compensated for by reduced field plot costs. For (2) FIA data analysis suggests the major problem is natural forest change. For example, for an inventory that is but 5 years old, 14% of the aspen stands have changed to the extent that they are no longer dominated by aspen. Thus unless inventories are conducted more frequently than the current 10-20 years, it will be difficult to find the stands to execute the plans. But to conduct them more often means they will need to be much less expensive in terms of field observations and must take advantage of new remote sensing data, such as LiDAR, to update the inventories. To address that problem, remote sensing data are being tested for this need and we have developed alternative inventory designs and tool choices to facilitate faster, less expensive, more frequent inventories. However, with the new approaches and tools this can be accomplished and with a greater degree of ecological detail.

Activity Status Final Report Summary *(September 23, 2015)*: Study results through the previous Activity Status report have been the subject of further trials, verification and refinement, particularly in the areas of planning model applications and NPC imputation. David Wilson's PhD thesis will elaborate (expected fall 2015) on ecological imputation results. Included as well are software and algorithm refinements and report/manuscript drafting. This has also involved presentation of key findings to state and county participants and discussions of implementation interests. At this point results for this activity have been synthesized in terms of key findings detailed below.

Substantial savings are possible from the above project activities. The first part of savings is in the reduction in the number of field plots needed for updating inventories. Related to this is the recognition that nearby and past data can effectively augment new field plot data. The second part of savings is from recognizing that large field plot sample sizes are not needed for harvest scheduling, i.e., a crucial element of forest planning. The third part of savings is possible from imputation of ecological data, e.g., developing NPC classifications for the vast majority of public (and some private) forest lands not yet visited in the field for NPC classification). Additional cost savings will also result from agencies using the imputation capability to focus their data collection for mapping ecological variables for those areas where high imputation accuracy is most difficult to achieve--while many other areas can be quickly and accurately imputed.

Habitat values for individual stands and across the stands in your forest can now be estimated—as well as changes in habitat values overall—from a packaging of location, covertype and habitat suitability. A PC package to implement such analyses is now available. This tool will be important to integrating economic and habitat considerations in forest planning models and processes.

Alternative inventory designs are being made available to fit diverse circumstances. Practical alternative inventory designs have been summarized for consideration and choosing by practitioners/users. It is expected that the ground component of these forest inventories can be reduced in cost dramatically, perhaps to a half of present costs.

V. DISSEMINATION:

Description: Project cooperators will receive regular summaries of study progress and findings plus notice of publications. These summaries and reports/publications will be provided via the already established Interagency Information Cooperative (IIC) website (http:iic.umn.edu. This website is part of a state chartered information cooperative effort directed by the Project Manager. IIC members (county, state and federal and industry personnel) will also receive regular electronic notices of progress reports and new information. Technical journal articles will also be developed to convey the findings and operational approaches. Additionally, findings and specific model practices for using existing data and imputation for inventory design and execution will be conveyed through workshops planned to reach county, state, federal and private forest management staff statewide. Finally, project personnel will assist county land departments and MnDNR staff in developing future forest inventory proposals for their respective ownerships.

Activity Status as of *(January 2014)*: The project manager (Alan Ek) and staff (John Zobel) have formally contacted all of the federal, state and county entities noted earlier with data requests and advised them on the advantages of participating in the project. This contact has included both supervisory individuals (e.g., county land commissioners) and technical staff in the area of forest inventory. The project manager has also updated these entities on progress formally (at meetings of the Minnesota Forest Resource Partnership (MFRP) and informally in other group and individual settings. A web site for the project has also been established and will be referenced in periodic email communications with the above individuals and others interested in the project. See https://sites.google.com/a/umn.edu/rfi/home. The web site will be used to communicate technical findings, operational suggestions and training opportunities.

Activity Status as of *(September 2014)***:** The project manager and research staff has updated entities on progress formally (at an August 21 meeting of the Minnesota Forest Resource Partnership (MFRP)) and informally, together with project research staff, in subgroup and individual settings. A web site for the project has also been established, but is now being reconfigured per changes required by the University in their overall web design and software. With those changes, we will intensify email and meeting communications with the above project participants. The web site will be used increasingly to communicate technical findings, operational suggestions and training opportunities. A Lidar workshop is also being offered twice to provide an update on remote sensing technologies that can improve stand polygon description. Finally, Merril Flannery, a research fellow, has been hired to fill in on analysis and communications for John Zobel, who left for a faculty position at the University of Tennessee. A first step in her role will be developing specific project communications, notably workshops for the last year of this work.

Activity Status as of *(March 2015)***:** The project manager has presented project progress and various results at several meetings of participating professionals and agencies in St. Paul and outstate. Additionally, the project manager and staff have met with the DNR Forestry Resource Assessment supervisor to plan the incorporation of project results into agency inventory efforts, advising on both alternative inventory designs, imputation methodology, remote sensing and proposals to work with counties on implementation of these ideas. The project findings are now being implemented into the revised website, now a part of the Interagency Information Cooperative (IIC) website http://iic.umn.edu. We are currently focused on developing deliverables in terms of reports and tools for each of the project cooperators, i.e., the MN DNR Division of Forestry and county land departments. Workshops are also being developed for the purpose of conveying results and technology transfer.

Activity Status Final Report Summary *(September 23, 2015)***:** The project manager has presented project progress and various results at several meetings of participating professionals and agencies. These communications have focused on inventory design and a DNR Forestry implementation proposal directed to the LCCMR. David Wilson has also been working with DNR Forestry on the implementation of ecological imputation findings. Workshops have been developed and presented on lidar applications. Additionally, a DNR Forestry Supervisors meeting at the Cloquet Forestry Center involved a field presentation on "Lidar in the woods" which described the methodology and forest inventory applications.

Going forward, publication, workshops and training are an important step in implementation and success. The project will be offering more workshops for participants later this year to introduce these ideas in operational detail. Some these will be offered through the Sustainable Forests Education Cooperative (SFEC) from the University's Cloquet Forestry Center. These workshops will cover developing local yield tables, the use of judgment (located) plots, and choosing your inventory design from among alternatives. We are also making the data mining and habitat estimation capability available as software for PCs over the next several months. Details on all of these findings and their implementation will also be made available as University of Minnesota Forestry Research Notes at www.forestry.umn.edu and on the Interagency Information Cooperative website at iic.umn.edu.

Finally, the subject of this LCCMR project is an increasingly common and internationally important topic. Many states and countries are faced with similar problems. Thus publications and methods developed from this project will likely spur further study and applications well beyond Minnesota.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget:

Budget Category	$ Amount	Explanation
Personnel:	$ 251,061	**A) Faculty:** One month of summer salary and fringe (0.397) for two years (University of Minnesota Co-PI faculty on 9-month appointments – H. Hoganson ($28,560), and J. Knight ($23,355); 0.1 FTE each); Totals 0.2 FTE, $51,915. **B) Research support:** Research Fellow D. Wilson for 1.11 year; Totals 1.11 FTE, $65,660 and Research Associate J Zobel for one year; 0.20 FTE, Totals $12,560. **C) Graduate Students:** Salary and fringe (0.8636) for two University of Minnesota graduate students for 1.3 years, each at 50% time (20 hours/week). Graduate fringe is budgeted at 0.87 of salary load and includes tuition for the academic year, health care for the fiscal year, and social security and Medicare for summer pay periods. Work will be conducting imputation trials under guidance of PIs and Research Fellow with a focus on planning and improving map information, respectively. Totals 3.0 FTE, $108,926. **D) Civil Service Research Support:** Salary and fringe for two recently graduated forestry students with B.S. degrees (Bargaining Unit employees) to provide some of the research support provided in B) above, notably because J Zobel has moved to the University of Tennessee. $12,000.
Equipment/Tools/Supplies:	$ 8,939	**Equipment/Tools/Supplies:** Expendable field measurement and data capture equipment and supplies; for data verification at the Cloquet Forestry Center, on cooperator sites and for demonstration, such as, for example: …Criterion RD 1000 Electronic BAF-scope/Dendrometer @ $1,470; …Haglöf Laser Vertex Hypsometer @ $2,140; ...Juniper Systems ruggedized field data recorder with GPS receiver @ $1,600.
Travel Expenses in MN:	$ 2,000	Travel Expenses in Minnesota: Travel - to pay mileage (75%) and per diem costs (25%) for project personnel to collect project data and meet with study cooperators on results and in workshops.
TOTAL ENRTF BUDGET:	**$ 262,000**	

Explanation of Use of Classified Staff: N/A
Explanation of Capital Expenditures Greater Than $3,500: Field measurement and data capture equipment for testing, demonstration and training of county, state and other project participants, e.g., in workshop settings.

Number of Full-time Equivalent (FTE) funded with this ENRTF appropriation: 4.7
Number of Full-time Equivalent (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			
Cooperating Counties, notably St. Louis and Carlton	In kind	0	Providing forest past forest inventory data files and data descriptions
State			
MnDNR	In kind	0	Providing forest past forest inventory data files and data descriptions
University of Minnesota	$77,524	0	Project manager and project faculty time providing project research leadership
TOTAL OTHER FUNDS:	**$77,524**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners: The University of Minnesota will receive the funding and also contribute substantial time and effort to the project. Project team members are from the University's Department of Forest Resources and include Professors Alan Ek, Thomas Burk and Howard Hoganson and Assistant Professor Joseph Knight. Cooperators include land departments from a large county (St. Louis) and a small county (Carlton) and the MnDNR. The USDA Forest Service Northern Research Station Forest Inventory and Analysis unit will be a research collaborator in terms of FIA database access and tabulations. Additional counties are also expected to participate with their inventory and/or appraisal data as project resources and time permits, e.g., Aitkin, Crow Wing and Lake counties. The cooperators will provide their respective ownership forest inventory data, supporting map and data compilations, and user review in the evaluation of project outputs. Those evaluations will include making data available for evaluations of feasibility, utility and costs savings of the new inventory approach.

B. Project Impact and Long-term Strategy: A Two-year project length is needed to be able to collect existing agency data, develop imputation methodology and trials, and to identify the utility and costs savings of these approaches for timber inventory, ecological assessments, habitat characterization and planning purposes. .

C. Spending History: Aspects of the new approach to forest inventory have been under development since 1997 at the University of Minnesota with funding as part of various research projects sponsored by the Minnesota Agricultural Experiment Station. However, no ENRTF anf MRRF funds have been in used in those efforts.

Funding Source	M.L. 2007 or FY08	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12-13

VIII. ACQUISITION/RESTORATION LIST: Not applicable.

IX. MAP(S): Not applicable.

X. RESEARCH ADDENDUM: Not applicable.

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted not later than January 15, 2014, September 15, 2014, and March 15, 2015. A final report

and associated products will be submitted between June 30 and August 15, 2015 as requested by the LCCMR.

GRAPHIC: Rapid Forest Ecosystem and Habitat Inventory by Imputation

Intro: Map based forest inventories typically involves two efforts:

(1) Development or updating a base map of forest stands (polygon boundaries) and descriptions
(e.g., cover type, age, tree size class, site quality, habitat type, ecological classification)
(2) Field plots to describe the per acre stand characteristics at the inventory point in time
(tree species, sizes, product potentials, on-the-ground management details)

Below is a graphic describing the location of 6,139 FIA plots in Minnesota (each consisting of four 1/24th acre subplots) and the type of information collected…data that can be used to impute the characteristics of the forest stand polygons in map based inventories…potentially saving the cost of the field plot effort (2) above. Imputation is the substitution of known values from an existing dataset to another which lacks some of the existing dataset details.

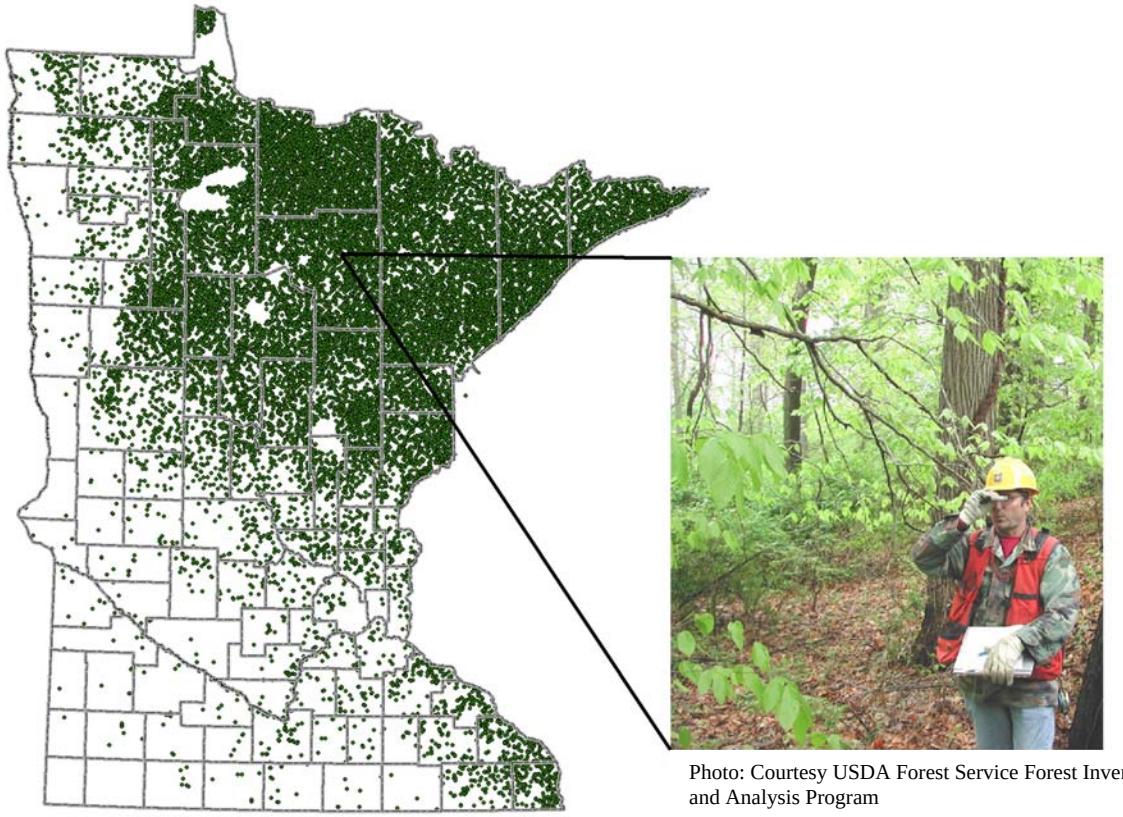

Photo: Courtesy USDA Forest Service Forest Inventory and Analysis Program

Figure 1**:** FIA plots in Minnesota. Plots are remeasured every 5 years on a rotating basis thus providing annually updated estimates of forest area, cover type area, and including ecological conditions, habitat indicators, and numerous other measures.

Project Activity: Correlate the large FIA data set to a subset of similar stand data in map based inventories and conduct trials of imputation precision and accuracy for timber, wildlife habitat, and ecological conditions. Additionally, the project will examine the utility of the imputation approach for forest planning and also ways to increase the speed, precision and accuracy in updating base maps.

Results: Improved timeliness of map based forest inventories for assessment, planning and management and dramatically reduced the cost of such inventories.

Attachment A: Budget Detail for M.L. 2013 Environment and Natural Resources Trust Fund Projects

Legal Citation: M.L. 2013, Chp. 52, Sec. 2, Subd. 03g
Project Manager: Alan R. Ek
M.L. 2013 ENRTF Appropriation: $ 262,000
Project Length and Completion Date: June 30, 2015
Date of Update: June 30, 2015

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget Activity 1 02/15/2015	Amount Spent	Balance	Budget Actitvity 2 02/15/2015	Amount Spent	Balance	Budget Activity 3 02/15/2015	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM											
Personnel (Wages and Benefits):	$ 53,500	***53,500***	$ -	$ 90,000	***90,000***	$ -	$ 107,561	***107,561***	$ -	$ 251,061	$ -
A) Faculty: One month of summer salary and fringe (0.397) for two years (University of Minnesota Co-PI faculty on 9-month appointments - H. Hoganson (Activity 2&3 $28,560), and J. Knight(Activity 2&3 $23,355); 0.1 FTE each); Totals 0.2 FTE, $51,915.											
B) Research Fellow: D. Wilson for 1.11 year (Activity 1,2 &3); Totals 1.11 FTE, $65,660 - and Research Associate J Zobel for one year; 0.20 FTE, 12,560).											
C) Graduate Students: Salary and fringe (0.8636) for two University of Minnesota graduate students for 1.5 years, each at 50% time (20 hours/week). Graduate fringe is budgeted at 0.87 of salary load and includes tuition for the academic year, health care for the fiscal year, and social security and Medicare for summer pay periods. Work will be conducting imputation trials under guidance of PIs and Research Fellow with a focus on planning and improving map information, respectively. (Activity 1,2 &3) Totals 3.0 FTE, $108,560											
D) Civil Service employees: employ two recently graduated U of MN forestry students (with a B.S. degree, but not enrolled as graduate students) to conduct short trials to demonstrate field aspects of actual imputation methodologies for inventory. These students (Kylee Berger and Paul Swanson) are employed as Civil Service Bargaining Unit employees. $12,000.											
Equipment/Tools/Supplies: Expendable field measurement and data capture equipment and supplies. for data verification at the Cloquet Forestry Center, on cooperator sites and for demonstration, such as, for example: …Criterion RD 1000 Electronic BAF-Scope/Dendrometer @ $1,470; ...Haglöf Laser Vertex Hypsometers @ $2,140; …Juniper Systems ruggedized field data recorder with GPS receiver @ $1,600.	4,500	4,500	0				4,439	0	0	8,939	$ -
Travel expenses in Minnesota: Travel - to pay mileage (75%) and per diem costs (25%) for project personnel to collect project data and meet with study cooperators on results and in workshops.	500	500	0	500	0	500	1,000	23	977	2,000	$ 1,477
COLUMN TOTAL	**$ 58,500**	**$58,500**	**$0**	**$90,500**	**$90,000**	**$500**	**$113,000**	**$107,584**	**$977**	**$262,000**	**$ 1,477**