Data Management for Urban Tree Monitoring – Software Requirements

Prepared by Azavea for the Pennsylvania Horticultural Society and the USDA Forest Service

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Abstract

The creation of this report was organized by the Pennsylvania Horticultural Society (PHS) and the USDA Forest Service Philadelphia Field Station to explore how technology could be used to support the long-term systematic monitoring of urban trees by trained professionals, student interns and volunteers; assist with tree planting and maintenance data processes; and enable data to be organized and shared between researchers and practitioners.

Interviews with researchers and forestry practitioners led to the development of user stories demonstrating how various individuals would interact with a software tool designed for long-term urban forestry monitoring. The information gathered from the interviews also resulted in a list of related system requirements for an ideal software monitoring system. Using that list of requirements, an evaluation of eleven existing software platforms in three general categories (proprietary forestry software, proprietary non-forestry specific software, and free and open source software) was completed and options listed for expanding the software to meet the system requirements. Data model and data integration workflows for a software system that met the majority of the system requirements were outlined, and PHS served as a test case for how such a system might work for tree planting and monitoring. The report concludes with a series of recommendations regarding cost and tech support, establishing an open data standard, creating a central data repository, and balancing collaboration and leadership.

Introduction

Trees in urban settings play a vital role in our communities. Whether newly planted or decades old, urban trees provide crucial environmental, economic, community, and aesthetic benefits. A healthy urban forest can assist with stormwater mitigation efforts, shade buildings to save energy, beautify neighborhoods, increase property values, positively impact human health, and encourage community members to spend time outdoors.[1]

Growing a vibrant urban forest requires maintenance, stewardship, and the regular planting of new trees. Planting campaigns by governmental, non-profit, and community groups have resulted in millions of young trees added to cities throughout the United States in recent years.[2] While many of these new trees are catalogued and counted as part of the planting initiative, less data is available about urban trees as they grow and eventually die.[3] Information about stewardship activities such as pruning, watering, and planting site improvements is also seldom tracked consistently after trees are planted, despite research demonstrating that such activities may directly impact the health and growth of the tree.[4] [5] [6]

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[1] Nowak, DJ, JF Dwyer. 2007. Understanding the benefits and costs of urban forest ecosystems, pp 25-46 In: *Urban and community forestry in the Northeast*, 2nd ed., JE Kuser, ed. Springer: New York, 571 pp.
[2] Young, RF, EG McPherson. 2013. Governing metropolitan green infrastructure in the United States. *Landscape & Urban Planning* 109: 67-75
[3] Roman, LA, EG McPherson, BC Scharenbroch, J Bartens. 2013. Identifying common practices and challenges for local urban tree monitoring programs across the United States. *Arboriculture & Urban Forestry* 39: 292-299.
[4] Koeser, AK, EF Gilman, M Paz, C Harchick. 2014. Factors influencing urban tree planting program growth and survival in Florida, United States. *Urban Forestry & Urban Greening* 13: 655-661.
[5] Vogt, JM, SL Watkins, SK Mincey, MS Patterson, BC Fischer. 2015. Explaining planted-tree survival and growth in urban neighborhoods: A socio-ecological approach to studying recently planted trees in Indianapolis. *Landscape & Urban Planning* 136: 130-143.

Long-term monitoring data related to urban tree health, growth and mortality rates, and longevity is useful to urban forestry professionals, scientists, and local community groups for four key purposes:

1. Gathering tree growth, mortality, and health data for planting programs as a means to evaluate performance, inform program management, and adapt practices over time
2. Coordinating community stewardship activities to encourage tree health and survival
3. Understanding how urban forests change through time in terms of population dynamics, including growth, mortality, and species diversity
4. Generating empirical data for use in accurately projecting urban tree populations and the related future estimated ecosystem services in order to demonstrate the value of planting campaigns toward environmental targets and goals

As part of long-term monitoring, it is essential to track longitudinal[7] data about the same individual trees and planting sites. However, that process can be time-intensive, require extensive staffing resources, and result in large amounts of data that may be difficult to organize and quickly access or search. Although there are several existing software platforms designed for tracking urban tree asset and works management activities, conducting tree inventories, and estimating ecosystem services, these systems are not specifically focused on gathering and managing long-term monitoring data or stewardship and management data.[8] In order to increase the amount of available empirical data, it is crucial to explore how to use technology to accurately gather tree data over time using field crews with varying levels of experience and then manage that data in a way that enables sharing information between groups.

Organized by PHS and the USDA Forest Service Philadelphia Field Station, the following report outlines the key issues related to longitudinal tree data gathering, the necessary technical features to support such data gathering, and a design for proceeding with a new software architecture for tracking long-term data, searching existing data, and connecting data between inventory systems. While the report consistently uses the term monitoring to describe data collection, the data gathered also relates to stewardship and management practices. Consistent gathering of this management data supports opportunities to evaluate progress toward the achievement of management objectives over time. Long-term data collection is thus a central component of adaptive environmental management.[9] The report was commissioned to evaluate user needs and compare those needs against existing software options; this report and its authors do not advocate for any particular software solution.

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[6] Roman, LA, LA Walker, CM Martineau, DJ Muffly, SA MacQueen, W Harris. 2015. Stewardship matters: Case studies in establishment success of urban trees. *Urban Forestry & Urban Greening* 14: 1174-1182.

[7] Longitudinal data is repeated observations on the same individuals over time. For other definitions relevant to urban tree mortality and monitoring, see: Roman, LA, JJ Battles, JR McBride. 2016. Urban Tree Mortality: A Primer on Demographic Approaches. Gen. Tech. rep. NRS-158. Newtown Sq., PA: USDA Forest Service, Northern Research Station. 24 pp.

[8] Roman et al. (2013)

[9] For more information on adaptive environmental management, see:

- Argent, RM. 2009. Components of Adaptive Management, pp 11-32 In: *Adaptive environmental management: A practitioner's guide*, 1st ed., C Allan, GH Stankey, ed. Springer Science: The Netherlands and CSIRO Publishing: Collingwood, Australia, 351 pp.
- Armitage, DR, R Plummer, F Berkes, RI Arthur, AT Charles, IJ Davidson-Hunt, AP Diduck, et al. 2008. Adaptive co-management for social–ecological complexity. *Frontiers in Ecology and the Environment* 7: 95–102.

The report focuses on the annual planting program at PHS as a case study for managing tree data at a local level. The results of the investigation, however, are applicable to urban forestry programs across the United States and around the world. This report can assist urban forestry researchers, practitioners, and volunteers in reviewing their data gathering protocols to consider additional opportunities for tracking and sharing urban tree data.

Urban Tree Monitoring Needs

Background

This report grew from several years of work by urban forestry researchers and professionals who were interested in long-term data collection. In September 2011, The Morton Arboretum in Lisle, Illinois hosted the Urban Tree Growth symposium, a research conference on urban tree growth and longevity intended to encourage discussions between researchers and practitioners, share recent research findings, and outline priorities for additional studies and collaboration. Researchers and managers at the symposium noted in a roundtable discussion that the lack of high-quality, long-term, robust data sets prevents rigorous scientific investigation into how planting techniques, maintenance activities, volunteer initiatives, and other management elements impact tree health and life expectancy.[10]

The Urban Tree Growth symposium highlighted the need for urban tree monitoring protocols and standardized data collection that would provide the quality necessary for the data to be useful for scientific research and tree management decisions. The need for accurate and consistent urban forestry data has long been a focus of the Urban Tree Growth & Longevity (UTGL) Working Group who organized the symposium. UTGL, a working group of the Arboricultural Research and Education Academy under the International Society of Arboriculture, is an international community of practice. UTGL's mission is "to foster communication among researchers and professionals, enrich scientific exchange, and enhance the quality, productivity, and timeliness of research on tree growth and longevity through collaboration."[11] [12]

Based on the priorities set at the symposium as well as a national survey of thirty-two local urban forestry organizations[13], the UTGL working group created the Urban Tree Monitoring Protocol, a framework for gathering standardized, long-term tree data. The protocol was developed with input from researchers, practitioners, and students and is designed to collect data that will both assist with answering key research questions and inform the planting and maintenance practices of urban forestry professionals. The protocol is divided into a minimum data set that includes the standard fields an organization could gather if they wish to participate in long-term monitoring initiatives and four supplemental data sets that focus on a more in-depth analysis of tree health and growth, the planting site, human management practices and stewardship, and characteristics of the human community surrounding the tree (Figure 1).[14]

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[10] Leibowitz, R. 2012. Urban tree growth and longevity: An international meeting and research symposium white paper. *Arboriculture & Urban Forestry* 38: 237-241.
[11] Scharenbroch, BC, LA Roman, EG McPherson, J Bartens, D Boyer. 2014. The pulse of the urban forest: Working group focused on urban tree growth and longevity. *Arborist News* Dec: 54-55.
[12] Campbell, LK, ES Svendsen, LA Roman. 2016. Knowledge co-production at the research-practice interface: Embedded case studies from urban forestry. *Environmental Management* dx.doi.org/10.1007/s00267-016-0680-8.
[13] Roman et al. (2013)
[14] Urban Tree Monitoring Protocol, http://www.urbantreegrowth.org/urban-tree-monitoring-protocol.html

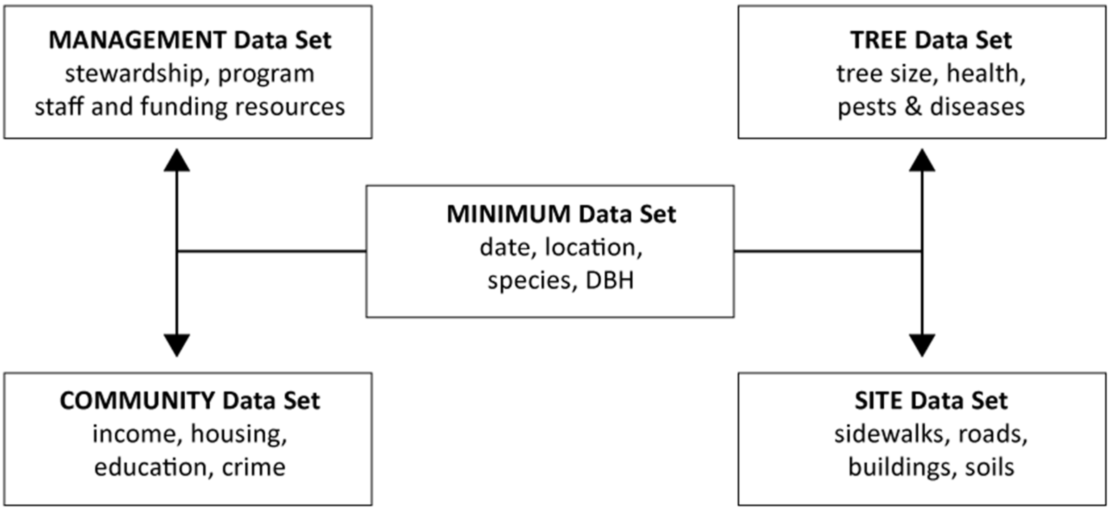

Figure 1. Data sets framework for the urban tree monitoring protocols developed by the UTGL working group.

The survey respondents frequently mentioned that staffing and funding issues prevented them from regularly monitoring trees, and some organizations also expressed that considerable staff time was spent determining what and how to monitor. The urban tree monitoring protocol increases the efficiency of the monitoring process by providing standardized data fields that can be customized to meet the needs of the organization. For many groups, collecting the information in the minimum data set (including observation date, tree location, species, stem diameter; Figure 2) may meet their management objectives and fit within the available resources. Other organizations may wish to focus on one of the four supplemental data sets based on the goals of their monitoring project or their organizational mission.

Field testing of the minimum data set was conducted in several cities in summer 2014. Field crews were classified into three types – expert, intermediate, and novice – based on their self-reported experience levels with urban forestry and field data collection. All groups used the field guide that provided explanations of how to gather the variables in the minimum data set. Researchers then analyzed the results of the data collection to determine how experience level impacted the accuracy of data gathered via the minimum data set. The results were mixed based on the city, but initial analysis shows that the minimum data set field guide and overall process were generally understood by the field crews and straightforward to gather. Refinement of the minimum data set is in progress based on the results of the pilot test.[15]

[15] For preliminary findings from the pilot test of the Urban Tree Monitoring Protocol, see: Roman, L. January 2015. Errors and consistency in urban tree data: A pilot test of the urban tree monitoring protocol. *Urban Tree Growth & Longevity Newsletter*. http://www.urbantreegrowth.org/uploads/1/1/1/7/11172919/monitoring_protocol_pilot_testing.pdf

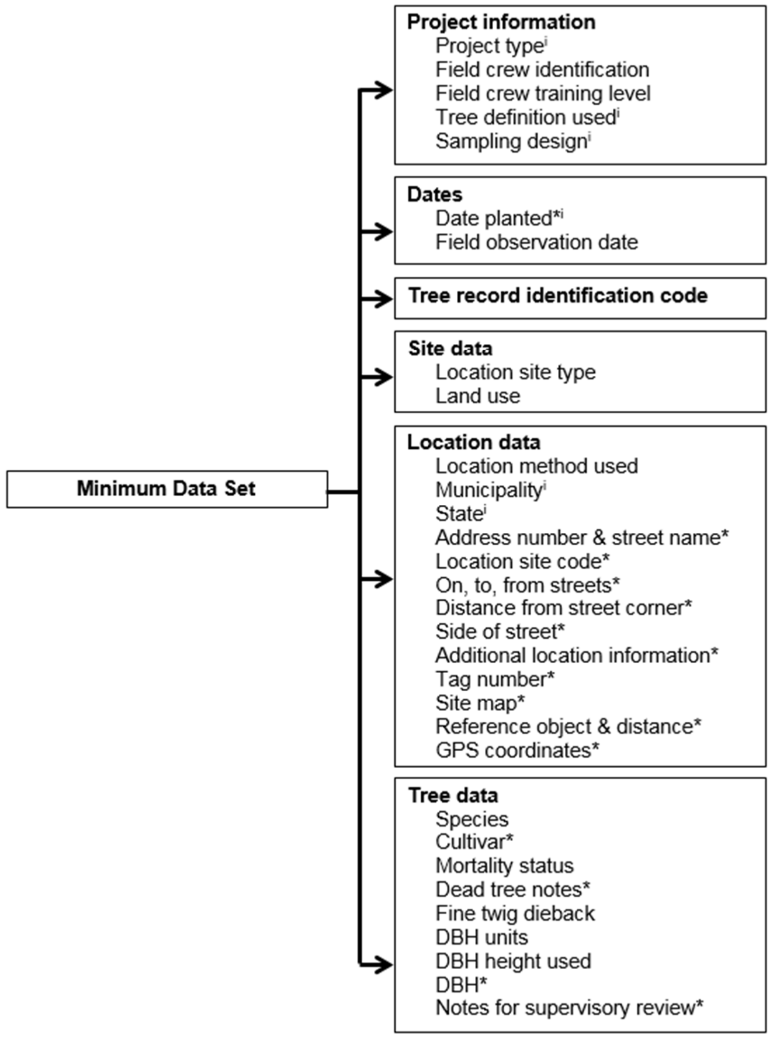

Figure 2. An overview of variables included in the minimum data set. Variables marked * have different options according to project type, tree site type, and field crew training level. For example, several methods for location are available, depending upon the site type. Variables marked [i] are recorded in-office by the project supervisor, others are collected in the field. A working draft of the field guide and other supporting documents are available at www.urbantreegrowth.org.

Objectives of this Report

While the urban tree monitoring protocol is an important step toward establishing best practices for long-term data collection, the protocol does not provide recommendations for a software system to use for data collection. A critical next step is to develop software systems to support monitoring or to adapt existing systems. Additional information is needed from researchers and practitioners on their technology needs, software systems they have used thus far for inventory and monitoring, and the funding or other resource constraints that might influence the software they implement.

PHS and the USDA Forest Service Philadelphia Field Station requested this report to achieve the following key objectives.

1. Develop a list of user needs through a series of interviews with practitioners and researchers
2. Outline data needs of PHS as a case study
3. Create user stories based on identified needs
4. Translate user needs into a list of software system requirements
5. Identify top priority requirements
6. Evaluate existing urban forestry software tools to determine whether the software includes the identified system requirements
7. Create a data model and system architecture that meets the system requirements
8. Apply the data model to the PHS tree planting and data workflow as a case study
9. Provide overall software architecture recommendations

While the urban forest is broadly defined to include street trees, yard trees, and park trees, this report is primarily focused on street trees. Many of the issues discussed here would also apply to yard trees and open-grown trees in city parks and plazas. There are additional considerations for monitoring trees in wooded areas with closed canopy that have been addressed by forest ecologists.[16]

The following sections outline the activities conducted to complete those objectives.

Practitioner and Researcher Interviews

Proposing a useful software framework for gathering and managing data varies depending on the needs of urban tree inventory and monitoring projects. There are differences in the goals for urban forestry data gathering (e.g., scientific research, grant reporting, planting program evaluation), the number of trees surveyed, the available technical and human resources, and the timeframe for updating the tree data. Despite the varied goals, these projects generally have some similar needs including a system that encourages efficient standardized data entry, options for quality checking and storing that data, and flexible methods for searching and sharing the information with other organizations and researchers.

To identify specific urban tree monitoring needs, interviews were conducted with over twenty researchers, practitioners, and volunteers from organizations throughout the United States that had participated in tree data gathering projects. The interviewees included individuals from federal agencies such as the USDA Forest Service, researchers working at academic institutions, urban forestry practitioners at both non-profit groups and municipal governments, volunteers who assist the non-profit groups, and students who participated in data collection.

Each of the interviewees had participated in or organized a tree data gathering initiative although the purpose and length of those projects varied. Interviewees were asked to describe their project workflow, specifically in terms of data management before, during, and after field data collection. They were encouraged to describe the usefulness of both the visual interface for setting up a field monitoring project, gathering the data, and the robustness of the administrative functionality such as managing and editing the collected data. The interviews also included discussions of how software could be used to support repeated monitoring visits to the same tree, data collection by users with varying levels of

[16] van Doorn, N.S. 2014. Best practices and quantified error rates for long-term tagged-tree inventories: Examples from a temperate forest. Chapter 3 in: *Patterns and processes of forest growth: The role of neighborhood dynamics and tree demography in a northern hardwood forest*. PhD dissertation, University of California, Berkeley. Berkeley, CA.

experience, and options for sharing collected data with other users. Interviewees were also asked about the technical resources at their institution and their overall goals for using technology in their urban forestry related work. A full list of the interview questions is available in Appendix A.

The interview process demonstrated that the urban forestry data needs of municipal governments often vary from those of researchers and non-profit groups. Many municipal governments must focus on managing work orders relating to tree maintenance, identifying and pruning or removing hazard trees, coordinating tree removal or pruning for public works projects, and responding to tree inquiries and concerns from the general public. To deal with these logistical issues, municipal parks and recreation departments often utilize existing works management systems and integrate with 311 systems. While municipal governments are frequently interested in the systems requirements outlined below, they may be hampered by software contracting agreements and data processes in place at the departmental or municipal level that prevent them from switching to a new software framework. The needs of municipal forestry workers have been included as much as possible while not extending the systems requirements or proposed software architecture beyond the needs of the other intended users.

Systems Requirements

Whether focused on research or tree planting and maintenance, interviewees consistently reported similar difficulties with the data collection and storage process. The key concerns are organized into three areas:

- Data gathering: How information about the trees is added and updated using the software
- Data management: How administrators manage and customize the data fields and collection process
- Technical infrastructure: How the software is implemented and available support options

These features serve as an overall list of systems requirements that the proposed software architecture should meet. The system requirements support the two most common data gathering projects reported by interviewees:

- Cohort monitoring: Tracking data on trees planted around the same time and often as part of a single program (e.g., monitoring trees planted by PHS)
- Repeated inventories: Gathering baseline data for existing trees in a geographic area (e.g., city, neighborhood, campus) and then conducting additional data gathering in future years (e.g., repeated street tree inventory for an entire city or repeated i-Tree Eco plots)

Data Gathering

1. Add Data Via Mobile Interface

All interviewees saw mobile software as crucial for efficient data entry but had used a variety of existing applications for that data entry. Interviewees expressed concern about mobile applications that required data plan access as some areas may not have sufficient cellular data signals. Offline data editing that can later be synced with the main database should ideally be an option but is not a necessity.

If an organization intends to support volunteers or employees adding data via their personal devices, the mobile software for data entry should not be limited to a single platform such as iOS devices or Android devices. In general, software that works on multiple platforms provides greater flexibility in the type of devices that can be purchased and the number of people able to add data. The mobile interface must include a simple, easy to use interface that supports adding new tree details or editing existing data. A flexible data workflow is also essential. One field crew, for example, may wish to add one data point (such as species) for several trees and then the next data point (such as trunk diameter) rather than entering all the data on a single tree before proceeding to the next tree. Another field crew may have one team take all the photos of trees surveyed by the rest of the field crew. As much as possible, the mobile interface should not overly limit how field crews may gather data.

2. Prioritize User Friendly Design

User experience design has frequently been overlooked in favor of the functional needs of data gathering. Long-term monitoring projects are more likely to be dependent upon volunteers and student workers for data entry, however, and a well-designed user interface will improve the field data gathering experience and encourage citizen scientists to repeatedly participate. One interviewee noted that he is wary of specialized software systems as they generally require more extensive training time and field crews lack familiarity with the system and make simple errors that would not occur if using a more common system like Microsoft Office. The software system must be simple to understand and utilize a design that prevents field crews from submitting data errors due to poor placement of buttons, incorrectly formatted data fields, and other design related items. The design of the adding and editing interface can also assist with improving data quality by clearly explaining how to gather data and providing training materials.

3. Support Multiple Methods for Accurate Tree Location Identification

Interviewees frequently mentioned both the importance of accurately determining a tree's location and the difficulty in identifying that same tree for monitoring in the future. While the location of a tree may be noted during an inventory or in a list of planted trees, the locations may be identified with insufficient detail or at a spatial resolution that prevents field crews from confidently locating the tree. Problems can arise from trees that die and are replaced (without sufficient notation to distinguish the original tree and the replacement tree), when methods for tracking location change from one survey to the next, or because the chosen location method may not result in detailed enough coordinates or other geospatial notes.

For example, a field crew may list a six-inch Red Maple at location X in 2007. Five years later, the field crew returns to the site and cannot find any tree at the exact geospatial coordinates or address for location X. The nearest tree is a three-inch Zelkova, and there is a seven-inch Red Maple several feet away. Did the six-inch Red Maple die with the Zelkova planted as a replacement? Or, alternatively, was the original location of the Red Maple inaccurately reported, and therefore the nearby seven-inch Red Maple is the same tree as the six-inch Red Maple reported in 2007? Tree identification tags affixed to the tree would solve this dilemma and such tags are standard practice in rural forest monitoring. However, urban foresters rarely employ tree tags due to concerns over vandalism as well as residents' discomfort with tree tags.

These and other issues frequently arise due to insufficient methods for tracking location. With tree planting programs, for example, an address might be sufficient for funding and reporting requirements, but address alone will generally not be enough information to monitor those trees for mortality. While setting protocols for how to enter location data during field work is outside the scope of this report,[17] many of the interviewees mentioned the necessity of viewing and setting tree locations using a map and tracking location using more than one method. Any software framework must accommodate multiple tree location identification methods including:

- Placing a point on a satellite image of a map
- Entering latitude and longitude coordinates
- Entering an address
- Entering notes describing the tree's location
- Entering distances from the tree to a semi-permanent object (fire hydrant, light post, etc.)
- Uploading a ground-level photo of the tree's location
- Uploading an aerial or satellite image of the tree
- Tracking street tree location in connection with a block edge, based on distance from the curb corner (also known as the TreeKIT method)[18]

4. Enable Photo Upload and Integration with Tree Data

Photos can be a useful tool for identifying or confirming location. They also assist with demonstrating the health of a tree or visually tracking a tree feature that a field crew member may wish for another colleague to examine, such as validating species identification or investigating a health problem. Despite these benefits, several interviewees noted that taking photos and associating them with the correct tree was logistically difficult. Field crews may take photos on a device other than that which they are using to record data, making it challenging to later associate the correct image with the gathered data. If they do take the images on the same device used for data collection, there may not be a method for immediately associating the photo with the field data.

This problem is exacerbated when many photos are taken of the same tree (full profile, close-up of planting site, canopy image, etc.) or when an image includes a tree in the foreground and another in the background. Adding images using the software in which the tree data is tracked may be a solution, but interviewees also expressed concern regarding the storage costs for hosting large numbers of images.

5. Support Multiple Data Entries on a Single Tree

Long-term monitoring studies result in repeated surveys of the same tree over multiple years. The software system should include functionality to associate multiple pieces of data with a single survey, view previous surveys for the same tree, and search for data across all surveys. Each survey should also include information on the user who logged the data to assist researchers in investigating data quality.

6. Support Data Tracking via Paper Forms

While the above list reflects the increasing reliance on digital technology for gathering data and tracking tree stewardship, there remains a sizeable group of individuals who prefer collecting data via paper. Several interviewees mentioned they had gathered data via both mobile device and paper forms and found the paper forms useful as a semi-permanent record of the collected data. The forms were

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[17] The appropriate uses of various tree location methods are reviewed in the Urban Tree Monitoring Protocol. See http://www.urbantreegrowth.org/field-guide.html.

[18] Silva, P, E Barry, S Plitt. 2013. TreeKIT: Measuring, mapping, and collaboratively managing urban forests. *Cities and the Environment* 6: article 3. Available online at http://digitalcommons.lmu.edu/cgi/viewcontent.cgi?article=1126&context=cate.

scanned and served as a resource to "double check" when there was confusion in data tracked via the mobile app. However, mobile data collection was the preferred option for most interviewees because of concerns around keeping track of papers, the need to have crews spend time on data entry, and the possibility of transcription errors.

Duplicate data collection via paper and mobile device may be repetitious and too resource intensive for some groups, but the ideal software system would include options for printing a paper data collection form and enable adding location information other than just geospatial coordinates from a mobile device. It is possible that improved user experience on mobile devices would reduce the need for paper options. Yet even for interviewees that wish to rely solely on mobile data collection, paper data sheets also remained important as a back-up for days when the technology failed (e.g., broken devices, GPS coordinates not recording properly).

Data Management

1. Create Consistent but Customizable Data

Interviewees expressed interest in both a recommended set of data fields as well as the ability to customize the fields to meet the needs of their own organization. The Urban Tree Monitoring Protocol developed by the UTGL working group may serve as the initial fields listed in the software, but researchers and practitioners want the option to add to the list of fields.

2. Enable the Ability to Set the Fields Visible and Editable by Field Crews

The organizer of a monitoring project may have different field crews gather certain data based on their field collection experience. In future years or for quality assurance checks, the organizer may set up another project so that field crews can see some but not all of the data from a previous survey. The software system should include options for project administrators to customize which data fields can be viewed by field crews, which fields can be edited, and which fields may display information from a previous survey.

3. Provide Training Materials and Collection Reminders

The software system should include in context training material as part of the mobile interface in the form of data collection notes or a help tip icon that can be selected for additional information. Interviewees noted species identification and diameter measurement techniques as key areas where guidance is useful to citizen scientists and student workers. Providing informative text in an unobtrusive way is essential to prevent the training materials from cluttering the data entry form. A printed sheet may be useful as an accompaniment to online resources (and such printed materials for the Urban Tree Monitoring Protocol are already under development by UTGL).

4. Document Name and Training Level of Data Collector

Information about who gathered the data and the training those individuals received provides researchers and practitioners the ability to analyze data quality and understand how field crew training and prior experience impact quality. Metadata on how data fields were collected (tree condition evaluated according to these variables, for example) should be included as a data dictionary in any data export.

5. Support Several Types of Data Export

Users should be able to search and query the collected data - ideally via a reporting dashboard that includes standard reports (number of trees per species, queries for data on trees of a certain diameter) as well as the option to create custom reports. In addition or as an alternative, the software should include the option to export data for use in an external system such as a statistical analysis system or a works management platform. Key export data types include a comma-separated values (CSV) file for use in software such as Microsoft Excel, a shapefile for use in a Geographic Information System (GIS), XML files for use in meeting metadata and archiving requirements, and as a file that includes the fields necessary for analysis in the USDA Forest Service's i-Tree software.

Technical Infrastructure

1. Create Software as Open Source or with a Free Version

While not all the software used for previous monitoring activities was open source, many interviewees mentioned they were more interested in open source software as a way to decrease the cost of a data gathering project. Several groups noted that they did not have the internal technical support to implement open source code, however. There was sometimes conflation of open source software with free software when these two are not synonymous[19]. Interviewees frequently turned toward free or low-cost software tools due to financial resource constraints as well as limited in-house capacity to implement open source options.

2. Implement as Web and Cloud-Based to Support Multiple Users and Devices

All interviewees felt that the software system and associated data should be accessible to multiple users at the same time from various devices – mobile, tablet, and desktop. The system should not be hosted on a single desktop computer or type of device although some functionality such as the ability to customize fields or edit multiple trees at once may be limited to a non-mobile interface. Ideally, the system would require user accounts to track data entry but not have restrictions on the number of available accounts. Data storage would be cloud-based to prevent hosting issues impacting access.

3. Include Ability to Store Associated Data

Any software system for data monitoring must include options for storing additional data associated with the trees such as photos and scanned paper forms. Users may also wish to upload files including satellite imagery and urban tree canopy analysis that are associated with several tree records.

4. Encourage Interoperability with Other Systems

Organizations may use different software systems for gathering and managing tree data, but any software data architecture designed for long-term monitoring should include integration options for importing data from another system and exporting data for inclusion in another system. This process may be manual via a series of exports and review of potential data conflicts or it may involve an Application Programming Interface (API) to automatically move data between systems.

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[19] Open source software has the code publically accessible and available for others to use, yet implementing such code often requires having programmers or other technical experts on staff, or paying a software firm to customize it. Conversely, free software may not have code that is publically available. In the context of urban forestry, i-Tree is an example of free software and OpenTreeMap is an example of open source software.

5. Provide Options for Technical Support

Few organizations have the internal technical support to provide maintenance for software tools and guidance on using the system. The software system should have technical support options including online materials, user forums, and potentially direct access to the developers of the software to assist with customization and usability questions.

Philadelphia Case Study

In this report, we highlight a case study from a tree planting program in Philadelphia, as a way to dive deeper into the specific program needs for tree monitoring and software management. PHS is a non-profit organization founded in 1827 that provides educational workshops, leads tree planting activities, and organizes other vital programs to promote horticulture, urban forestry, and community greening initiatives. PHS has an active Tree Tenders training program and leads large-scale tree planting efforts in the spring and fall. They work closely with the City of Philadelphia to organize those plantings and have created a Tree Checkers program to ensure recently planted trees are monitored within a year of that planting. PHS often partners with researchers at the USDA Forest Service Philadelphia Field Station and professors at universities across the country who are interested in tree monitoring and stewardship.

All these activities result in a significant amount of data about both the newly planted trees and older trees that are monitored by local Tree Tenders groups. As of the writing of this report, that data was managed through a variety of spreadsheets, although PHS has since implemented the Urban Forest Cloud system from Plan-It Geo in late 2015. Like many non-profit and governmental organizations, PHS receives and shares data with several other groups. Their process for managing tree planting requests, gathering data as part of those plantings, and monitoring trees serves as a case study for the needs of many groups.

Current Tree Planting Data Workflow

Tree plantings are conducted in the spring and fall, and trees are typically placed in street tree planting sites in sidewalks. Each planting involves coordinating information between PHS, the various community Tree Tenders groups (currently numbering around thirty), the property owner requesting the tree, and the City of Philadelphia Department of Parks and Recreation. The workflow described below is current as of the spring 2015 planting season.

1. The property owner submits a paper application to the Tree Tenders group associated with their neighborhood. Each Tree Tenders group has a defined geographic area they manage. If no Tree Tenders group is available in the area, the request comes directly to PHS.
2. The Tree Tenders group compiles all the requests for their area into a template spreadsheet provided by PHS and then submits the spreadsheet to the planting coordinator at PHS. The fields in the template were selected to match the fields in the database the City of Philadelphia uses to manage tree plantings.
3. The PHS planting coordinator creates a master spreadsheet from the spreadsheets for each Tree Tenders geographic area, which includes some data clean-up and organization.
4. The PHS planting coordinator sends the master spreadsheet to the City of Philadelphia. The master spreadsheet includes a look-up table that integrates the street names, inspector codes, zip codes, and park districts associated with the address where the requested tree will be planted.

5. Based on the spreadsheet, a supervisor at the City sends inspectors to the address associated with the requested tree to inspect the site where the tree will be placed along the sidewalk. The inspectors have a paper worksheet printed based on the data in the spreadsheet and note whether the tree location is approved or denied and what species they recommend for the location. If the planting site is a new location, the inspector marks the concrete for cutting.
6. The City updates the spreadsheet with the new data including whether the location was approved or denied, the allowed species, the size of the planting site, the date approved, if the location needs concrete cutting, and any notes about the location including a site ID code (1F for first tree in the front, 1S for first tree on the side, etc.) that associates the tree with the correct planting site at the address. This data is logged in the City's tree database.
7. The City returns the spreadsheet to the PHS planting coordinator who forwards the data related to each Tree Tenders area to that Tree Tenders group. The Tree Tenders groups contact the property owners regarding the approval or denial of their tree request. If the property owner no longer wishes to have a tree planted, the Tree Tenders group updates the spreadsheet and informs the PHS planting coordinator.
8. The PHS planting coordinator sends the spreadsheet to the nursery to confirm the availability of the approved species. The spreadsheet is updated with substitute species if necessary.
9. Tree plantings happen on a single weekend during each planting season and are managed by the Tree Tenders group. The PHS planting coordinator sends an online survey to the Tree Tenders group to collect details on the planting event and any resources that might be needed.
10. After planting, the Tree Tenders group contacts the PHS planting coordinator if certain trees could not be planted (property owner changed his or her mind at last minute, an unforeseen obstruction in planting site prevented new tree, etc.).
11. The PHS planting coordinator updates the master spreadsheet. The spreadsheet is not considered "final" until after planting day. Lastly, the PHS planting coordinator sends the spreadsheet to the City who updates their database to reflect cancelled plantings.

The tree planting data workflow has several identified issues including:

- A generally cumbersome and complex process with too many steps.
- Uncertainty regarding location of the trees. The location is identified by address, site ID code, and any notes left by the City inspector or the planting group. Geospatial coordinates are not recorded and locations can lack the specificity needed to map plantings as accurately as possible for future monitoring.
- Spreadsheets must frequently be edited and moved between groups, increasing the potential for data quality issues.
- No event or user data is stored as part of the tree data workflow.

Current Tree Checker Data Workflow

The Tree Checker program encourages Tree Tenders groups to gather survival, condition, trunk circumference, crown vigor, and stewardship information on recently planted trees, identify potential issues, and note where replacement trees are needed. Property owners are responsible for caring for their new tree for the first two years. The Tree Checker field work serves as an opportunity to review the condition of the tree, address maintenance needs, and educate the property owner in basic tree maintenance. This is a citizen science approach that relies on volunteers in the Tree Tenders program participating in Tree Checker. The below workflow is current as of the spring 2015 planting season.

1. Each June, the PHS planting coordinator creates a spreadsheet for each Tree Tenders group that includes the trees planted in their geographic area the previous spring and fall. The PHS planting coordinator sends the spreadsheet and a Tree Checker report card to the leader of the Tree Tenders group.
2. Most Tree Tenders groups print out their spreadsheet and forms and collect the data on each tree on the paper form. PHS is primarily interested in identifying trees that have died and need to be replaced as well as species mortality, but the form asks about other condition features.
3. The Tree Tenders group updates the spreadsheet based on their paper notes and returns it to the PHS planting coordinator.
4. The PHS planting coordinator reviews the returned spreadsheets to locate the trees noted as dead. The planting coordinator then updates the upcoming fall planting spreadsheet for that group to include an entry for a new tree at the location of the current dead tree. Replacements within five years do not require the property owner to complete a new application or the City to inspect the site again.
5. The PHS planting coordinator creates an annual report summarizing mortality by species based on gathered Tree Checker data.

The Tree Checker workflow has several identified issues including:

- The potential for duplicate trees requested to replace the dead tree. The property owner may already have requested a replacement tree as part of the upcoming fall planting. Address formatting issues have caused two requests for the same planting site to appear on a single fall planting spreadsheet.
- The Tree Checker data forms are stored as individual forms and not integrated into a master database or the original planting sheet, making it difficult to track the search for and locate the gathered data or compare several trees.
- Replacement trees are not connected with the previous tree at the site, limiting the ability to track the history of the planting site over time.

Philadelphia Data Workflow Needs

The current data workflows highlight the difficulties many organizations face when tracking tree planting and stewardship records. The many groups involved in planting a tree have varied needs and including them all can result in a lengthy process that does not capture all the needed information. In addition to the issues outlined above, review of the data workflow and interviews with those involved in the process shows several needs.

1. **Accurate Location** – Tree plantings must be associated with geospatial information other than address and site ID code. A large property may contain several trees or a site ID code may no longer be accurate if a planting site is added or removed (i.e., there used to be trees 1F and 2F, but after tree 1F is removed, tree 2F becomes 1F). Including some type of geospatial coordinates or placement of the tree on a map image in addition to the address and site ID code would assist with accurate location tracking.

   Identifying a tree's location is particularly crucial when an organization wishes to integrate data gathered by another group. Researchers who have worked in Philadelphia have agreed to provide their field data to PHS. However, that data can be difficult to integrate with the PHS tree tracking system due to different ways of identifying location or uncertainty as to whether a tree in the field data matches a tree in the planting spreadsheets. Map-based location information and accompanying photographs, if possible, would assist with long-term monitoring efforts. The Urban Forest Cloud solution PHS is implementing will move to a more map-based location identification option.

2. **Tracking Stewardship Activities** – The Tree Checker forms include condition information that can be valuable for exploring why trees succeed in the first few years after planting, especially if combined with additional information on stewardship activities for that tree. Many stewardship activities likely go unrecorded. Several of the interviewees noted that they track some items but others “we just know about” in a type of mental record keeping. The level of stewardship notes are likely to vary by group but having a database in which the Tree Tenders groups could log these actions would support scientific research efforts, provide valuable information for PHS on which groups operate most effectively in terms of tree care, and influence future tree plantings. Several interviewees expressed interest in having an option to log more detailed information or noted that they already keep additional notes shared between members of their group.

3. **Photos** – Many groups take photos on planting day. Several interviewees mentioned the benefits of being able to associate a photo with recorded data to both confirm the location of the tree and reference condition changes.

4. **Tracking Volunteer Data** – PHS is not unique in having a well-trained and enthusiastic group of volunteers. Those volunteers can provide valuable information and contribute to monitoring efforts. While data is organized by Tree Tenders group, a workflow that includes data on the person who planted the tree, the person who monitored the tree, the person who provided maintenance for the tree, and the level of training all these individuals received would facilitate research into how volunteer training impacts tree health and enable PHS to provide the most effective guidance to Tree Tenders. Additionally, tracking more detail on volunteer data may enable PHS to provide more thorough volunteer reports to funders or as part of grant proposals.

5. **Data Migration** – While data is shared between groups as part of the planting process, having a defined data migration system would support more frequent updating of records between systems. For example, PHS could provide stewardship related data to the City of Philadelphia that may influence pruning and maintenance activities, and the City could provide information about maintenance activities including street and sidewalk construction that are likely to impact trees maintained by a Tree Tenders group. Although challenging, this type of data migration can be accomplished through shared tree or site ID numbers, APIs to more seamlessly move data between systems rather than via spreadsheet uploads, and consistency in tracked data fields.

PHS is not unique in the data challenges it faces. Organizations across the country struggle with accurately tracking data, encouraging individuals to log stewardship actions, and efficiently sharing data between groups.

Intended Users of the Software

The interviews and the Philadelphia case study demonstrate that several types of users are likely to contribute data via an urban tree monitoring software system and those users will often have varying levels of urban forestry knowledge and field data collection experience. User experience designers often recommend creating user personas and user stories to assist in defining how a piece of software will be used and illustrating the functionality it needs to include.

User Personas

Examples of existing urban tree monitoring work show five user personas that may frequently use long-term tree monitoring software.

Student Intern

Our example student worker is Will. Will is a 21-year-old college student who is majoring in biology. He is interested in urban ecosystems and accepted a summer internship with his local regional planning commission to assist with a tree survey focused on gathering key pieces of data – species, diameter, location, and condition – for several hundred trees in a city neighborhood. Previous survey data about the trees is not available for this neighborhood. Will has taken a couple ecology and environmental studies classes but does not have experience with field data collection. He has never measured a tree in the field before but has practiced botanical identification in his coursework.

During the first week of his internship, Will received two days of training on species identification, tree condition assessment, how to measure tree diameter, and other items related to urban forestry field work. Will was observed in the field and received feedback on data collection as part of his training. Will is a technology enthusiast, a regular smartphone user, and cannot remember the last time he printed something out on paper. He is enthusiastic about the project but that enthusiasm combined with lack of background knowledge and reluctance to ask for help may lead to over-confidence in his tree data collection abilities. He will be gathering data with a partner and will be surveying trees for at least 25 hours a week.

Citizen Scientist

Our example citizen scientist is Susan. Susan is a 60-year-old accountant and long-time volunteer with Trees Are Super, a non-profit organization that focuses on community greening, urban tree planting, and educating diverse audiences about the importance of urban natural resources. While Susan has no formal training in urban forestry or ecology, she has participated in trainings offered by Trees Are Super, regularly attends planting and stewardship events, and believes strongly in the importance of neighborhood involvement in greening initiatives. Trees Are Super is hoping to more consistently track the stewardship activities conducted by community members as well as revisit and gather data on newly planted trees annually for the first three years after planting. Because Trees Are Super wants to engage community members in tracking trees and due to a lack of resources for hiring interns, the group will rely heavily on volunteers like Susan to gather that data.

Susan is comfortable with technology but not a consistently heavy smartphone user. She finds it easier to make notes on paper when she is working on tree stewardship but is happy to learn to use an app instead. Susan visits the trees in her neighborhood frequently, especially to keep them watered in the summer. She sometimes does not track all her stewardship activities because she does things quickly or figures it is more important to do the maintenance than to track it. She knows the necessity of proper monitoring but gets nervous about incorrectly logging data. She will be gathering data sometimes by herself and other times with experienced volunteers or first-time volunteers with little to no urban tree knowledge.

Practitioner – Urban Greening Non-profit

Marcus is the 35-year-old community tree manager at Trees Are Super, where he is in charge of organizing planting events, coordinating tree stewardship activities with volunteers, and managing all tree related data. Marcus has extensive experience in both urban forestry and community engagement initiatives and uses technology, including his smartphone, on a daily basis for both professional and personal purposes.

Marcus is interested in improving the data tracking and information sharing processes at Trees Are Super. The organization frequently shares data related to tree planting and stewardship activities with Treestown, the local municipal government, as well as community volunteers and sometimes research partners. It can be difficult to determine the most current data or know whether all activities have been tracked because different data is tracked by each group. Marcus also wants to utilize the dedicated Trees are Super volunteers to more actively monitor trees on a regular cycle in order to track growth and mortality over time. This will help Marcus to better understand program performance, and his program’s funders have also been starting to ask for performance reports about mortality. Before Trees Are Super can begin that project, however, Marcus wants to have a system in place, both logistically and technically, to effectively allocate volunteer hours and encourage the submission of high quality data. Marcus will organize tree surveys and planting activities but expects to have considerable assistance from both his coworkers and volunteer leaders.

Practitioner – Municipal Government Parks Department

Rita is the 45-year-old municipal arborist at Treestown Department of Parks and Recreation. Treestown is a mid-sized city, and the modest forestry budget is primarily intended for removing hazard trees and conducting an annual tree planting campaign. Trees are pruned every few years as funds are available, but there are no financial resources available for stewardship activities or regular data gathering. Rita manages a yard tree giveaway program, coordinates and shares data with Trees Are Super for their annual street tree planting campaign, and assists with directing pruning crews. Rita’s predecessor at Treestown had interns do a tree inventory for asset management using a state grant, but that inventory is now ten years old and out-of-date. When time allows, that inventory is sometimes updated with tree plantings and removals but data is not consistently added or removed and the overall accuracy of the inventory is unknown. Rita is a frequent user of technology and feels very comfortable with using her smartphone for both personal and professional activities.

Rita wants to streamline the process of sharing data with Trees Are Super and other groups but must work within the constraints of her department. She is unlikely to be able to purchase a new piece of software and her current data process is primarily a combination of the asset management system and spreadsheets related to tree plantings. Rita would like to have access to the monitoring data gathered by Trees Are Super as she feels it will be useful for understanding urban tree health and maintenance practices. She is hesitant, however, about how much of it will be integrated into her asset management system since she is nervous about the quality of volunteer data. Rita also hopes to more easily share pruning and planting data with other groups but will need to have the Parks and Recreation Commissioner confirm that data sharing is allowed.

Research Scientist

Lucy is a 50-year-old ecologist who specializes in urban forestry and is based at a large university. She's interested in studying urban tree growth and mortality patterns, how stewardship activities impact tree health, and how urban tree species may shift due to climate change. While Lucy receives some funding for fieldwork and can easily recruit student interns, she does not have the resources to regularly conduct tree monitoring at the scale necessary to gather the amount of data she needs. Lucy is comfortable with technology although she has regularly still uses paper forms when gathering data in the field. She's found that many students seem comfortable with a form that looks more "official" rather than a smartphone app that lets them add data quickly but makes it difficult to reference the entered data later in the day. She has become very good at reading a variety of poor handwriting.

Lucy would like to use data gathered by non-profit organizations, municipal governments, and other groups but is concerned about the quality of the data. In order for such data to be used in her research, Lucy needs to have the raw data but also background information on the training for the citizen scientists, how trees were selected for surveying, and other items related to how her partners collected data. She is interested in doing more systematic quality control checks on urban tree data collected by her interns and by volunteers with the local nonprofit. Lucy is open to sharing the results of her research with other organizations and researchers but feels it is important to credit the source of the information and any studies that result from it.

User Stories

While all five of these user personas are interested in collecting and using tree data, they have different purposes and needs as part of that process. The chart below outlines some of those user stories and can be read as "[Persona] wants to [Goal] so that she/he can [reason]." These user stories assisted in selecting the features included in the software evaluations.

Persona	Goal	Reason
Will: Student Intern	Enter tree data as efficiently as possible	Inventory all the trees in the neighborhood before the end of his internship
	View information from previous tree monitoring surveys	Determine whether the planting site features a new tree or a tree previously tracked in the database
	Use a mobile interface to enter data	Avoid keeping track of paper forms and inventory trees more efficiently
Susan: Citizen Scientist	Receive guidance on data entry	Feel confident in the quality of data that she is entering
	Have the option to use a paper form	Enter data even if her mobile device does not have data plan access or if she is not comfortable with the mobile app interface
	Feel that she is part of a community initiative	See the importance of her contributions and show others why they should become volunteers

Marcus: Practitioner – Urban Greening Non-profit	Manage plantings and survey monitoring in a single database	Have a single source of information about the trees managed by his group and more easily update the records
	Limit the data that can be edited and who can edit it	Ensure only trained volunteers contribute high quality data
	Have someone to call for tech support	Focus on tree data rather than worrying about how to keep the software running
	Use a software system that is free or low-cost	Devote more of his limited budget to tree plantings and maintenance
	Edit the entered data	Correct inaccurate information or update details from an older tree survey
Rita: Practitioner – Municipal Government Parks Dept	Manage city contractors and service requests in the same system as her inventory	Have a single source of information about municipal trees and reduce confusion
	Import data from the local tree organization	Update her works management system to include the most current data on tree condition, which may impact scheduled maintenance
	Analyze inventory data	Make effective management decisions about tree planting, pruning, and hazard tree removal
	Use the works management software system in place	Avoid a lengthy budgeting process that will likely prevent the implementation of a new system
Lucy: Research Scientist	Get high quality data from a variety of sources	Investigate the factors that influence tree growth, health, and mortality.
	Get data in a consistent format	Minimize the time spent reformatting data and instead focus on her research
	View information on how the data was gathered	Understand the collection methods and explore their impact on data accuracy
	Have one website to visit to access multiple data sources	Minimize the time spent contacting dozens of organizations and discussing their data and instead focus on her research

The five user personas and their resulting user stories provide a valuable framework for understanding how different individuals may interact with software intended for long-term tree data monitoring. The needs of these users should be included in any discussion of software development and particularly when exploring the user interface and workflow processes for a software tool. Software solutions for urban tree monitoring may not fully meet the needs of all users, so it is critical to consider who the primary users are.

Software Evaluations

There are several existing pieces of software developed to track urban tree asset and works management activities, conduct tree inventories, and estimate ecosystem services. Few of these systems, however, are designed to support the gathering and managing of long-term monitoring data by diverse groups of users ranging from volunteers to trained arborists.

It may be possible to adapt an existing system to meet the system requirements outlined above and the general needs described in the interviews, user stories, and the Philadelphia Case Study. To evaluate that possibility, eleven existing platforms were analyzed to determine their capability for adaptation to support long-term monitoring.

Selected Software Platforms

Software was selected for review based on recommendations from individuals who have completed inventory and monitoring projects as well as a survey of commonly used existing services for data gathering by citizen scientists. The software systems fell into three general categories.

Proprietary Forestry Software

The proprietary forestry software systems are developed by businesses that provide access to the software tools for a fee. In general, these systems focus on providing tools for conducting tree inventories, organizing works management tasks, and managing planting activities. Four such systems were evaluated.

- ArborPro developed by ArborPro Inc.
- ArborScope developed by Bartlett Tree Experts
- TreeKeeper developed by Davey Tree Expert Company
- Tree Plotter developed by Plan-It Geo

These systems vary in terms of available features, options for public access, and pricing. In some cases, a free or low-cost version may be available that includes some functionality of the larger system. The systems share some similarities such as:

- A focus on the needs of urban forestry inventory and works management, although not necessarily long-term monitoring of the same trees
- A core set of data collection and inventory management functionality that can be customized either by the administrator or by the company from which the software was purchased
- Mobile access from a variety of types of devices
- Extensive support and help options available via phone and email
- Pricing available upon request and customized based on the number of users
- A user interface focused on the functional needs of data gathering
- Primary use by a small group of arborists or staff members of the organization purchasing the software rather than a large-scale citizen science volunteer effort or large group of interns

Each of the systems was evaluated by a technical and non-technical user based on the information available online. The draft evaluation was then provided to the business for review and updated based on their feedback.

Proprietary Non-Forestry Specific Software

Two software platforms are designed for data collection by a variety of users but are not specifically designed for use in forestry projects.

- AppSheet developed by AppSheet
- Collector for ArcGIS developed by Esri

These platforms differ from the proprietary systems described above by focusing primarily on providing options for creating many different types of data collecting projects. While very different from each other, the systems share some similarities such as:

- A flexible data model that enables the administrator to add and organize data fields as needed for the particular project
- A focus on providing options for a non-technical administrator to create and organize data gathering
- Emphasis on mobile data collection
- Online support available in user forums
- Pricing based upon the number of users, either for a monthly fee or as part of a larger software subscription
- A simple user interface designed for use by non-experts

Both AppSheet and Collector were included in this evaluation due to their use by academic and non-profit groups for urban forestry data collection. Each of the systems was evaluated by a technical and non-technical user based on the information available online.

Free and Open Source Software

Several software systems are available as free or open source tools that can be used without any required licensing fee. Four such systems were evaluated.

- i-Tree Eco developed by the USDA Forest Service and The Davey Institute
- Open Data Kit core development by University of Washington's Department of Computer Science and Engineering
- OpenTreeMap core development by Azavea and a paid subscription version available
- PyBossa with initial development by Open Knowledge and the Citizen Cyberscience Centre

i-Tree Eco and OpenTreeMap were specifically designed for use in gathering urban forestry data while Open Data Kit and PyBossa are general frameworks for supporting citizen science data gathering and are not specific to any industry. While very different from each other, the systems share some similarities such as:

- A flexible data model that can be adapted by the administrator without technical assistance (not a component of i-Tree Eco)
- Mobile data collection options but also some desktop data organization and collection available
- Some online support available and varying degrees of phone and email support
- Free versions available with some subscription or paid support options

- A user experience and interface that supports contributions from users with varying levels of forestry experience

Each of the systems was evaluated by a technical and non-technical user based on the information available online. The draft evaluations for i-Tree Eco and OpenTreeMap were then provided to the respective groups who manage those systems for review and updated based on their feedback.

Other

The Healthy Trees, Healthy Cities application developed by the University of Georgia in partnership with The Nature Conservancy and the USDA Forest Service was also evaluated although it is not yet widely available. The project focuses on gathering the data fields outlined in the Urban Tree Monitoring Protocol using student interns and volunteers with a variety of experience and was recently beta tested in Philadelphia and New York City. Since the purpose of the application overlaps considerably with many of the goals of long-term monitoring, a member of the Healthy Trees, Healthy Cities project team completed the evaluation form based on the initial version of the application. The Nature Conservancy expects to make the Healthy Trees, Healthy Cities application more widely available in the future. It is currently available for free via the Google Play store.

One additional urban forestry app is not evaluated in this report. In 2015, the New York City Department of Parks and Recreation launched a project called TreesCount! 2015, an initiative to map and gather data on every street tree in New York City. TreesCount was developed with the intention that community members would contribute to the data collection via the use of a digital application. Created as an open source project, the TreesCount software supported the organization of tree mapping events, options to view progress maps and statistics, an online training system, and data collection via a web application called the Treecorder. The Treecorder uses the TreeKIT mapping method where tree points are added based on measuring distances along the street block edge. Over 500,000 trees were surveyed with this method in 2015 with additional data collection expected in 2016. The volunteer-gathered data is in the process of being reviewed and integrated into NYC Parks' operational database.

While the TreesCount code is available under an open source license and can be used by other groups, the software was not evaluated as part of this report as it has only been used for a single project and will not remain under active development. However, it serves as an example of a large-scale urban forestry data gathering project that used online software to support community involvement.

Long-Term Monitoring Features in Existing Software Systems

Based on the system requirements outlined earlier in the report, the evaluation is organized into four categories – Overall, User Experience and Management, Data Gathering Features, and Data Analysis and Export Features. Each category includes specific features related to long-term data monitoring and management, and the software is evaluated as fully meeting, partially meeting, or not meeting the data management needs supported by that feature. The evaluation also includes an unknown option if it was not possible to determine whether the software included a particular feature.

Full evaluations of each of the software platforms are available in Appendix B. The eleven reviewed software tools were created for different purposes, and systems indicated as missing some features for long-term data monitoring may still be excellent tools for tree inventory and urban forestry management projects. No existing system meets all the identified system requirements although all the systems support tracking geospatial data associated with the tree.

Twelve key features are listed in the chart below with icons indicating whether the software includes that feature. These features were selected based on the immediate needs of any long-term monitoring project whose organizers wish to customize the project to meet their needs, support data gathering by many individuals using mobile devices, and have the option to share data with other systems.

Details about the features are provided in Appendix B, but we offer some additional notes about two feature in particular here: the ability to enter geospatial data as well as additional location information about a tree. Methods for recording tree location vary widely and location methods available through these software platforms may need to be modified for long-term repeated observations of individual trees in the landscape. Reliably re-locating trees over many years of data collection was a major concern from many interviewees. A full evaluation of the pros and cons of various location methods is outside the scope of this report; careful consideration of tree location techniques will be essential for successful tree monitoring software moving forward.

Overall Comparison

This legend applies to the chart on the following page.

Legend	
	Fully Meets
	Partially Meets
	Does Not Meet
	Unknown

	AppSheet	ArborPro	ArborScope	Collector for ArcGIS	Healthy Trees Healthy Cities	i-Tree Eco	OpenDataKit	OpenTreeMap	PyBossa	TreeKeeper	Tree Plotter
Ability to Enter Geospatial Data for a Tree	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Administrator Can Customize Data Fields	✔	✔	✔	✔	⊖	⊖	✔	✔	✔	✔	✔
APIs to Support Interoperability with Other Systems	⊖	⊖	⊖	⚠	⊖	⊖	✔	✔	✔	✔	⊖
Bulk Uploads of Existing Data	✔	✔	⚠	✖	⚠	✔	✔	✔	✔	✔	✔
Data Export as CSV	⊖	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Mobile Access	✔	✔	✔	✔	✔	⚠	⚠	✔	✔	✔	✔
Open Source or Free Version Available	⊖	⊖	⊖	⊖	✔	✔	✔	✔	✔	⊖	✔
Photo Upload	✔	✔	✔	✔	✔	⚠	✔	✔	✖	✔	✔
Supports Gathering Data Across Time via Multiple Surveys	⊖	✔	⚠	✔	⚠	✔	✔	⚠	⊖	✔	⚠
Supports Multiple Levels of User Roles	⊖	⚠	✔	⚠	⊖	⚠	✖	✔	⊖	✔	✔
Supports Multiple Users at One Time	✔	✔	✔	✔	✔	⚠	✔	✔	✔	✔	✔
Trees Assigned a Unique Identifier	⚠	✔	✔	✔	✔	✔	✔	✔	⊖	✔	✔

Extending Existing Platforms to Support Long-Term Monitoring

As evident from the chart above and the full evaluations available in Appendix B, there is no current software system that meets all the requirements identified by interviewers and through analysis of previous urban forestry monitoring projects. The existing systems were designed for a range of purposes and may not necessarily focus on long-term monitoring of urban trees by trained professionals, interns, and volunteers, the particular focus of this report. Several of the software tools could potentially be adapted to meet the needs of a monitoring project, but the cost of those adaptions and the ease with which a non-technical individual can use the resulting software will vary by system.

Proprietary Forestry Software

The proprietary forestry software systems vary from each other and the ability to add functionality to any given system will depend upon the specific tool. The evaluation of the existing tools shows:

1. These systems come with a cost that may be based on the number of users or the desired functionality. The cost of using the software for long-term monitoring projects may increase if the application is intended to be used by a larger group of citizen scientists or student interns or if advanced functionality is required. Pricing generally requires an estimate from the company.
2. The software systems generally include most of the major features related to data gathering although few of the systems support multiple levels of user roles by default.
3. The user interfaces often focus on the functionality of data gathering and may not be intuitive to users with less field work experience or who are less comfortable with technology.
4. Several platforms are primarily used by arborists or trained staff members at the organizations purchasing the software rather than large numbers of citizen scientists or student workers.
5. Technical support functionality is excellent, which will be useful for groups that may not have experience with the software.
6. Options for data export and import are common and would enable project organizers to download the data for analysis or creating reports.
7. APIs are seldom offered, which prevents the ability to move data between software systems.

Each of the identified proprietary software solutions could likely be extended to include the features needed for a long-term monitoring project. Those extensions will generally happen because the business supporting the system identifies a need for the features in the urban forestry community or because an organization pays for additional features and customizations.

If the long-term monitoring project will focus on data gathered by citizen scientists or other individuals not trained as arborists, the user interfaces for the software may need to be revised to focus on a design and user experience that users of a variety of technical and field work abilities feel comfortable using. The balance between functionality and aesthetics is challenging and design enhancements may need to be secondary to the addition of new functionality.

Proprietary Non-Forestry Specific Software

The proprietary non-forestry specific software tools focus on providing the administrator with options for customizing the data fields and structure to meet the needs of different types of projects. The evaluation of the existing tools shows:

1. These systems come with a cost that may be based on the number of users. The cost of using the software for long-term monitoring projects may increase if the application is intended to be used by a larger group of citizen scientists or student interns.
2. Several key features related to long-term monitoring are not available including multiple levels of user roles and some data import and export functionality.
3. The ability to customize the data fields is extensive and would be very beneficial for long-term monitoring projects, but since the software is not specific to urban forestry, the administrator would need to create much of the data structure rather than relying on built-in default fields such as species and trunk diameter.
4. Technical support is provided via online forums.
5. The user experience generally assumes some familiarity with data collection, but there is also a focus on providing a general user interface that is fairly intuitive since the applications created with the software may be used for a variety of purposes.
6. Some API support is available although not sufficient functionality to support moving data between the system used for tree inventory and another system.

AppSheet and Collector for ArcGIS have different pricing models since AppSheet is a standalone product while Collector for ArcGIS is tied to ArcGIS Online. AppSheet's per app pricing option may support using it for a monitoring project with more individuals collecting data, although the data structure would be challenging to adapt to collecting data on the same tree over many years. Collector for ArcGIS has more robust functionality, but the number of users would be limited by the ArcGIS Online account.

In both cases, the proprietary system would require that the business build any additional features necessary to support long-term data monitoring. Since the software is not specific to urban forestry, it is unlikely the businesses would add features based on the needs of the forestry community. AppSheet may provide some customizations for a fee since it appears to be a smaller business, but Esri, the organization developing Collector for ArcGIS, is unlikely to build specific features for individual clients.

Free and Open Source Software

The software systems in this category vary widely from each other and are difficult to compare directly. The ability to add functionality depends on the individual platform.

i-Tree Eco

i-Tree Eco specializes in gathering urban forestry data that can be used for providing information on environmental and economic benefits. With that purpose in the forefront, the software lacks some of the customization options available in the other evaluated software systems. The system supports two levels of users - multiple users gathering data via the web form and one administrative user may access the data via the desktop application.

Since trained field workers are expected to be gathering the data for analysis in i-Tree Eco, the interface emphasizes efficient data collection rather than providing a user experience that may be beneficial to users with less field data collection experience.

i-Tree Eco includes extensive data validation and a workflow that encourages the gathering of high-quality data – two features that would be important for long-term monitoring projects. Adapting the system to meet long-term data monitoring needs would require extensive customizations and would perhaps best be done by creating a separate i-Tree module that supported exporting data in a format that could allow i-Tree Eco analysis.

Open Data Kit and PyBossa
These tools are created for citizen science data gathering and are not specific to urban forestry. The data model is very flexible and an administrator at an organization could likely adapt it to meet some of the needs of a monitoring project. Since the software is not specific to urban forestry, the administrator would need to create much of the data structure rather than relying on built-in default fields such as species and trunk diameter.

Each software tool lacks key functionality including multiple user roles and relational database features essential to tracking the history of a tree or planting site over time. Both platforms emphasize data collection rather than management or display of data and may best be used in conjunction with another system for data management. Each system includes extensive APIs for moving data between systems.

Open Data Kit and PyBossa are both open source, meaning a software developer could build additional features needed to support long-term monitoring without needing to pay a licensing fee. Adapting either of these platforms is an option for constructing a software tool for urban tree monitoring rather than building a completely new system. Such adaptations would require considerable time and resources and would need to be done by a software developer rather than a non-technical user.

OpenTreeMap
OpenTreeMap focuses on supporting urban forestry data gathering by various groups including internal staff at an organization or a large number of citizen scientists or student workers. With that focus in mind, the user experience emphasizes easily adding data in an interface that is intuitive for data collectors with a variety of field experience.

While the system includes several key features for long-term monitoring such as an ability to customize data fields and user roles, it does not include an option to view previous data gathered for a tree and only shows the most current data. Data imports and exports are available as well as APIs to support moving data between systems.

OpenTreeMap is available as an open source system but that code lacks some features such as a graphical interface for certain administrative functionality. A software developer's knowledge would be needed to set up the open source code and add the other functionality necessary for long-term monitoring, which would require time and financial resources.

The paid subscription version of OpenTreeMap could also be extended to meet the needs of a long-term monitoring project. Those extensions will generally happen because the business supporting the system identifies a need for the features in the urban forestry community or because an organization pays for additional features and customizations.

Other

The Healthy Trees, Healthy Cities application is still in development and pilot testing and thus lacks several of the key features that would be necessary for a long-term monitoring project including customization options, export functionality, and multiple levels of user roles. Several of those features are scheduled for development and the collaborative nature of the project (The Nature Conservancy, USDA Forest Service, and University of Georgia) may provide resources to support expanding the application in ways that support its use by both citizen scientists and arborists for urban forestry data collection.

The code for the TreesCount! 2015 application is available online for other organizations who may wish to set up similar projects. Adapting the TreesCount project to support long-term monitoring would require extensive customizations and new features but is possible under the available software license.

Proposed Software System

While several of the evaluated software systems include many of the features mentioned by practitioners and researchers as crucial for long-term monitoring studies, no single system includes all of the desired options. The below sections outline general technical system requirements, a database model, and a systems integration plan for a software tool that meets the systems requirements and user stories outlined above.

Technical System Requirements

These general technical systems requirements are based on the intended use of the platform and the needs outlined in both the interviews and the evaluations of existing platforms.

Mobile Access

Any proposed system must include mobile access via, at minimum, iOS and Android smartphones and tablets. There are several options for creating mobile applications.

1. **Native Applications** – Native applications are built specifically for one mobile platform – iOS, Android, Windows Phone, etc. The applications utilize the software development kit (SDK) provided by the smartphone or tablet developer that includes standard software development tools for that mobile platform. Native applications generally provide the most reliable mobile experience that fits the design and interaction standards of each platform and can enables apps to access the phone or tablet’s camera, microphone, compass, and other functionality.

   Native applications are expensive, however, because a separate app must be built for each mobile platform. Most projects wish to support mobile applications on both iOS and Android, and it can be challenging to keep the applications in sync in terms of new features and bug fixes. Maintenance needs can be extensive as new versions of the mobile platforms are released, and developers frequently specialize in either iOS or Android – necessitating the use of multiple software developers. Native applications can also limit the app from being used by those with Windows Phones and Blackberry devices or field computers such as Trimble devices.

2. **Hybrid Applications** – Hybrid applications are built using cross-compatible web technologies that enables the same code base to be used for both the Android and iOS version of an application. While some customization is needed for each platform, PhoneGap, one of the most common frameworks, supports building the cross-platform mobile apps using technologies like HTML, JavaScript, and CSS that are standard in both mobile platforms.

   Hybrid applications will generally result in reduced development costs compared to native apps although they will still require ongoing maintenance to support new versions of the mobile operating system. A hybrid application may also be limited in terms of what functionality it can access on the phone and the general look and feel of the app may not seem as high of quality as a native application.

3. **Web App and Responsive Design –** A mobile web application is a mobile-optimized version of a website or software tool. A mobile web app frequently makes use of responsive web design concepts wherein the website design adapts to fit the screen size and functional capabilities of the device – whether that is a desktop computer, a tablet, or a smartphone. A site built using responsive design will not need to have a separate application; the user will simply view a mobile-optimized version of the site when using a tablet or smartphone. A responsive site can support data entry on a desktop laptop as well as via a mobile device which is useful when safety or weather conditions or the design of the data workflow encourage paper data collection rather than a smartphone or other handheld device.

   Mobile web applications have the benefits of removing the need for development and maintenance of separate mobile applications. Some functionality of the software tool may not be reasonable for use on a mobile device, however, and would only be available on the desktop version of the system. Mobile web applications also cannot directly access some functionality of the phone including the camera. Users wishing to associate a photo with tree data, for example, would need to exit the webpage to take the photo by opening their camera and then reenter the webpage to upload the photo from their gallery. Web applications also require internet connectivity which requires purchasing a data plan. Depending on how the application is constructed, it may also not support local storage of data on the device. If data is not immediately submitted to a remote server, it may be lost if the internet connection fails. This can be particularly important when adding images of trees, which may take some time to upload.

   A mobile web app has the broadest potential for use as any individual with a smartphone or tablet and an internet connection can access the software tool via their browser. Because the web application is not a native or hybrid application, however, it will not be available for download via the Google Play or Apple App Store, which may limit its visibility to users. While mobile web applications require ongoing maintenance, they are perhaps less likely to require the constant testing and updating required for apps when a mobile platform releases a new operating system.

Although there are benefits and disadvantages to each of the three options, the needs of this project and the potential resource limitations make a web application and responsive design website the most cost-effective option that would enable the largest number of people to use the application. A hybrid application may also be an option but would require the support of an agency willing to fund ongoing maintenance and updates to the system.

Mapping and Satellite Imagery

The proposed software architecture supports logging a tree's location by placing a point on a map, manually entering geospatial coordinates, entering notes on the location, or using user defined fields to create other data entry options to track location information. The software will need to include a mapping service and satellite imagery as well as a geocoding service to find geospatial coordinates based on the tree's placement on a map or the address entered by a user.

There are several mapping options, and the platform selected will likely depend on an organization's comfort with using a proprietary system and the available financial resources. Many organizations wish to use Google Maps since volunteers are likely to be familiar with the interface and the map data, satellite imagery, and geocoding functionality is high-quality. Esri, a Geographic Information Systems provider, also provides satellite imagery and a geocoder that may provide a level of accuracy sufficient for this project. OpenStreetMap, the openly licensed map created by a community of volunteers, also maintains a detailed base map.

Ideally, the system should also enable administrators to upload shapefiles for use in filtering the collected data. The ability to view and export tree information associated with a particular neighborhood, city council district, or volunteer area would provide additional flexibility in using the system as a data gathering and visualization tool.

Archiving

Clearly documenting a data set through the inclusion of metadata is essential for creating information that can be used in other research. The proposed framework should support entering associated metadata that meets the Content Standard for Digital Geospatial Metadata (CSDGM) created by the Federal Geographic Data Committee (FGDC) and adopted by the USDA Forest Service. The geospatial location associated with the tree is an integral data element and following geospatial metadata guidelines enables federal agencies to use the proposed framework and supports sharing the gathered data via the GeoPlatform portal and the National Spatial Data Infrastructure Clearinghouse Network.

Non-spatial data should meet the metadata standards outlined in the Biological Data Profile that serves as an enhancement of the CSDGM and is formally referred to as the FGCD Biological Data Profile of the Content Standard for Digital Geospatial Metadata.[20] Additionally, any metadata guidelines provided as part of the Urban Tree Monitoring Protocol should be supported in the software framework, and the framework should include options to customize metadata notes to meet the requirements of other archiving methods. To support multiple archiving methods, the proposed software model supports exporting information as XML, CSV, and shapefiles.

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[20] More information about metadata standards is available at http://www.fs.usda.gov/rds/archive/Metadata/Standards.

Cloud-based Data Hosting

As described above, interviewees almost uniformly expressed desire for a cloud-based system that enabled their data to be accessed from more than one location. The proposed software design is well suited for cloud-hosting and could be implemented in Amazon Web Services (AWS) (currently one of the most prominent cloud-based hosting services) although it does not require that specific hosting service. Cloud hosting costs vary based on the hosting service selected, the complexity of the system, the level of stability and backups included, and the number of users. Projects with a couple thousand users and basic mapping functionality may cost anywhere from $100 to $1,000 a month on average.

If the system will be accessed by a large number of users at one time, it is recommend to have a systems operation engineer who specializes in cloud-hosting assist with the development. Hosting in AWS or another cloud-based system becomes more challenging if the proposed system is developed as part of an existing system that is hosted on an organization's internal server rather than as a completely separate system.

Systems Integration

The proposed software includes a model for integrating data with external systems. This integration can happen via uploads of spreadsheets or other data files or via an API, a method that enables systems to interact directly and creates a more automated method of moving data. Data sharing will require the participation of the organizations using both systems. When one of the systems uses proprietary software, implementing an API will require some modifications to that proprietary software. While the proposed model attempts to limit the amount of data reformatting that must be done to integrate various data sets, organizations and researchers should also expect to spend some time on data organization.

Updates, Maintenance, and Technical Support

Any software must receive regular updates and maintenance to assure that it functions as new versions of internet browsers, operating systems, and mobile devices are released. Ideally, that maintenance and support would be provided at least twice a year and some technical support would be available for users who face issues with their implementations of the software.

Open Source

Many interviewees noted they would prefer an open source system for several reasons.

a. Reduced costs as no proprietary licensing or usage fee required
b. Grants and funders occasionally indicate a preference for open source software when awarding funding
c. Increased ability to customize and build on an existing framework with the assistance of a community of developers
d. Philosophical preference for the open data/open source movement and sharing of technical resources

The data model proposed below works well with several open source frameworks and could be built using Django, a web application framework written in Python, which is a standard framework in the software industry to support rapid and quickly changing software development. The model would also support use of PostgreSQL, an open source object-relational database, with the PostGIS extension that supports geographic objects.

While open source development of the system is possible and even recommended in order to encourage broader implementation, there are several important issues facing open source projects.

1. Building a community of developers and supporters is difficult and requires time and attention. The most active communities have dedicated members who provide feedback, lead the integration of code contributions from various people, and contribute extensively themselves. Finding those members may be difficult for a new project unless the urban forestry community can build upon existing partnerships or reach out to software developers associated with forestry organizations.
2. Open source software still has costs to the organization seeking to use it. Even if all code is freely available under a permissive open source license, setting up the system will likely require software development knowledge, which many non-profit organizations may not have. Creating a one click installer that automatically sets up the software will require more extensive development and likely the oversight and guidance of an organization that consumes those costs in order to make the software more widely available.
3. Developers at non-profit, research, and municipal organizations may not be as familiar with the open source frameworks or cloud-hosting of the system. While this concern is decreasing as open source development becomes more common, it is important to note that an organization may have dedicated information technology staff who are not experienced or comfortable with implementing an open source system.
4. Some open source licenses may be in conflict with the license on a proprietary system, preventing integration of parts of the open source within a proprietary system or potentially even limiting how APIs are able to move data between systems.
5. Open source projects frequently do not come with the email or phone support that organizations may need.

Despite these potential concerns, creating an open source system may be a key first step toward building a software platform for urban tree monitoring that will be widely used. Such a system must have guidance and support from a larger funding entity or agency, however, in order to provide the ongoing development, maintenance, and technical support that users – particularly those at smaller organizations with limited resources – may expect.

Additional Desired Features

In addition to the required features described above, the below feature may be useful for the proposed system.

Accessibility

If the intended users of the software include citizen scientists, the platform may need to meet web accessibility standards that promote use of the software by as many individuals as possible. The Web Content Accessibility Guidelines 2.0 (WCAG 2.0) recommended by the World Wide Web Consortium (W3C) provide standards for creating software that enables broad usage and does not create barriers that limit how individuals can access the information and participate in data gathering.[21]

[21] A description of the Web Content Accessibility Guidelines 2.0 is available at http://www.w3.org/TR/WCAG20/.

Translation

The individuals interested in participating in a data monitoring initiative may speak languages other than English. The software should include translation elements so that it can easily be adapted to languages other than English, should that feature be of use to an organization or researcher. Commonly referred to in the software field as internationalization or i18n, internationalization may involve implementing text translations as well as other localization changes such as the use of metric measurements, adjustments to date and time formatting, or supporting right to left writing. While full internationalization is likely not necessary for this project, creating the software to support translation files will increase the number of users the software supports. Organizations may need to provide translation files that indicate how words should be translated in the user interface for the software.

Data Model

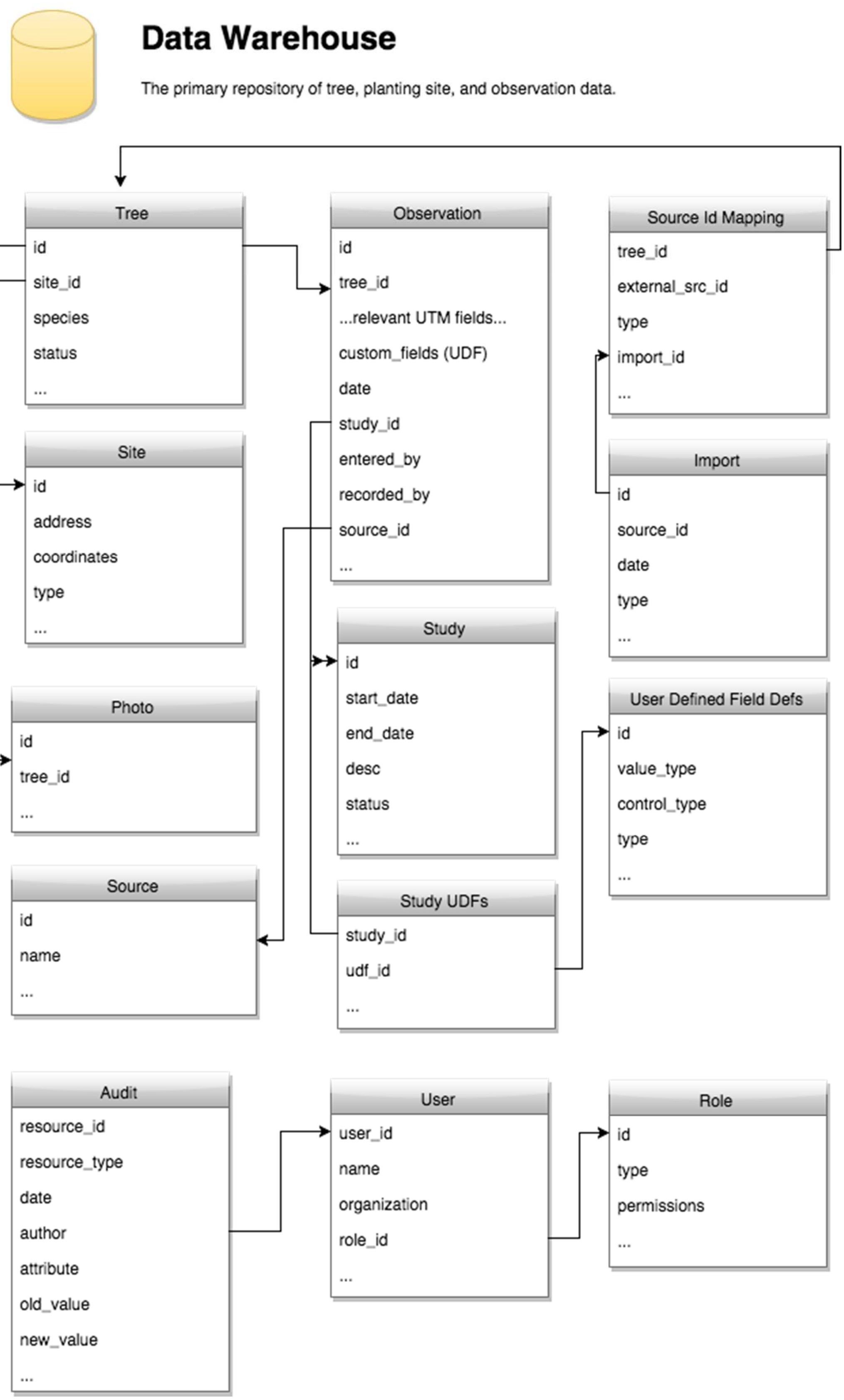
While the technical requirements outlined above are important for understanding the key items any created software tool for long-term tree data monitoring must include, the core of that software tool is a data model that supports the various user stories described earlier. The data model must provide basic structure for data collection while also including options for customization by an administrator.

The diagram below illustrates a conceptual data model intended to support long-term, longitudinal studies of tree and plot related observations. In the proposed system, trees occupy the primary focus of attribution and the associated tree_id becomes the attribute which new data must be reconciled against when integrating sources of external data. Sites are a distinct entity, associated with a tree, in order to enable tracking, reviewing, and preserving the history of different trees at an individual planting site over time. However, the data model does not require that a site have a corresponding tree so that empty sites can be tracked as a way to show potential planting locations. Multiple trees may be associated with the same site_id over time as trees die and are replaced with a new tree. The site_id could also potentially be used as the attribute against which new data is reconciled when integrating sources of external data if the user is interested in updating site rather than tree information.

This model includes a core set of data fields but provides flexibility for the administrator to create additional fields as necessary to meet the needs of the organization. The model includes several distinct but connected tables for storing data.

Table Name	Description
Tree	Tree specific information such as tree_id, species, status (tree alive, standing dead, removed, etc.) that is generally static. These fields are less changeable than the fields tracked as part of an Observation. Edits to these fields likely indicates a major change such as the existence of a new tree at that planting site or removal of an old tree.
Site	Planting site information (site_id, address, geospatial coordinates, etc.)
Observation	Tree and site related data gathered as part of a single tree survey (observation date, tree related fields, user who gathered the data, etc.). Examples of tree related fields include condition and diameter.

Study	Information about a monitoring or inventory project (study purpose, start and end dates, status of the study, etc.). Examples study purpose include “research study to annually monitor trees for five years after planting”, “non-profit young tree monitoring project using citizen scientists”, and “municipal forestry street tree re-inventory in conjunction with five-year pruning cycle.”
User Defined Fields	Custom data fields set by the administrator for use in gathering specific tree information. Examples of user defined fields include tree sponsor and stewardship information.
Source	Data on the user or study associated with an observation. Examples of source data include the name of the user entering the observation and that user’s institutional affiliation.
Photo	Images associated with a specific tree_id



Data Warehouse
The primary repository of tree, planting site, and observation data.
Tree
id
site_id
species
status
...
Observation
id
tree_id
...relevant UTM fields...
custom_fields (UDF)
date
study_id
entered_by
recorded_by
source_id
...
Source Id Mapping
tree_id
external_src_id
type
import_id
...
Site
id
address
coordinates
type
...
Import
id
source_id
date
type
...
Study
id
start_date
end_date
desc
status
...
Photo
id
tree_id
...
User Defined Field Defs
id
value_type
control_type
type
...
Source
id
name
...
Study UDFs
study_id
udf_id
...
Audit
resource_id
resource_type
date
author
attribute
old_value
new_value
...
User
user_id
name
organization
role_id
...
Role
id
type
permissions
...

This model uses the approach of recording observations using a pre-set list of core attributes identified here as UTM (Urban Tree Monitoring) fields and that match the minimum data set defined by the UTGL working group. These core data fields will be visible in the data model by default although administrators may choose whether or not collect them or have them visible.

Administrators may also create User Defined Fields (UDF) that meet the needs of their individual organization. Such fields may relate to the goals of the monitoring project (more extensive observations of condition, for example) or serve as a method for tracking maintenance activities (tree watered, pruning completed). An option for flagging data for review could be included as either a default UTM field or a customized UDF. Both UDF and UTM fields are associated with an entity referred to as a Study. A Study includes its own collection of UDFs that define the associated data fields, value types and other metadata regarding how field crews should collect the particular data for the study. An administrator can indicate that a Study should only apply to certain trees or a specified geographic area, limiting the likelihood that data will be added to the incorrect trees.

The data collected by a field crew during a single tree survey is stored collectively as an Observation. An Observation includes the completed data fields as well as data related to that survey such as who recorded the data, when it was recorded, what Study it is part of, etc. Trees can accept Observations from multiple Studies. An Observation record, owing to its relationship to both a Study and a Tree (as well as the Site associated with the Tree) can be viewed in the context most appropriate for the user. Some example requests may be:

- Show all observations of trees planted at this site for all time
- Show all observations for a particular tree relating to a particular study
- Show all observations for all trees in a particular study
- Show observations and attributes from other studies and sources for trees participating in a particular study

Observations entered into the system do not need to be associated with a specific Study, but all Observations include attributes for entered_by and recorded_by to indicate the field crew member who recorded the observation in the field and the scribe who entered the survey data into the system.

Observations are also connected to a Source, which is an arbitrary reference to the organization or group who was the original source of the data. For example, trees imported as part of a file from the Parks and Recreation Department may list Parks and Recreation as the Source, and trees planted in a cohort as part of a tree non-profit group's spring planting may list that group's name as the source. If the tree was not added as part of a larger initiative or using data from a different source, the Source may simply be the user listed in the entered_by field. Since all observations are associated with a Source, administrators of the system can review the Source data and the entered_by fields as a tool for prioritizing and evaluating the quality of the observations based on who entered the data.

This model also provides for the addition of other arbitrary, non-required metadata related to the Tree such as Photos. Additional data tables such as comments or notes could be added and associated with a Tree using the tree_id field. Scanned paper documents could also be uploaded to the system and associated with a tree record based on the tree_id field. Longer study related background documents could be associated with a study using the study_id field.

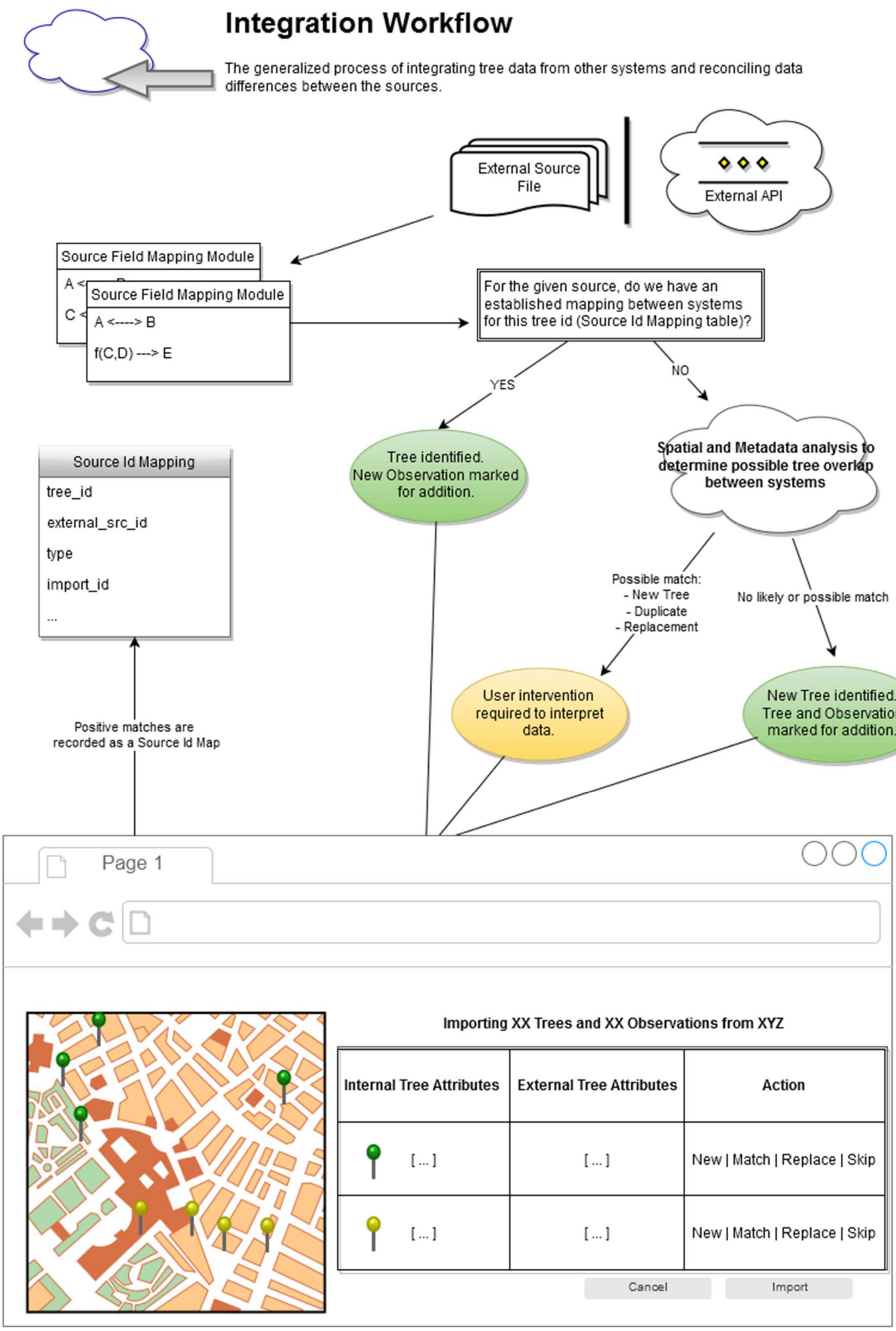
The system supports tiered role-based User accounts, which could limit the ability to view or edit certain data fields or support granting editing and viewing privileges only for data from certain Studies or Sources. Attributes associated with any of the tables will be included in an Audit system, which tracks changes to recorded values and associates those changes with the User who made them.

Integration with External Systems

A crucial need outlined by many researchers and practitioners was the ability to integrate tree related data from several systems. Multiple organizations may survey the same set of trees for various purposes over the course of the lifetime of the tree. A non-profit group may plant the tree, a community group may manage the stewardship for that tree, a municipal government organization may keep a record of the tree for works management and construction purposes, and a student may gather data on the tree for a class project.

Ideally, that data could be combined in a single system to support efficient tree management and research on tree growth and mortality. The organizations involved in tree planting and maintenance frequently focus on different aspects of urban forestry, however, and are likely to utilize a variety of works management, event management, inventory, and other software systems.

The database model described above supports accommodating the integration and reconciliation of data on Sites, Trees, and Observations from external sources. The below Integration Workflow diagram visualizes that process.



Integration Workflow
The generalized process of integrating tree data from other systems and reconciling data differences between the sources.
External Source File
External API
Source Field Mapping Module
Source Field Mapping Module
A <----> B
f(C,D) ---> E
For the given source, do we have an established mapping between systems for this tree id (Source Id Mapping table)?
YES
NO
Tree identified. New Observation marked for addition.
Spatial and Metadata analysis to determine possible tree overlap between systems
Source Id Mapping
tree_id
external_src_id
type
import_id
...
Possible match:
- New Tree
- Duplicate
- Replacement
No likely or possible match
User intervention required to interpret data.
New Tree identified. Tree and Observation marked for addition.
Positive matches are recorded as a Source Id Map
Page 1
Importing XX Trees and XX Observations from XYZ
Internal Tree Attributes
External Tree Attributes
Action
[...]
[...]
New | Match | Replace | Skip
[...]
[...]
New | Match | Replace | Skip
Cancel
Import

First, the data model described above will be exposed via authenticated external APIs and a web-based graphical user interface. This enables administrators to follow the workflow described below to add tree data either via bulk import of existing files (CSV, Excel, Shapefile, etc.) or a specially programmed interface between two software systems.

Second, a customized Source Mapping Module must be developed for each system that will be integrated with the original system. This module indicates how the data structure can be transformed from the provided source in the external system to the internal representation. This may include rules for directly mapping fields between the two systems, merging or disregarding fields, performing operations and calculations to generate derived values from existing fields, and implementing validation and data integrity checks to ensure only high-quality tree data is added to the system. Creating the Source Mapping Module will need to be a manual process that is dependent upon the data fields included in each system, possible differences between the fields, and whether the administrator wishes to bring some or all of the data from one system into the other system.

Third, after the source file from the external system has been mapped to a suitable internal format using the customized Source Mapping Module, the original system attempts to determine if Trees from this Source have been previously mapped in the system using matched IDs, spatial rules (tree is at or near a point currently in the system), and/or metadata rules (data for the tree at that geographic location matches several data fields for the tree at that location in the external system).

For a positive match, the system records an external source Id to an internal Id so that future imports from the same source are efficiently and correctly matched. When no explicit match is available for a Tree, the system software performs analysis based on spatial and data attributes to determine possible matches that could fall into the categories:

- New Tree in system
- Tree is likely a duplicate of an existing Tree in system, reconcile and record the Ids
- Tree is new, but likely replaces an existing Tree in the system

Determining which of three categories the tree belongs in is a complex process and would require user verification as a penultimate step prior to importation. The system would perform some naive classification of the trees that places them into one of the three categories. An administrator would then view a graphical interface that would display the tree's data and geographic location and the system's suggestion for which category it is. The administrator would make the final determination of how to treat the data coming from the external source by indicating if they believe that data reflects a new tree, a tree that matches a tree in the current system, or a tree that replaces a tree in the current system. The system would note that such a decision was made as part of the tree's record, providing an audit log of changes and data integration between systems.

When the user reviewing the import is satisfied and has reviewed the questionable data, they can confirm that new Trees and Observations should be created in the existing system and Ids from the external system should be matched to internal Tree Ids to support future imports from the external source.

Additional Needs

The above database infrastructure is designed with the flexibility to support a variety of use cases through the implementation of User Defined Fields, extensive tracking of user related information, the separate observations and studies, and the ability to join additional tables to the model. While not directly related to data architecture, the following features would assist with creating a system that supports both research and management needs.

1. **Standardized Data Fields**
While the above infrastructure model supports integration of data from multiple sources and a process for reconciling differences in that data, a standardized set of data fields that are consistently tracked throughout a variety of works management, inventory, and other urban forestry systems would assist with more efficient data sharing and integration. The proposed architecture streamlines the process of reconciling data sets but still requires administrative review. A recommended set of data fields that includes best practices for formatting would decrease the time organizations must spend on restructuring data sets and encourage sharing of information. More information about this option is discussed in the Recommendations section below.

2. **Customizable Reporting and Export System**
The proposed data infrastructure ideally will result in an increased number of tree surveys and more frequent data sharing between software systems – resulting in a larger number of data points for each tree. To effectively utilize this data, the proposed system should include a customizable reporting system that enables administrators to query the data, create reports, and export raw data and maps. Features should include:

    - **Pre-set standard data filters** – Several queries are likely to be frequently used and are not dependent upon a specific use case or type of organization. These queries could be selected from a default list or drop-down menu where the administrator could then customize the date range to which the query should apply. Possible pre-set filters include number of trees per species, trees by size distribution, recent changes, and edits by user.
    - **Recommended filters for urban tree monitoring** – Created with guidance from researchers involved in longitudinal urban forestry studies, these filters would assist organizations in summarizing and reporting on changes in the urban forest over time. These filters are more difficult to summarize in a simple phrase but may include options such as number and percentage of trees that have increased by size distribution X in a set date range or between two recorded observations, number and percentage of trees by species that died or were removed in a set date range or between two recorded observations, tree size change for trees with recorded maintenance activities vs those with no recorded maintenance activities, etc. These filters could be pre-set and listed in a separate “urban tree research” menu on the reporting page as a way to call attention to their importance in the research process.
    - **Customizable filters set by the organization** – Administrators should have the option to create a search query and then save it as a custom filter that can be applied to the data at any time. Custom filters are ideal for querying the data based on a User Defined Field, a specific Study, or another aspect of the data model that was customized by the administrator.

- **Visual reports** – Running a search may result in a simple list view of all trees, users, or edits that meet those search parameters, but the administrator should also have the option to view the data as chart, graph, or other visual representation. These visualizations should include options for exporting the graphic along with an accompanying legend or summary as a PDF, PNG, or other media type that could be inserted into a report or shared online.
- **Data exports** – Some data export functionality may be available via the public interface for the system, but the administrative reporting and export system should include options for exporting the data connected with a search result. Suggested data formats include CSV and Shapefile. Data exports, along with the API recommended as part of the overall data architecture, enable data from the system to be integrated with other systems or shared with other researchers and practitioners.

3. Customizable Data Validation Checks and Quality Assurance Rules

The proposed system supports data collection by users with varied levels of urban forestry knowledge and field data gathering experience. Building data validation (how users may enter data) and quality assurance checks (how data is flagged for review) into the system supports higher quality data and decreases the amount of review required by an administrator. Two options are recommended for data validation.

a. **Pre-set checks** – These options would be part of the standard system and available to all administrators without the need for customization. While not overly sophisticated, they provide a base level of validation that limits the number of errors. Some default checks would include forcing the user to choose from a defined list of options when completing a field, preventing the placement of a tree at the same geographic location as another tree, and setting minimum and maximum values for numeric fields. Administrators would ideally have the option to turn these pre-set checks off if they desired to do so.

b. **Customizable data validation checks** – The administrator could create data validation checks for the default Urban Tree Monitoring fields or User Defined Fields that causes an action to happen based on the data entered in that field. Such checks might include making the choices available for certain fields dependent upon the data entered in a previous field, limiting data choices based on the entered species, only displaying certain species in the choice list for a specific Study, displaying a warning message when a user selects a certain data choice (a species uncommon to that region, for example), and limiting the geographic placement of trees based on proximity to another tree currently in the system. The administrator should be able to configure the checks without requiring the assistance of a software developer, which requires more technical complexity and may limit the number or type of customizable data validation checks allowed in the system.

After users add data to the system, administrators must also have options for conducting quality assurance checks. All recent activity in the system should be visible on an administrative page, but the quality assurance system would automatically flag select data for closer administrative review. As with data validation, these rules should include both pre-set and customizable options.

a. **Pre-set quality assurance rules** – Select quality assurance rules may be standardized and available to all administrators without the need for customization. These rules could include data flagged by a user or administrator as needed for review, flagging all data added by users assigned to the user role with the fewest editing privileges, data added by a user with no previous edits, or data that indicates a tree has been removed. Administrators would ideally have the option to turn these pre-set checks off if they desired to do so.

b. **Customizable quality assurance rules** – The administrator could also create quality assurance rules based on the default Urban Tree Monitoring fields or custom User Defined Fields, Observations, and Studies. Such checks might include flagging all data entered by a specific user, data that includes a tree with an uncommon species, data that shows the tree size increasing by >X since the previous Observation, data associated with a specific Study, or data with select words in a notes field. The administrator should be able to configure the rules without requiring the assistance of a software developer, which requires more technical complexity and may limit the number or type of customizable quality assurance rules allowed in the system.

While reviewing flagged data, an administrator could confirm that the data was accurate, flag it for field review (ideally by assigning it to another user who would receive an automatic notification to check that tree), or remove the data from the system.

User Workflows

The software model described above is flexible in order to adapt to meet the needs of various organizations and individuals. Some users may be deeply involved in the development of the data fields and creating methods for data collections while other users may experience the software primarily via data collection using the mobile interface. The below sections describe potential uses by the user personas defined earlier in this report as well as how the Philadelphia Case Study could be streamlined using this system.

User Stories

The five identified user personas would interact with the proposed software system in various ways.

Student Intern

Will, the student intern, would add Observations as part of his field work. In order to reach the goals outlined earlier in this report, he primarily will:

- Interact with the mobile interface and focus on efficiently and correctly updating data
- Add new Observations
- View previous Observations for the Tree or Site to confirm he is updating the correct information
- Take and upload photos of the Tree or Site
- Perhaps only be granted access to update select data fields on specific trees
- Perhaps gather data via paper and then enter the information later using the desktop interface

Will most likely will not be creating a new Study or setting User Defined Fields. He is also unlikely to be handling administrative actions such as importing existing inventories or ingesting and reconciling data sets from external systems.

Citizen Scientist

Susan, the citizen scientist, would add Observations as part of her field work. Those Observations may be as part of an inventory project or smaller, more frequent recordings of stewardship and maintenance information. In order to reach the goals outlined earlier in this report, she primarily will:

- Use the mobile interface for some Observations
- Gather data via paper and enter the information later using the desktop interface or provide the paper forms to another citizen scientist to enter into the system
- Add new Observations that may involve entering or updating info in a few fields related to stewardship or maintenance
- Perhaps only update select data fields for trees in a defined geographic area

Susan is the user most likely to enter data via both the mobile interface and paper forms. She will not be handling administrative actions or creating a new Study or User Defined Fields. However, she may have input on what User Defined Fields should be added based on her regular stewardship activities.

Practitioner – Urban Greening Non-profit

Marcus, the community tree manager for a non-profit group, will extensively use the administrative options available in the software system. In order to reach the goals outlined earlier in this report, he primarily will:

- Create and manage User Defined Fields based on the needs of a particular Study
- Create a new Study, including metadata information on how the data is collected for the Study and by whom
- Set which Users can edit select data fields, update content on certain Trees, and add data as part of a Study
- Review the Audit logs as a quality control measure to maintain high quality data
- Query the system to view data and create reports
- Upload existing data sets
- Ingest and reconcile data sets from external systems
- Add new Observations if participating in field work

Marcus may wish to designate some administrative activity to other members of the non-profit. The User system supports giving such administrative privileges to several different users, although increasing the number of administrative users should only be completed after extensive training.

Practitioner – Municipal Government Parks Department

Rita, the municipal arborist, may use the software system for gathering Observations if her department is participating in tree inventories. She is also likely to analyze the data from the system to make management decisions. In order to reach the goals outlined earlier in this report, she primarily will:

- Ingest data from the system into her department’s works management system
- Query the system to view data and create reports
- Provide municipal tree data for integration with the other tree data in the software system

- Perhaps create Studies and User Defined Fields to support maintenance activities such as pruning or removals

Rita could also use the software for gathering Observations, but it may not meet all of her works management needs. The software may be useful as an option for Rita to use if she needs to periodically conduct a large scale tree inventory as grant funds become available.

Research Scientist

Lucy, the research scientist, may use the software for both organizing data gathering initiatives and viewing data gathered by other organizations that may be useful for her research. In order to reach the goals outlined earlier in this report, she primarily will:

- Create Studies and User Defined Fields to support gathering data for a specific research project
- Set which Users can edit select data fields, update content on certain Trees, and add data as part of a Study
- View the metadata associated with a Study to understand how the data was collected and by whom
- View the Source info to understand the origins of ingested data sets
- Review the Audit logs as a quality control measure to maintain high quality data
- Query the system to view data and create reports

Lucy may coordinate her fieldwork with the local non-profit group in order to use the software already set up by that group. In that case, she would create a separate Study with unique User Defined Fields and then assign it to only the select, trained Users who were her student interns.

Philadelphia Case Study

The data model described above supports the needs of both of the common data workflows undertaken by PHS – gathering data related to plantings and adding data as part of the Tree Checker program.

Tree Planting Workflow

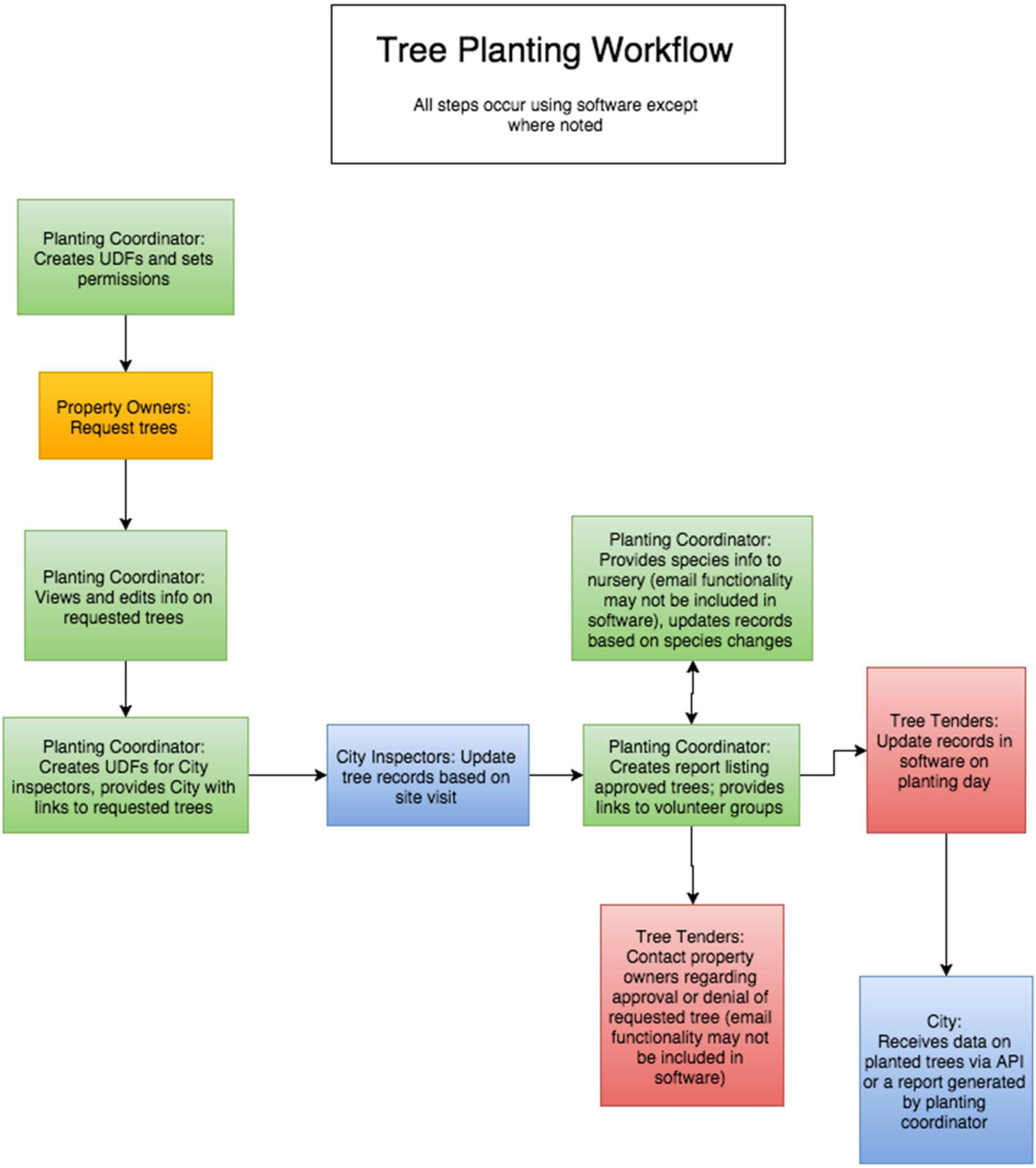
The below workflow outlines the process of planting a tree from the original property owner request to the final data tracked on the planting day. Informative text or field names are examples and would be edited to meet the specific needs of the organization.

1. The PHS planting coordinator would create a UDF called Request a Tree and grant public users who have created a login the ability to add a new site and set the Request a Tree field to yes. The planting coordinator can choose whether to make additional fields such as requested species and size of planting location available to the public users or limit the options to just Request a Tree.
2. The planting coordinator would create and view a report showing sites with the Request a Field tree set to "yes." The coordinator could then delete any sites that do not meet the requirements for the street tree planting program. The coordinator or a member of the Tree Tenders group associated with the location could contact the user regarding their denied request using the email address associated with the username that added the site. If an email system is built into

the system, the software could also automatically send an email indicating the request was not approved.

3. The PHS planting coordinator would export a list of all sites in the system that include a “yes” response to the Request a Tree field. Ideally, the system would support uploading a file outlining the geographic areas of certain Tree Tenders groups so that the planting coordinator could filter and export a list for each Tree Tenders group.
4. The planting coordinator would provide the exported list to the City of Philadelphia along with a list of links to the records in the software system. If an API connection existed between the software system and the City’s asset management system, the data could be fed into the City’s system although that may be a premature task that should not be done until the sites are approved.
5. The planting coordinator or a supervisor at the City would create additional UDFs related to the process of approving the site such as allowed species, size of planting site, whether the site is approved, the date approved, location notes, and the need for concrete cutting. City inspectors would have user accounts in the system that grant them the ability to view and edit these fields.
6. The City inspectors would visit the sites and update the UDFs described above. This information would be logged as a new Observation and immediately be visible to the planting coordinator and Tree Tenders group leaders if they are granted the required permissions.
7. After viewing the updated records in the system, the Tree Tenders groups contact the property owners regarding whether their requests have been approved or denied.
8. The planting coordinator exports a list of the records where the site was approved to provide to the nursery in order to confirm species availability. The planting coordinator then makes any necessary species updates to the records based on feedback from the nursery. Individuals at the nursery could also edit the records directly in the system if they are interested in doing so.
9. Once updated with the species, the records in the system serve as the working list of what will be planted on planting day.
10. Tree Tenders group leaders update the tree records during and after planting day to note any changes to location or other information that may have changed during planting.
11. If the API is being used, the updated data can be automatically provided from PHS’s system to the City’s asset management system. If not, the planting coordinator can export a list of plantings for the season to provide to the City.
12. Any additional updates including stewardship information, photos, or comments about the tree can be added directly in the software system and be viewed by some or all users based on permissions set by the planting coordinator.

The workflow can also be shown using the following diagram.

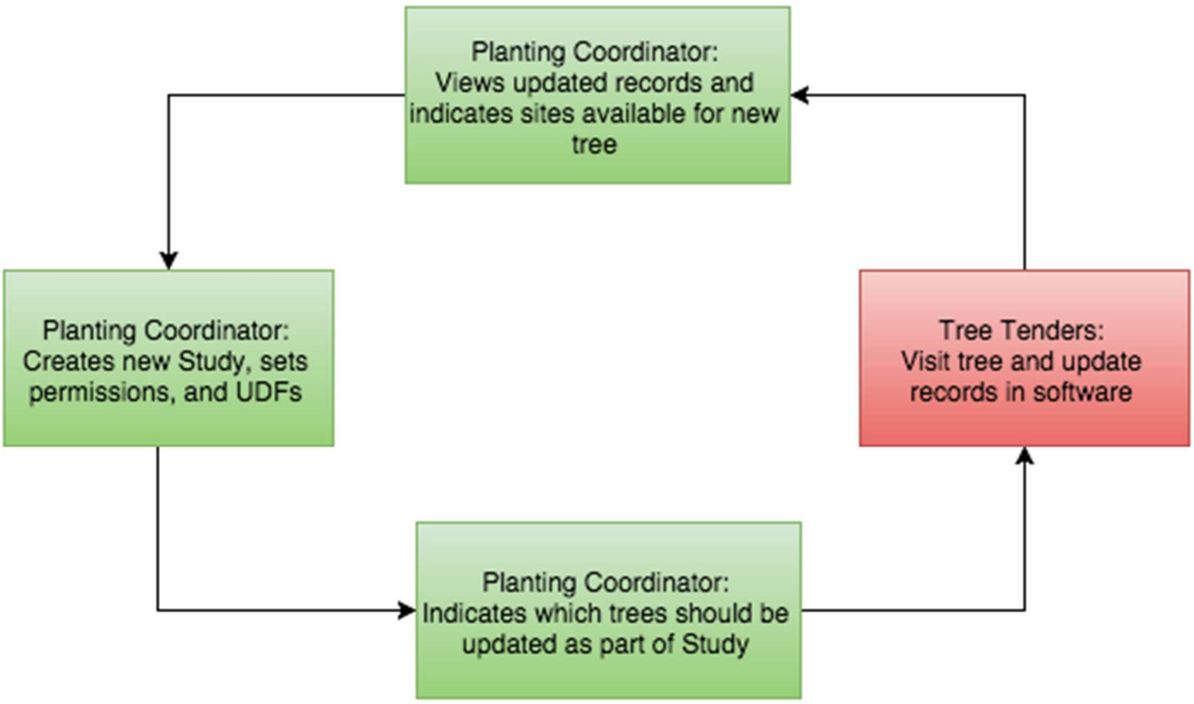

Tree Planting Workflow
All steps occur using software except where noted
Planting Coordinator: Creates UDFs and sets permissions
Property Owners: Request trees
Planting Coordinator: Views and edits info on requested trees
Planting Coordinator: Creates UDFs for City inspectors, provides City with links to requested trees
City Inspectors: Update tree records based on site visit
Planting Coordinator: Provides species info to nursery (email functionality may not be included in software), updates records based on species changes
Planting Coordinator: Creates report listing approved trees; provides links to volunteer groups
Tree Tenders: Update records in software on planting day
Tree Tenders: Contact property owners regarding approval or denial of requested tree (email functionality may not be included in software)
City: Receives data on planted trees via API or a report generated by planting coordinator

Tree Checker Workflow

The below workflow outlines how the Tree Checker program could use the software to update tree data. Informative text serves as an example and would be edited to meet the needs of the organization.

1. The PHS planting coordinator would create a new Study named Tree Check Spring 2015. Creating a Study involves adding a date range for which the study is active, the purpose of the study, and any User Defined Fields that should be gathered specifically as part of that Study.
2. The planting coordinator would indicate which users could add data as part of the Study.
3. The planting coordinator could indicate the trees to update as part of the Study. The planting coordinator could either run a report (all trees planted between DATE and DATE) and indicate which results of the report should be eligible for updating as part of the Study or draw a polygon on a map to indicate the geographic area in which trees can be updated as part of the Study.
4. The Tree Tenders groups visit each tree that is due for a Tree Check and update the tree's record in the software. The update is automatically logged as an Observation associated with the Study and includes the user name of the individual who updated the data.
5. The planting coordinator views the updated records and identifies any trees noted as dead. The planting coordinator can then coordinate the dead tree's removal and update the software to indicate the planting site is no longer associated with a live tree. The previous tree's information remains in the system with a status that indicates the tree is no longer present. This supports using the software as a record of the history of the planting site.
6. The process could be repeated for any number of studies.

The workflow can also be shown using the following diagram.



Additional Recommendations

The technical requirements, data model, integration process, and additional needs outlined above are the core recommendations as to how a software system could be implemented to support long-term urban forestry monitoring. Based on the interviews, evaluations of existing software platforms, and the needs of the defined user groups, however, there are several additional recommendations that will increase the likelihood the software is widely adopted.

1. Municipal Tree Managers May Have Additional Data Needs

Throughout the process of conducting interviews, identifying systems requirements, evaluating software, and creating a proposed software architecture, municipal government tree managers were shown to have unique needs compared to non-profit groups and scientific researchers. Budget issues frequently require municipal tree managers to focus on identifying and pruning or removing hazard trees and responding to tree inquiries and concerns from the general public. A municipal forestry division often must work with other governmental departments including the streets, public works, and planning divisions to coordinate tree removals. These activities may require the municipal forestry group to use existing works management systems and integrate with 311 systems. These systems may be customized to the needs of the individual municipality and creating services to move data into and out of the works management system will also require customization. Switching to a new software system, especially one that uses open source technologies, may not fit within the information technology plans for the municipal government as a whole and the procurement process may be lengthy.

The needs of municipal forestry workers were included as much as possible in the proposed software architecture while not extending the basic functionality beyond the needs of the other intended users. There are several key features, however, not included in the software model that may limit its usability to municipal foresters such as

- An **assignment process** that enables an administrator to assign a task or study to a specific user or field crew
- A **notification system** that sends emails to work crews or displays alerts when a user logs in
- A **311 system** integration that automatically attaches a 311 request from a member of the public to a tree and creates a work management order
- Options for **managing contractors** including budgeting, assigning locations for plantings, and other operations processes
- **Condition assessment tools** that take into consideration work history and potential risk
- Extensive **GIS capabilities** for analysis and planning
- The inability to use **citizen science data** due to liability issues

The proposed framework's User Defined Fields and the option to create new tables connected to the Tree or Site in the data model support some of the above uses but would require fairly extensive customization to meet the needs of many municipalities. Municipal foresters may not be able to secure the funding for a new system that requires customization, especially if other municipal departments are using the same works management system or the city initiatives require internal software development or contracts with approved vendors. There are also existing works management systems that may be more suited to the needs of municipal forestry agencies.

Although the proposed framework may not meet all the needs of municipal foresters, the integration workflow would support integrating data from a municipal system into the software framework. Perhaps the most complex aspect of the integration would be matching trees between the systems and creating a series of rules to clarify how data should be updated. Once the rules are created, there may also be logistical difficulties in keeping the systems in sync. Some external sources may be able to feed data automatically into the proposed software system via a series of Application Programming Interfaces (API), but that functionality may not be available in a proprietary municipal works management system.

2. Low Cost Software and Tech Support are Essential to Broad Adoption

Urban forestry organizations frequently operate with budget limitations that prevent investment in software or long-term monitoring projects. During the interview process, numerous people mentioned the need for any developed tool to be available for a low cost and provide options for technical assistance. Balancing these needs with the software development time necessary to create such a tool is a challenge that will require financial investment from a larger organization if funds are not available from the individual users.

Often, individuals prefer open source technology and equate it with low cost. While open source software lacks the licensing fees common to proprietary software, the development of the software requires investment in the form of a software developer’s time, management of the development process, and testing and maintenance of the created system. The proposed software framework is suited to using open source technologies, but non-profit and academic organizations may lack the internal information technology resources to implement the code themselves or the software developers at the organization may not be familiar with the programming language used in the open source project. Possible options for providing the software at a lower cost include:

- Having a large organization or grant funding entity provide the financial resources to lead the development of the open source software framework
- Creating a software system that can be implemented and customized by organizations and researchers without requiring software development experience
- Providing a basic version of the software at no cost but indicating that implementation of additional functionality must be done using the services of an urban forestry business or by the organization implementing the open source code using their own software development resources
- Subsidizing use of the software via a one-time fee or a small monthly cost to the organization
- Developing forums and user listservs to support sharing information
- Providing technical support at no or low cost, depending on the resources of the lead organization
- Releasing the created code under an open source license that supports its integration into other tree inventory and works management systems

Development of a software tool is the first step but encouraging broad adoption of the system will require allocating funds and support for maintenance and technical support. Organizations may be more willing to implement a software framework if it provides benefits while not increasing costs. As described previously, the widespread adoption of a system for long-term urban forestry monitoring would generate data to support research initiatives and improve maintenance and planting decisions. The establishment of an open data standard and the creation of a central repository, as described below, provide additional benefits to encourage the use of the framework by more researchers and greening organizations.

3. Urban Tree Monitoring Protocol Established as an Open Data Standard

The Minimum Data Set included in the Urban Tree Monitoring Protocol under development by the Urban Tree Growth & Longevity Working Group should be finalized and established as an open data standard that is widely adopted by groups and individuals gathering urban forestry data. An open data standard serves as a series of guidelines on what data should be gathered and how it should be formatted in order to support greater sharing between data systems.

Many organizations, particularly municipal governments, will likely need to continue using an existing software tool due to cost constraints and hesitance to implement a new system and deal with legacy technical issues. A multitude of data gathering systems can prevent efficient sharing of data, and many interviewees mentioned the significant time they needed to spend reformatting data they received. An open data standard would enable organizations to keep existing systems but adjust their data fields and formatting to match the information gathered by other groups. Similar data fields and formatting would greatly increase the efficiency of the systems integration process described as well as enable individuals to more easily understand how the data is structured and integrate it into their own research.

Open data is increasingly the focus of many governments who wish to make information more widely available to their citizens. Several open data initiatives have focused on creating standard formatting that is implemented at a national level.

- **Open311** is an international initiative to standardize how citizens can report non-emergency issues to municipalities. New York City, Chicago, Washington D.C., Boston, and other cities in the United States have implemented elements of the Open311 standard. Open311 is organized by OpenPlans, a non-profit group.
- The **Google Transit Feed Specification** (GTFS) standard is used by hundreds of municipal governments to provide information on public transit. This data is used to create applications related to transit scheduling, delays, and access to mass transportation. GTFS was initially developed as a collaboration between TriMet, the public transit agency in Portland, and Google.
- **Local Inspector Value-entry Specification** (LIVES) is a municipal restaurant inspection data is visible on Yelp and other restaurant listing websites. LIVES is implemented in San Francisco, Los Angeles County, New York City, and other municipalities. LIVES was initially developed as a collaboration between the Cities of New York and San Francisco and Yelp.
- The **Dublin Core Metadata Initiative** is a set of standards developed around sharing metadata and is particularly prevalent in the library and information science communities. The Dublin Core group began as a group of interested individuals and later formed a non-profit organization to assist with management.

The scientific community is also increasingly interested in focusing on standard data formats that increase the ability to share data, access large-scale data sets, and build upon previous research. Some projects may focus on standardized data collection while others seek to implement metadata standards that promote high-quality data documentation.

- The **Global Biodiversity Information Facility** (GBIF) is an international open data infrastructure focused on providing access to published biodiversity data. Currently, GBIF features over

570,000,000 records from hundreds of institutions related to occurrences (observations, specimens, etc.), sample-based data, checklists, and metadata. GBIF created an Integrated Publishing Toolkit (IPT) to support data publishing using common practices and standards. The IPT is an open source software tool that uses open standards to publish biodiversity datasets in a consistent way that promotes sharing and reuse. The open data standards include Darwin Core and the Ecological Metadata Language.

- **SciServer** is a project supported by the National Science Foundation and administered by Johns Hopkins University that is exploring how to make large-scale data sets more widely accessible to the scientific community. Current projects in the fields of astronomy, genomics, oceanography, soil ecology, and other areas make full data sets available in a common format and standard user interface. Although the formats may not yet be widely adopted throughout the scientific field, the SciServer project also focuses on making sufficient metadata available for researchers to understand the data gathering and organizational process.
- The **Horizon 2020** program in Europe includes an emphasis on research infrastructures and the establishment of an e-infrastructure for scientific data that supports the sharing of data and improved data interoperability.
- **eBird** enables individuals across the country to submit bird observation data to a central repository using a standardized set of data fields. Founded by the Cornell Lab of Ornithology and the National Audubon Society, eBird now has dozens of affiliates and sponsors and is available in seven languages. Regional portals enable local groups to provide guidance regarding the birds in their areas and all data entered through a portal is immediately made available in eBird. Data is also shared from eBird to other data systems such as the Avian Knowledge Network and the Global Biodiversity Information Facility.
- The **USA National Phenology Network** provides a standardized framework for researchers and citizen scientists to submit plant and animal observations. Participants return to a site regularly to observe and then log the phenological status of the plants and animals at that site. The procedures used for National Phenology Network data collection informed the development of the Phenology Monitoring Protocol in the Northeast Temperate Network of the National Park Service. Additional protocols are available for acoustic and camera monitoring.
- The **International Tree Failure Database** collects information about the mechanical failure of urban trees and is hosted by the University of California. Standard data about tree failure cases (trunk breaks, branch breaks and uprootings) is submitted by users from across the globe, with a concentration of professional arborists collaborating on this project in California. The data is used to create "failure profiles" of tree species. The project website is offline as of publication of this report, but it is an example of efforts towards standardized data reporting in urban forestry.

The establishment of an open data standard generally requires a collaboration between a policy setting agency or governmental entity at the state or federal level, businesses, and non-profit groups. A governmental organization or other group that dispenses grants could encourage the adoption of such a standard by requiring that data gathered as part of a grant be submitted in a certain format. Non-profit and other urban forestry groups may be more likely to adopt such a standard if they see other organizations implementing it, and businesses will build the open data standard into their software if their clients indicate organizing data via that standard is a requirement of any software they use. In some ways, the i-Tree software tools have begun this process by requiring certain data in order for ecosystem benefit calculations to be processed. As a result, some state funders have requested that urban tree inventory data be reported in a format that meets the requirements of i-Tree Streets. That type of public-private partnership could be expanded to support the creation of an open data standard and such data fields and formatting would then become a built-in part of any proposed software framework used for long-term monitoring.

4. Centralized Data Repository

A central data repository could be established to store urban forestry data gathered by organizations across the United States. This repository would provide researchers, practitioners, and public citizens the opportunity to access high-quality data sets and metadata about how that information was gathered without requiring the logistical difficulties associated with retrieving data from each organization individually.

Centralized data repositories or archives are a common feature in many scientific disciplines and may be organized by topic area or associated with a specific data collection and research program.[22] Some repositories may focus on sharing data sets while others include articles published on a particular topic but not the data. The Forest Inventory and Analysis (FIA) Program of the USDA Forest Service is an example of a central data repository. The Data and Tools section of the FIA website provides options for users to download data contributed to the FIA DataMart and the UrbanDataMart.[23] The USA National Phenology Network and eBird also support download of phenology data via a single website.[24]

An urban forestry data repository may include high-quality data sets and would benefit from the establishment of the Urban Tree Monitoring Protocol as an open data standard although it is not dependent upon the creation of that standard. Any data submitted to the repository should have metadata that clearly outlines how the data was collected, who collected it, and when the survey occurred. Contact information for the organizer of the survey should be included as well as recommendations for how to cite the data and links to other related data for that city or group. The repository does not need to be limited to tree inventory and monitoring data and could also include urban tree canopy analyses.

Some organizations and researchers may be reluctant to share data out of liability concerns or the need to keep data private until publications are released. Urban tree condition data may be especially concerning for municipalities facing liability issues. Submitting data would not need to be mandatory, although tying receipt of grant funds to submitting gathered information to an open data site would quickly increase the amount of data made available. As previously mentioned, some states already require that tree inventories collected with the support of state grants should be reported back in i-Tree Streets format. If a new central data repository were created, organizations may choose to make a select number of data fields available for public viewing, list the fields that were collected but are not visible, and indicate that users should contact them directly for access to the additional data. Researchers may also choose to submit only a subset of data until their initial research results are published.

A central repository will require some administration including approving proposed data sets or monitoring data sets that are posted by users. There are also hosting, storage, and maintenance costs associated with making large amounts of data available on a single site. Other open data and scientific data sharing sites such as the FIA Program, Data.gov, SciServer, the USA National Phenology Network,

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[22] Michener, WK. 2015. Ecological data sharing. *Ecological Informatics* 29: 33-44.

[23] More information about FIA is available at http://www.fia.fs.fed.us/.

[24] Details on downloading phenology data are available at https://www.usanpn.org/results/data. Details on downloading eBird data are at http://ebird.org/ebird/eBirdReports?cmd=Start

and eBird are organized by governmental, academic, or non-profit groups working unilaterally or in collaboration. While one group may take the lead on hosting and organizing a central repository, an advisory committee made up of researchers and practitioners could provide guidelines on displaying the data and administering the repository.

5. Balancing Leadership and Collaboration

Establishing data standards, creating a central data repository, and supporting the development of low cost software are large tasks that will require both financial and human resources. The recommendations are more likely to be broadly adopted if they are created via the collaborative contributions of a variety of organizations with the support of leading organizations that hold authority in forestry and natural resources. This process will take different forms for each recommendation.

1.1 Low Cost Software with Technical Support

While open source software is generally developed by a community of users, a core set of software developers and web designers with identified institutional support is often needed to complete a project by a defined deadline. An organization with urban forestry experience can also provide valuable guidance on the features and user experience necessary to create a system that meets the needs of the forestry community.

To encourage broad adoption of the software, the code could be developed openly in order that interested parties may view the work and contribute if they desire. That process will require a group to serve as the lead in defining standards for how the code will be developed and what contributions could be implemented, keeping the project on schedule, and providing opportunities for testing the system with a variety of users. Depending on the open source license given to the project, development may be enhanced by other for-profit and non-profit groups using portions of the code to integrate the software framework into their own products, providing additional opportunities for organizations to adopt the framework using the software system they already have in place.

1.2 Open Data Standard

The UTGL adopted the approach of a joint construction of knowledge during the creation of the draft Urban Tree Monitoring Protocol. Participation in defining and testing the protocols was entirely voluntary and participants contributed as individuals rather than as defined representatives of a particular organization. Pilot testing locations were chosen based on the interest of the researchers and arborists who contributed their time to the studies rather than at the direction of any authoritative governing body. While the International Society of Arboriculture, with which the UTGL is affiliated, has highlighted the protocols at a conference symposium, no professional or governmental organization has of yet endorsed the protocols as a best practice for urban forestry data collection.

Developing the protocols using a series of committees enabled individuals from academic organizations, federal and municipal government agencies, non-profit greening groups, urban forestry firms, and other groups to all participate without requiring formalized approval from their organization. The knowledge brought by individuals working in different aspects of urban forestry was crucial to creating a data gathering protocol that was useful for the work done by various organizations. Testing the protocol using a more grassroots system that was not dependent upon extensive external funding also more closely replicates the environment in which users are likely to be gathering data – limited financial resources, use of citizen scientists and student workers to gather data, and a limited time span in which data is gathered.

While the protocol has thus far been developed and tested by a group of dedicated volunteers, encouraging the widespread integration of the protocol into daily tree monitoring processes will require organizational support. As shown by the examples in the second recommendation, open data standards frequently are established by a group of interested parties that include:

- National and state level federal agencies that provide an authoritative voice encouraging use of the standard
- Funding and grant providing agencies interested in supporting projects that encourage data sharing and reuse
- Academic organizations that implement the standard into their research process and educate students in its use
- Non-profit groups that use and produce data according to the process
- Corporate entities that create software with the protocol built in as the default data gathering method

If the Urban Tree Monitoring Protocol is to become the standard series of fields included in all tree monitoring initiatives, the non-profit, municipal, and academic organizations gathering the data must be convinced of its usefulness and have access to tools that easily and efficiently enable the gathering of those data fields. For the continued use of these protocols and the creation of effective software and data repository systems, it will be critical to have major organizations in forestry, arboriculture and natural resource management use and endorse the protocols. This has already begun to happen at the state and regional level, with programs beginning to adopt the protocols and use the Field Guide in their tree monitoring work. For example, the protocols were adopted to monitor trees planted by the Massachusetts Department of Conservation and Recreation Asian Longhorned Beetle Reforestation program, the Arbor Day Foundation Energy-Saving Trees program, Pennsylvania Department of Conservation and Natural Resources' TreeVitalize program, and the PHS Tree Checker program. The protocols were also used to establish permanent street tree plots with baseline inventories conducted in Philadelphia and New York City by the Healthy Trees, Healthy Cities initiative of the Nature Conservancy. As more state and regional organizations employ the standards, they may not rely on the same software for gathering or storing data, but could be encouraged to submit that data to a central repository. An open data standard will be critical to support comparing the collected data.

Municipal and community greening groups frequently operate with limited funding and staff to devote to monitoring projects. Few groups will have the financial resources to customize an inventory tool solely for the purpose of meeting the data field requirements of the protocol and would be more likely to gather the fields if they were included as default data fields in tree inventory software. If the Urban Tree Monitoring Protocol is recommended by governmental and funding agencies as the standard minimum data set that could be gathered for urban trees, businesses working in the urban forestry field are more likely to accommodate the protocols in their inventory software and the tree assessment services they provide.

1.3 Centralized Data and Publication Repository

Perhaps more so than the creation of an open data standard, the formation of a centralized data and publication repository will require the leadership of a group that can provide the oversight, authority, and resources to manage the organization of large amounts of data and the technical infrastructure to support searching and hosting such data.

Creating a centralized data and publication repository includes:

1. Developing and providing guidelines for organizing data, creating metadata, archiving data sets, and submitting data for inclusion in the repository
2. Reviewing submitted data sets to determine whether they meet required standards for data structure and metadata
3. Creating a user interface and user experience that supports uploading and searching data sets
4. Creating a user interface and user experience that supports adding information on published studies and searching the repository of studies
5. Building and maintaining a technical infrastructure that includes hosting capabilities to support importing, viewing, and downloading large numbers of raw data sets

To encourage broad use, an advisory group that includes research scientists, urban forestry practitioners, and potentially representatives of urban forestry professional organizations and urban forestry businesses could oversee the repository. One organization, however, will likely need to serve as the key organizer of the creation and maintenance of the site including devoting resources to providing administrative support and software maintenance. Such daily and technical activities can be challenging to manage via a group and would benefit from the leadership of a single organization who may be able to secure funding and dedicate staff to reviewing data sets and responding to user questions.

An academic, governmental, or professional organization is the most likely group to serve as the main developer and contact for a central data repository. These groups may be able to secure grant funding to support the creation of a repository and subsidize costs for short periods of time in which external funding is not available. Ideally, the organization also would have a reputation within the forestry field that ensures researchers and urban forestry practitioners are comfortable submitting their data. Individuals may be hesitant to share data with a corporate entity or a non-profit group that does not appear to have the funding and staffing continuity to provide for the data portal. The long-term stability of the data repository may be improved if the lead organization works in partnership with another group, as is the case for both eBird and SciServer, or eventually transitions to working as a separate non-profit organization.

Conclusion

Caring for urban trees is a collaborative task. As non-profit groups, municipal foresters, researchers, student interns, citizen scientists, and others work together to grow and maintain our urban forests, technology can be a valuable tool to assist in gathering data, coordinating management and planting activities, and demonstrating the economic and ecological value of trees. This report explores the need for a software tool to assist with long-term tree monitoring and identifies

- the various types of users involved with gathering and maintaining tree data,
- the potential ways those users need to interact with software designed for tracking tree data,
- a list of software system requirements to meet user needs,
- how existing software relates to those system requirements,
- a data model and system architecture for a new software tool, and
- how that tool could be used for long-term monitoring of urban trees.

Urban trees are important to the health of our communities. This report will ideally encourage innovation in urban forestry data monitoring and technology development to support further collaboration between the many individuals involved in tracking tree health, growth, and longevity. Improving the process of long-term tree monitoring is essential for creating high-quality data that can inform adaptive management decisions, guide future planting initiatives, and assist with research on understanding how urban forests change through time. By providing opportunities to share that data more widely, organizations can learn from other programs and work together to build stronger urban forests.

Appendix A – Interview Questions

Practitioners

Workflow

1. Describe the workflow steps in setting up a tree monitoring program – specifically regarding data management before, during, and after data collection.
2. Describe the interface of the data collection system you use. Do you find it user friendly?
3. Let's say you went back to that same tree or site years later to monitor it again. What kind of information from the previous field visit would you want displayed in front of you to make for a smooth work flow in the field? Do you have specific suggestions regarding recording tree location, diameter, or photos of the tree?
4. Any suggestions for how to make the software interface better?
5. Let's say you've finished collecting monitoring data for the season. How would you like to access that data and what specific things would you like to be able to display and summarize easily?
6. Would you want to see tree monitoring data from your city shared publicly as open data? Why or why not?
7. What other datasets beyond the Urban Tree Monitoring protocols minimum data set do you feel are important and/or can be collected at current staffing levels?
8. What questions are you trying to answer with the tree monitoring data that is currently being collected? Or what questions would you like to answer if you had more/better quality data?
9. How are you using your current tree dataset to make changes or improve your tree-related programs?

Technology

1. Do field workers have/need access to the internal office network?
2. What existing software does your organization have in place to manage tree data? Are those systems used for asset management, project management, or monitoring?
3. Is your organization currently evaluating tree management software? If so, what software packages are being considered?
4. Does your organization use ESRI products?
5. Does your organization currently support a centralized database? Ex. Microsoft SQLServer
6. If the software were open-source, would that influence your decision to use it or not?
7. What level of software/technology expertise does your organization have in house?
8. Who manages the tree database and/or monitoring data at your organization?
9. If your organization has previously implemented tree monitoring software, what implementation issues came up? Specifically
    a. collecting data
    b. processing data

c. going back to the data in later years

10. What software that you used in this context have you liked/not liked?

Devices

1. What, if any, specific devices do field workers use to record tree data? Ex. Apple iPad, Android smartphone, etc.
2. If devices are not available, do you envision them becoming available in the near future?
3. Are there any upcoming changes to device availability or software that you know about?

Funding

1. Generally speaking, does your organization have funds to contribute to or purchase software for long term urban tree monitoring?

Staffing

1. Would your organization consider using tree data that was primarily collected by volunteers or interns?

Researchers

Workflow

1. What kinds of field-based tree monitoring studies have you been involved with? How was that data collected in the field? How was that data managed after being collected?
2. For one of the tree monitoring studies you've been involved with, describe the workflow steps – specifically regarding data management before, during and after data collection. Any suggestions for how to make this smoother in terms of the software interface?
3. We've heard that there are sometimes issues regarding tree location for long-term monitoring, with crews having trouble identifying individual trees or plot boundaries over the years. Do you have any specific examples of this? Any suggestions as to how the technology interface could prevent problems with locational accuracy?
4. What tree data problems have you run into when using data from non-profits or municipalities?
5. Let's say you're using a device like a smartphone or iPad to collect tree data, and you went back to a tree that had been observed several years prior. What kind of information from the previous field visit would you want displayed in front of you to make for a smooth work flow in the field? Any specific suggestions regarding recording tree location, DBH, or photos of the tree?

6. Correct species ID can be a problem for tree monitoring when volunteers and interns are collecting data. Are there any specific ways that the technology or data collection device could help with this? When species ID fixes are done by supervisors after data is submitted, how exactly does that process work to find and fix errors?

Technology

1. Does your organization use ESRI products?
2. Does your organization currently support a centralized database? Ex. Microsoft SQLServer
3. If the software was open-source, would that influence your decision to use it or not?
4. What software that you used in this context have you liked/not liked?
5. What software do you use for analytics/research?

Devices

1. What, if any, specific devices to field workers to record tree data? Ex. Apple iPad, Blackberry with ArcPad.

Appendix B – Software Evaluations

Overall Comparison

Legend	
✔	Fully Meets
△	Partially Meets
⛔	Does Not Meet
⊗	Unknown

	AppSheet	ArborPro	ArborScope	Collector for ArcGIS	Healthy Trees Healthy Cities	i-Tree Eco	OpenDataKit	OpenTreeMap	PyBossa	TreeKeeper	Tree Plotter
Ability to Enter Geospatial Data for a Tree	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Administrator Can Customize Data Fields	✔	✔	✔	✔	⛔	⛔	✔	✔	✔	✔	✔
APIs to Support Interoperability with Other Systems	⛔	⛔	⛔	△	⛔	⛔	✔	✔	✔	✔	⛔
Bulk Uploads of Existing Data	✔	✔	△	⊗	△	✔	✔	✔	✔	✔	✔
Data Export as	⛔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

CSV											
Mobile Access	✔	✔	✔	✔	✔	△	△	✔	✔	✔	✔
Open Source or Free Version Available	⊖	⊖	⊖	⊖	✔	✔	✔	✔	✔	⊖	✔
Photo Upload	✔	✔	✔	✔	✔	△	✔	✔	✖	✔	✔
Supports Gathering Data Across Time via Multiple Surveys	⊖	✔	△	✔	△	✔	✔	△	⊖	✔	△
Supports Multiple Levels of User Roles	⊖	△	✔	△	⊖	△	✖	✔	⊖	✔	✔
Supports Multiple Users at One Time	✔	✔	✔	✔	✔	△	✔	✔	✔	✔	✔
Trees Assigned a Unique Identifier	△	✔	✔	✔	✔	✔	✔	✔	⊖	✔	✔

AppSheet

Data Management for Urban Tree Monitoring - Software Evaluation

Legend	
	Fully Meets
	Partially Meets
	Does Not Meet
	Unknown

Creator: AppSheet
Product: AppSheet
Website: https://www.appsheet.com/
Version Evaluated: Version available in August 2015

Summary: AppSheet is a software tool to create basic data gathering apps without the need to write software code. Apps are created based on data fields created and stored in spreadsheets on Google Drive, Office 365, or Dropbox, and the app creator uses those spreadsheets to manage all data.

Notes:

- AppSheet is primarily a tool focused on data-collection and does not have functionality directed towards workflows or limiting access to fields based on user roles.
- Apps created by AppSheet are built using spreadsheets in Google Drive, Office 365, Dropbox, and other cloud-based sites as the data source. App creators can view and edit the data fields and associated data in those spreadsheets.
- The ability to build an app without the need for writing code can be useful if technical assistance or funding is limited.
- The spreadsheet functionality may limit the ability to develop and enforce complex data models with rigorous data validation needs.

Overall - AppSheet

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request	⛔	
Tech Support Available	Help documentation, online forums, phone or email support	✅	
Web-Based	Supports use in the field or office	✅	
Cloud-Hosted Data	Data not stored just on local device or computer network	✅	Data hosted in Google Drive, Office 365, Dropbox, or other cloud-based sites
Mobile Access	Native app or web app	✅	Hybrid and web applications available
Offline Mobile Access		✅	Ability to sync with backend database after data collected
Free Version Available		✅	Only for personal use
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years	✅	The data fields available for collection are defined by the underlying spreadsheet and could be customized to match Urban Tree Monitoring protocols
Relational Database with Distinct Tables for Trees and Other Information		⛔	Appears to be a flat data structure that is row based with no available relationships
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically	✅	

User Experience and Management - AppSheet

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time		✅	Cost is based on the number of users with a per-app plan also available

Tracks User Name of Person Entering Data			
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc		Does not appear to have varying levels of user access
Administrator Can Customize Data Fields			Data fields are tied to spreadsheets created in Google Drive, Office 365, Dropbox, or other cloud-based sites
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event		
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		Audit capabilities are limited but some basic info could be tracked using custom fields in the spreadsheet

Data Gathering Features - AppSheet

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		Users must install the AppSheet app and click a link to the app that is provided by the app creator via email
Tree Assigned a Unique, Non-Duplicable Identifier			Data organized in spreadsheets so identifiers may need to be assigned by an administrator

Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		
Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location		
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool		
Photo Upload			
Interface for Editing Data on Single or Multiple Trees			Can only edit a single tree at a time
Users Can Flag Trees for Additional Data Review			Data structure is defined by the app creator who can add a field for flagging tree data for review
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting		
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		Data can only be entered via the mobile app. No desktop interface is available
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		Data is organized in a spreadsheet so the original spreadsheet could include an existing data set
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc		
In-context Training Materials	Help icons near a data field, embedded videos, etc		
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc		Basic type validation (select from list of options, for example) is available based on rules set in the spreadsheet but forestry specific checks on species, diameter, and other fields are not

			available
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		Data is visible on original spreadsheet source
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is tracked, surveys are distinct from each other, etc		Would most likely require creating a separate AppSheet app for each survey and the flat data structure may make it difficult to connect the tree data across surveys
Select Data Fields Limited to Certain User Groups			Only one general user type available other than the app creator and that user type cannot be limited to certain fields

Data Analysis and Export Features - AppSheet

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS		
Export as CSV			Data managed via spreadsheets which could be saved as CSVs
Export in i-Tree Eco Format			
APIs Available to Support Interoperability with Other Systems			
Metadata Persists in Export	How fields should be completed, how data is stored, etc		
Administrators Can Sort and Filter Data			
Administrators Can View and Edit Data Gathered by Field Crews			
Dashboard and Data Summary Information Available			A weekly status summary email is sent to the app creator each week and basic information is available within the app as well

ArborPro

Data Management for Urban Tree Monitoring (UTM) - Software Evaluation

Legend	
✔	Fully Meets
△	Partially Meets
⊖	Does Not Meet
⊗	Unknown

Creator: ArborPro
Product: GPS Tree Inventory
Website: http://www.arborprousa.com/
Version Evaluated: Version available in August 2015

Summary: The ArborPro software is designed to assist organizations in managing the urban forest using GIS technology. The software includes a GIS database that supports advanced spatial queries and provides an immediate visual representation of trees in urban environments. ArborPro user group includes municipalities, universities, national laboratories, county park systems, golf courses, etc.

Notes:

- Very similar to a raw desktop Geographic Information Systems (GIS) application inside of ArcMap that includes standard forms with a non-customizable layout.
- Includes an option to access the data on mobile device through the web or in a standalone Windows environment. Data is synchronized between the standalone database and cloud hosted service upon connection to the web.
- No description of database technology or API access available on the website.
- Map view and tools appear sophisticated and incorporate some GIS analogies.
- System was developed for use by arborists. The software is generally not used for citizen science or volunteer data gathering initiatives.

Overall - ArborPro

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request	⛔	
Tech Support Available	Help documentation, online forums, phone or email support	✓	Phone and online conference support, training resources and videos on website, onsite support available for local clients
Web-Based	Supports use in the field or office	✓	
Cloud-Hosted Data	Data not stored just on local device or computer network	✓	
Mobile Access	Native app or web app	✓	A full version of the software can be used on mobile devices that run Windows. The community edition of the software provides limited read-only data fields for public viewing via web-based access on a smartphone or tablet.
Offline Mobile Access		✓	Individuals using tablets that have access to the full version of ArborPro can gather data while offline. When the device is again connected to the internet, the data is automatically synced between the local device and the master cloud-hosted database. Software rules are in place to manage multiple edits in the unlikely event where the same tree is edited by multiple users while offline.
Free Version Available		⛔	
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years	✓	ArborPro will set up additional data fields as requested by the client, which could be customized to match the Urban Tree Monitoring protocols.
Relational Database with Distinct Tables		✓	Trees are associated with a specific site ID

for Trees and Other Information			
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically		ArborPro provides ongoing support for the product

User Experience and Management - ArborPro

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time			Pricing plans available based on numbers of intended users
Tracks User Name of Person Entering Data			
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc		Full access and read-only access is available. Partial editing access that supports viewing and changing only select fields is not available.
Administrator Can Customize Data Fields			ArborPro will add fields for clients by request. Clients can edit the list of choices available in drop-down menus at any time.
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event		Inspections can be set up as a type of work order and assigned to a user for completion. The system notes a date and the user name when a field is changed. The work order number is not associated with the edit, but work orders can have a set completion date and user could search for all edits completed on a specific date.
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		Users can create a work order for a group of trees and assign a user to complete that work order. Maintenance activities can also be scheduled for a date in the future, and users can search for upcoming maintenance activities by date.

Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		Full audit log kept for every edit

Data Gathering Features - ArborPro

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		The community edition includes a read-only option that enables the public to view data. Editing privileges are not available unless the user has contacted the client who purchased the software. Data collection is generally done by ArborPro arborists and employees of the client.
Tree Assigned a Unique, Non-Duplicable Identifier			Tree site has the ID
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		ArborPro arborists are generally responsible for initial data collection and note location based on GPS coordinates. Users can update the location using the map interface.
Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location		
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool		System uses a proprietary mapping service
Photo Upload			
Interface for Editing Data on Single or Multiple Trees			Users can edit multiple trees by selecting trees using a spatial query or completing a search and applying edits to all trees within the spatial query or returned as a search result
Users Can Flag Trees for Additional Data			Users with access to the full system can flag a tree

Review			for inspection. Members of the public cannot flag trees for additional data review if they are accessing the inventory via the community interface.
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting		
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		Data can be added while not in the field. The user can also run a search and print out a list of all trees found in that search result that need to be updated.
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		The client can upload shapefiles of existing data. ArborPro can also upload CSV files that include geospatial coordinates.
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc		
In-context Training Materials	Help icons near a data field, embedded videos, etc		
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc		Some automatic validation included in the form of selecting from an approved list of choices. System does not automatically flag data for review based on pre-set rules. User can run queries to compare data entries and look for anomalies.
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		ArborPro has internal queries designed to support quality checking the data gathered by their arborists. Users can custom queries to find data anomalies.
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is		The tree detail page shows the most current data. A separate tab includes previous data values for

	tracked, surveys are distinct from each other, etc		that tree.
Select Data Fields Limited to Certain User Groups	Administrator can limit the ability to access certain fields based on different user roles		Editing privileges cannot be assigned by user role. A community edition allows read-only access to select fields.

Data Analysis and Export Features - ArborPro

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS		
Export as CSV			
Export in i-Tree Eco Format			Users can export data configured for upload into i-Tree and analysis with i-Tree Streets. Data fields could be customized to match i-Tree Eco form. Exported data could then be edited as necessary and submitted for i-Tree Eco processing.
APIs Available to Support Interoperability with Other Systems			
Metadata Persists in Export	How fields should be completed, how data is stored, etc		
Administrators Can Sort and Filter Data			Users can create custom queries to sort and filter data.
Administrators Can View and Edit Data Gathered by Field Crews			Users can search by user name, work order, or date.
Dashboard and Data Summary Information Available			System includes fifteen to twenty built-in summary reports as well as a custom report builder.

ArborScope

Data Management for Urban Tree Monitoring (UTM) - Software Evaluation

Legend	
	Fully Meets
	Partially Meets
	Does Not Meet
	Unknown

Creator: Bartlett Tree Experts & UGA Consortium for Internet Imaging and Database Systems (CIIDS)
Product: ArborScope
Website: http://arborscope.com/
Version Evaluated: Version available in Fall 2015

Summary: Bartlett designed ArborScope™ to proactively manage urban tree populations and allow tree managers to systematically track tree maintenance needs. ArborScope™ is a high-tech landscape management software that overlays an inventory performed by Bartlett on top of Google™ Maps to provide a simple and efficient means of viewing, updating, and querying collected information.

Notes:

- As a proprietary system, some information about ArborScope™ is available online and pricing information is available upon request. ArborScope™ is built on Enterprise level software that is fully licensed with and supported by the originators. The server and database software is all based on reliable industry standards.
- Bartlett arborists complete many of the inventories performed using ArborScope™ although clients have access to view and edit all data fields. Product development is guided by user feedback.
- The software allows users, depending on access level, to see basic and detailed information about each tree inventoried, including work recommendations.
- ArborScope™ allows users to link photos, reports, and other files to an individual tree or to the inventory as a whole.

Overall - ArborScope

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request	⛔	
Tech Support Available	Help documentation, online forums, phone or email support	✅	Help documentation, YouTube instruction videos, and phone or email support are available
Web-Based	Supports use in the field or office	✅	
Cloud-Hosted Data	Data not stored just on local device or computer network	✅	
Mobile Access	Native app or web app	✅	Web application accessible on tablets and smartphones
Offline Mobile Access		⛔	
Free Version Available		⛔	
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years	✅	Clients could contact Bartlett to add and customize data fields to match UTM protocols. Field names and species list mirror information available in the US Forest Service's i-Tree software.
Relational Database with Distinct Tables for Trees and Other Information		✅	
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically	✅	Developed & maintained by Bartlett Tree Research Laboratories (BTRL) and Consortium for Internet Imaging and Database Systems (CIIDS)

User Experience and Management - ArborScope

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time		✅	

Tracks User Name of Person Entering Data		✔	Tracked during Initial data collection. Data changes are tracked and available on request.
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc	✔	There are eleven user access levels including six available for clients
Administrator Can Customize Data Fields		✔	Bartlett can customize data fields for clients both pre and post data collection
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event	△	Custom fields could be used to indicate works completed as part of a single event
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc	✔	Includes an option to apply work management actions to multiple trees in a single action
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data	△	Includes various data query features and results can be exported to common data types (csv, shp)

Data Gathering Features - ArborScope

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees	✔	User must be given an account, and the client administrator can provide different levels of user access
Tree Assigned a Unique, Non-Duplicable Identifer		✔	Both location and tree have a unique identifier
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map	✔	Tree location can be added via GPS coordinates or by placing a point on a map

Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location		
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool		ArborScope™ uses Google Maps API
Photo Upload			
Interface for Editing Data on Single or Multiple Trees			Users can edit an attribute on a group of trees by manually selecting the trees or drawing a polygon around select trees. Single tree editing also available.
Users Can Flag Trees for Additional Data Review			Custom data fields can be created for this function
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting		
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		No paper worksheet available but data entry supported while not in the field
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		Bartlett can upload existing data as the process requires some customization. Field names in bulk upload must match existing field names in ArborScope™
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc		
In-context Training Materials	Help icons near a data field, embedded videos, etc		YouTube Channel available showing common tasks with future expansion in this area planned
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list,		Built-in species list

	etc		
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is tracked, surveys are distinct from each other, etc		Future expansion in this area planned
Select Data Fields Limited to Certain User Groups	Administrator can limit the ability to access certain fields based on different user roles		

Data Analysis and Export Features - ArborScope

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS		
Export as CSV			
Export in i-Tree Eco Format			Client can automatically export fields needed for i-Tree analysis
APIs Available to Support Interoperability with Other Systems			
Metadata Persists in Export	How fields should be completed, how data is stored, etc		
Administrators Can Sort and Filter Data			Available to certain user types
Administrators Can View and Edit Data Gathered by Field Crews			
Dashboard and Data Summary Information Available			Robust reporting module with over 25 standard built-in reports and options for custom reports. Outputs available as a map and table.

Collector for ArcGIS

Data Management for Urban Tree Monitoring - Software Evaluation

Legend	
✅	Fully Meets
⚠	Partially Meets
⛔	Does Not Meet
⊗	Unknown

Creator: Esri
Product: Collector for ArcGIS
Website: http://doc.arcgis.com/en/collector/
Version Evaluated: v10.3

Summary: Collector for ArcGIS supports collecting and updating data in the field, including logging geospatial locations. Collector requires an ArcGIS organizational account and was designed to support data collection for a variety of industries.

Notes:

- Collector for ArcGIS is a generic framework for field collection of spatial data and could be used for a tree inventory although it does not offer forestry domain specific features.
- The base platform for Collector for ArcGIS is ArcGIS Online which charges per user, making use with a large number of volunteers potentially expensive.
- Export options are available in ESRI data storage formats, which is the industry standard for spatial data.
- All data is customizable to the extent that an administrator can create the underlying data sources in ArcMap and publish to ArcGIS Online.
- The location of trees would be indicated by a pin on the map.
- Collector for ArcGIS is a fairly new project but Esri is steadily developing and regularly updating it.

Overall – Collector for ArcGIS

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request		
Tech Support Available	Help documentation, online forums, phone or email support		
Web-Based	Supports use in the field or office		
Cloud-Hosted Data	Data not stored just on local device or computer network		
Mobile Access	Native app or web app		Native applications for Android and iOS devices
Offline Mobile Access			
Free Version Available			Included with ArcGIS organizational account
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years		Customization options could support adding UTM protocol fields
Relational Database with Distinct Tables for Trees and Other Information			Map and data structure can be composed of compatible ArcGIS Online spatial data design practices
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically		

User Experience and Management – Collector for ArcGIS

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time			
Tracks User Name of Person Entering			Uses ArcGIS online accounts

Data			
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc		Depends on organizational setup
Administrator Can Customize Data Fields			
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event		
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		Data fields are arbitrary, but historical data for a tree would rely on built in ArcGIS online capability.

Data Gathering Features – Collector for ArcGIS

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		Users may need an ArcGIS online account
Tree Assigned a Unique, Non-Duplicable Identifier			
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		
Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location		Customizable data fields

Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool	✔	Full ArcGIS online base layers
Photo Upload		✔	
Interface for Editing Data on Single or Multiple Trees		⚠	Can only edit a single tree at a time
Users Can Flag Trees for Additional Data Review		✔	Arbitrary fields are available and one could be set up as a flag
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting	✖	
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field	⛔	
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually	✖	
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc	✔	
In-context Training Materials	Help icons near a data field, embedded videos, etc	⛔	
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc	⛔	
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates	⛔	
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is	✔	

	tracked, surveys are distinct from each other, etc		
Select Data Fields Limited to Certain User Groups			

Data Analysis and Export Features – Collector for ArcGIS

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS		
Export as CSV			
Export in i-Tree Eco Format			
APIs Available to Support Interoperability with Other Systems			ArcGIS Online has some REST endpoints
Metadata Persists in Export	How fields should be completed, how data is stored, etc		
Administrators Can Sort and Filter Data			
Administrators Can View and Edit Data Gathered by Field Crews			
Dashboard and Data Summary Information Available			

Healthy Trees, Healthy Cities

Data Management for Urban Tree Monitoring (UTM) - Software Evaluation

Legend	
	Fully Meets
	Partially Meets
	Does Not Meet
	Unknown

Creator: Bugwood, University of Georgia
Product: Healthy Trees, Healthy Cities
Website: https://play.google.com/store/apps/details?id=org.healthytreeshealthycities.hthc
Version Evaluated: Beta app used for field testing in Summer 2015

Summary: Healthy Trees, Healthy Cities was designed by the University of Georgia in conjunction with The Nature Conservancy and the US Forest Service to support tree monitoring initiatives in urban environments.

Notes:

- This app was in beta testing during Summer 2015.
- App has a solid system for adding field-sourced data, but it does not include comprehensive support for managing that data for maintenance purposes (editing, reviewing, exporting, etc).

Overall – Healthy Trees, Healthy Cities

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request		Not currently open source code but developed by a university so may be an option in the future
Tech Support Available	Help documentation, online forums, phone or email support		Developers are responsive but there is not a specific method for reporting issues or tech support
Web-Based	Supports use in the field or office		In development; other Bugwood apps have web-based view of some collected data
Cloud-Hosted Data	Data not stored just on local device or computer network		Data gathered via app but only accessible by directly contacting the app creator
Mobile Access	Native app or web app		
Offline Mobile Access			
Free Version Available			
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years		Fields match the minimum data set in the UTM protocols
Relational Database with Distinct Tables for Trees and Other Information			
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically		Support from The Nature Conservancy but long-term support unclear

User Experience and Management – Healthy Trees, Healthy Cities

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes

Supports Multiple Users at One Time			
Tracks User Name of Person Entering Data			App includes a login system
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc		Limited to one type of user and an administrative user rather than customized levels of access
Administrator Can Customize Data Fields			
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event		
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		

Data Gathering Features – Healthy Trees, Healthy Cities

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		
Tree Assigned a Unique, Non-Duplicable Identifier			
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		GPS and pin on a map if a connection to the Internet is available

Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location		Includes TreeKIT location method (distance along street curb to each tree)
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool		Requires Internet connectivity
Photo Upload			Photos can be tagged as whole tree or as relating to crown transparency or species ID
Interface for Editing Data on Single or Multiple Trees			Can only edit a single tree at a time; trees are stored chronologically by time entered in the queue
Users Can Flag Trees for Additional Data Review			Includes a check-box indicating species ID assistance needed
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting		
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		Paper data sheets are not compatible with photos or GPS coordinates
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc		Metadata not included but details for every variable are in the Field Guide
In-context Training Materials	Help icons near a data field, embedded videos, etc		Helpful field description pop-up windows
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc		

Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		Currently administrators do QA on raw Excel files generated from the app
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is tracked, surveys are distinct from each other, etc		In development; current app supports field methods to enable future monitoring
Select Data Fields Limited to Certain User Groups	Administrator can limit the ability to access certain fields based on different user roles		

Data Analysis and Export Features – Healthy Trees, Healthy Cities

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS		
Export as CSV			Only by contacting app creator
Export in i-Tree Eco Format			
APIs Available to Support Interoperability with Other Systems			
Metadata Persists in Export	How fields should be completed, how data is stored, etc		
Administrators Can Sort and Filter Data			Administrators can sort and filter data in Excel or in web portal
Administrators Can View and Edit Data Gathered by Field Crews			Administrators can sort and filter data in Excel or in web portal
Dashboard and Data Summary Information Available			

i-Tree Eco

Data Management for Urban Tree Monitoring (UTM) - Software Evaluation

Legend	
	Fully Meets
	Partially Meets
	Does Not Meet
	Unknown

Creator: United States Forest Service
Product: i-Tree Eco
Website: http://www.itreetools.org/eco/
Version Evaluated: i-Tree Eco 5.1.7

Summary: i-Tree Eco is a software application designed to use field data gathered from either a full tree inventory or randomly located plots in coordination with pollution and weather data to provide information on the environmental and economic benefits generated by trees in the urban forest.

Notes:

- Primarily a survey tool for running sophisticated and well defined studies. Includes provisions for doing complete or sample tree inventories and running similar analysis for each. Has a strong focus on computing inventory makeup with local conditions to produce environmental impact data of trees. Data fields appear to be somewhat rigid to provide inputs for model-based estimates of tree benefits and valuation.
- Open source codebase could lead to extensions and interoperability with other platforms. However, primary data appears to be stored at a workstation level rather than a centrally located server, locally or hosted. This would make the integration with other software fragile and difficult.
- Location of trees can be identified via coordinates, addresses, sketches, or calculations from geolocated plot centers using the required fields of distance and direction to tree.

Overall – i-Tree Eco

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request		In “public domain” but source code not available online
Tech Support Available	Help documentation, online forums, phone or email support		Online bug tracking and user forum. Developers will respond within 24 hours on business days when contacted with questions.
Web-Based	Supports use in the field or office		Web-based data entry with project and results stored on a local machine
Cloud-Hosted Data	Data not stored just on local device or computer network		Data and software is stored locally on installation machine
Mobile Access	Native app or web app		PDA workflow needs resyncing with main desktop installation, web-based SmartPhone app needs additional server access. Users send data from desktop to server in order to access that data from the web-form.
Offline Mobile Access			No data connection is required while collecting.
Free Version Available			Software is no-cost
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years		Fields are not easily customizable but partially align with UTM protocols, which include a small subset of Eco variables
Relational Database with Distinct Tables for Trees and Other Information			Local database storage strategy is not clearly specified but appears to be supported by Microsoft Access
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically		Supported by US Forest Service

User Experience and Management – i-Tree Eco

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time			The desktop platform supports one administrative users, but multiple users may access the web-form for data entry
Tracks User Name of Person Entering Data			Surveyor name is available in mobile
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc		Field methods are very involved and will require training for interns and volunteers. Users can gather data via the web form without access to the project or submitted data.
Administrator Can Customize Data Fields			Some required and some optional fields, but they are pre-defined. No customizable fields.
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event		Primarily research-based data collection
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		Primarily research-based data collection
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		

Data Gathering Features – i-Tree Eco

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes

Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		Volunteers and interns can access web app from smartphones
Tree Assigned a Unique, Non-Duplicable Identifier			TreeID is can be seeded per mobile device and then generated sequentially
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		Optional field for paper based surveys, N/A for PDA or Mobile Web
Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location		Plot Address
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool		
Photo Upload			Photos are included, but handled apart from survey collection data (id/name on memory card)
Interface for Editing Data on Single or Multiple Trees			
Users Can Flag Trees for Additional Data Review			
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting		Locations within a plot are recorded using distance and orientation to plot center and no mapping is available
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		User decides whether paper or web-forms are used for data collection; neither is marked as preferred
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		Must be formatted to align with upload templates and only possible for complete inventories, not sample plots
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc		Fields are specific and aligned to i-Tree study methodology
In-context Training Materials	Help icons near a data field,		

	embedded videos, etc		
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc		Extensive built-in data integrity checks including limits on maximum diameter, limits on building related measurements, requirements that fields be completed before moving to next screen, etc
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		Hot and cold checks and defined QA methods used to reinforce field training but not quantify error rates. The methods are described but not integrated into the system.
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is tracked, surveys are distinct from each other, etc		
Select Data Fields Limited to Certain User Groups	Administrator can limit the ability to access certain fields based on different user roles		

Data Analysis and Export Features – i-Tree Eco

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS		Instructions available to import shapefiles (manually created) but not referenced as output
Export as CSV			
Export in i-Tree Eco Format			
APIs Available to Support Interoperability with Other Systems			
Metadata Persists in Export	How fields should be completed, how data is stored, etc		Metadata is available in the i-Tree Eco user guide
Administrators Can Sort and Filter Data			

Administrators Can View and Edit Data Gathered by Field Crews			
Dashboard and Data Summary Information Available			

Open Data Kit

Data Management for Urban Tree Monitoring - Software Evaluation

Legend	
✔	Fully Meets
△	Partially Meets
⊖	Does Not Meet
⊗	Unknown

Creator: Open Source – Core development by University of Washington's Department of Computer Science and Engineering
Product: Open Data Kit
Website: https://opendatakit.org/
Version Evaluated: Version available in May 2015

Summary: Open Data Kit is an open source toolkit to support mobile data collection. The core code includes tools to build a data collection form, collect the data via mobile device and send it to a server, and view and export the collected information.

Notes:

- Open Data Kit is a platform for creating mobile surveys and may be most appropriate to implement as part of a larger system for managing data.
- Open Data Kit supports extensive customization options but requires a fair amount of custom development work to create more than a simple questionnaire form, which may not be an option for all organizations.
- Open Data Kit may be used for a tree inventory application but was not created with the purpose of tracking tree-related data and lacks the urban forestry specific options available in other proprietary solutions
- The mobile user interface is very basic and only supported on Android deices.
- The backend system that receives the surveys is much more flexible and extensive than other non-forestry based platforms that were reviewed.

Overall – Open Data Kit

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request	✔	
Tech Support Available	Help documentation, online forums, phone or email support	✔	Community tools plus support can be provided by paid implementer companies
Web-Based	Supports use in the field or office	⚠	Some administrative components are web based
Cloud-Hosted Data	Data not stored just on local device or computer network	✔	From a variety of user supplied sources
Mobile Access	Native app or web app	⚠	Native app for Android only
Offline Mobile Access		⚠	With some custom development
Free Version Available		✔	
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years	✖	
Relational Database with Distinct Tables for Trees and Other Information		⚠	Yes, but this platform requires custom development
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically	✔	Widely used open source product

User Experience and Management – Open Data Kit

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time		✔	
Tracks User Name of Person Entering Data		✖	Could not find info on survey users

Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc		
Administrator Can Customize Data Fields			
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event		
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		Workflow is entirely customizable but not specifically built with an extensive audit log or scientific data gathering in mind

Data Gathering Features – Open Data Kit

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		
Tree Assigned a Unique, Non-Duplicable Identifier			
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		
Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location		

Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool	✅	
Photo Upload		✅	
Interface for Editing Data on Single or Multiple Trees		✅	
Users Can Flag Trees for Additional Data Review		✅	
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting	⛔	
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field	✅	Has some extensions for scanning in paper surveys
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually	✅	Would likely involve either an import directly to the database or as a script against the OpenDataKit endpoints
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc	✅	
In-context Training Materials	Help icons near a data field, embedded videos, etc	✅	
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc	⛔	
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates	⛔	
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is	✅	

	tracked, surveys are distinct from each other, etc		
Select Data Fields Limited to Certain User Groups		✗	

Data Analysis and Export Features – Open Data Kit

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS	⛔	
Export as CSV		✓	
Export in i-Tree Eco Format		⛔	
APIs Available to Support Interoperability with Other Systems		✓	
Metadata Persists in Export	How fields should be completed, how data is stored, etc	✓	
Administrators Can Sort and Filter Data		✓	
Administrators Can View and Edit Data Gathered by Field Crews		✓	
Dashboard and Data Summary Information Available		✓	

OpenTreeMap

Data Management for Urban Tree Monitoring - Software Evaluation

Legend	
✔	Fully Meets
△	Partially Meets
⊖	Does Not Meet
✖	Unknown

Creator: Azavea and open source contributors
Product: OpenTreeMap
Website: https://www.opentreemap.org/
Version Evaluated: Version available in May 2015

Summary: OpenTreeMap is an open source platform and subscription service to support community data gathering of tree and green infrastructure data, viewing of ecosystem benefits, and urban forestry analysis.

Notes:

- OpenTreeMap is an open source urban tree inventory management software platform. It is available as a subscription service or as open source code that can be set up as a standalone implementation.
- OpenTreeMap provides customizable data fields as well as fine grained user permission and roles but does not display multiple surveys for a single tree.
- As an open source product, it is easy extendable and has public REST APIs as well as tabular and GIS exports. It would require software development experience to implement and some graphical interfaces for administrative functionality are not available in the open source code.

Overall - OpenTreeMap

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request	✅	
Tech Support Available	Help documentation, online forums, phone or email support	✅	Open source issue tracking through Github, user mailing list, and tech support contracts available
Web-Based	Supports use in the field or office	✅	
Cloud-Hosted Data	Data not stored just on local device or computer network	✅	
Mobile Access	Native app or web app	✅	Native mobile applications for Android and iOS, web accessibility for tablets
Offline Mobile Access		⛔	
Free Version Available		✅	Free trial membership for subscription service and open source freely available
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years	⚠️	Ability to add custom fields but default field list is not an exact match for UTM protocol
Relational Database with Distinct Tables for Trees and Other Information		✅	
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically	✅	Active development and investment by Azavea

User Experience and Management - OpenTreeMap

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time		✅	

Tracks User Name of Person Entering Data			Full audit system
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc		Customizable roles with levels of access
Administrator Can Customize Data Fields			
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event		
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		Support for stewardship activities (watering, pruning, and other customized options) but not full works management system
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		Full audit log and ability to export raw data

Data Gathering Features - OpenTreeMap

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		
Tree Assigned a Unique, Non-Duplicable Identifier			
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		
Ability to Enter Tree Location	Indicate an address, site code, or		

Information	other notes regarding location		
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool		
Photo Upload			
Interface for Editing Data on Single or Multiple Trees			Single tree data editing only
Users Can Flag Trees for Additional Data Review			Administrator could create a custom field to use for flagging data
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting		
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		Data entry can be done while not in the field but no printable paper form included
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		Bulk uploads must match provided template
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc		Units and some metadata are configurable
In-context Training Materials	Help icons near a data field, embedded videos, etc		Can only be added by a software developer
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc		Administrators can limit the choices available for completing a field and customize a species list
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		Recent edits page supports administrative review, no automated error reporting or dashboards
Supports Gathering Data Across Time	Trees can be surveyed multiple		Trees may be edited but changed data not tracked

via Multiple Surveys	times, time of data gathering is tracked, surveys are distinct from each other, etc		as a separate survey
Select Data Fields Limited to Certain User Groups			

Data Analysis and Export Features - OpenTreeMap

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS		CSV exports include latitude and longitude coordinates which can be used with a GIS
Export as CSV			
Export in i-Tree Eco Format			Uses i-Tree Streets to generate ecosystem benefits
APIs Available to Support Interoperability with Other Systems			Mobile apps use a publicly available API
Metadata Persists in Export	How fields should be completed, how data is stored, etc		
Administrators Can Sort and Filter Data			
Administrators Can View and Edit Data Gathered by Field Crews			
Dashboard and Data Summary Information Available			Limited summary information on number of trees, recent edits page, and exports available

PyBossa

Data Management for Urban Tree Monitoring - Software Evaluation

Legend	
✅	Fully Meets
⚠	Partially Meets
⛔	Does Not Meet
⊗	Unknown

Creator: Open source with initial development by Open Knowledge and the Citizen Cyberscience Centre
Product: PyBossa
Website: http://pybossa.com/
Version Evaluated: Version available in May 2015

Summary: PyBossa is an open source framework for creating crowdsourcing projects with a variety of features including phone-based data collection, image pattern recognition, PDF document transcription, and more.

Notes:

- PyBossa is a generalized crowdsource data collection tool with no domain knowledge or provisions for dealing with tree data specifically. While tree information could be collected via this tool, it does not include some of the functionality necessary for exclusively maintaining an enterprise system of tree inventories.
- PyBossa is highly extensible via a RESTful API, which makes it a candidate to augment other systems lacking in crowdsourced mobile data collection.
- Data validation and user hierarchy is limited and other software would be needed to accommodate those features.

Overall - PyBossa

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request	✅	Completely open source with good documentation
Tech Support Available	Help documentation, online forums, phone or email support	⚠️	Some online documentation and issues tracked in Github
Web-Based	Supports use in the field or office	✅	
Cloud-Hosted Data	Data not stored just on local device or computer network	✅	No service included but could self-host in the cloud
Mobile Access	Native app or web app	✅	Web-based
Offline Mobile Access		⛔	
Free Version Available		✅	
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years	✅	All data collection tasks are custom field sets so could be adapted to support Urban Tree Monitoring protocol data fields
Relational Database with Distinct Tables for Trees and Other Information		⚠️	Structure of storage depends on the created task, but it does not look like it supports complex, nested relations
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically	✅	Open source and active with support from the Shuttleworth Foundation

User Experience and Management - PyBossa

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time		✅	For data collection
Tracks User Name of Person Entering		✅	

Data			
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc		Appears to just have task creators and task completers
Administrator Can Customize Data Fields			
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event		
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		Completely open ended and could potentially be configured to support a more rigorous data collection with customized fields and audit logs

Data Gathering Features - PyBossa

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		Single user role would have to accommodate everyone
Tree Assigned a Unique, Non-Duplicable Identifier			No concept of a tree in system and would have to code protections for it
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		Tasks are open ended and can be geospatial in nature
Ability to Enter Tree Location	Indicate an address, site code, or		

Information	other notes regarding location		
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool		
Photo Upload			Unclear if photo uploading is supported
Interface for Editing Data on Single or Multiple Trees			
Users Can Flag Trees for Additional Data Review			
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting		
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc		
In-context Training Materials	Help icons near a data field, embedded videos, etc		Can be customized to support training materials
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc		Can be customized to support data validation
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		
Supports Gathering Data Across Time	Trees can be surveyed multiple		Individual trees are not automatically associated

via Multiple Surveys	times, time of data gathering is tracked, surveys are distinct from each other, etc		with multiple surveys
Select Data Fields Limited to Certain User Groups		⛔	

Data Analysis and Export Features - PyBossa

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS	⛔	
Export as CSV		✅	
Export in i-Tree Eco Format		⛔	
APIs Available to Support Interoperability with Other Systems		✅	
Metadata Persists in Export	How fields should be completed, how data is stored, etc	⛔	
Administrators Can Sort and Filter Data		✅	
Administrators Can View and Edit Data Gathered by Field Crews		✅	
Dashboard and Data Summary Information Available		⚠	

TreeKeeper

Data Management for Urban Tree Monitoring (UTM) - Software Evaluation

Legend	
	Fully Meets
	Partially Meets
	Does Not Meet
	Unknown

Creator: Davey Tree Expert Company
Product: TreeKeeper
Website: http://www.davey.com/natural-resource-consulting/urban-forestry/urban-forestry-management-software/tree-keeper/
Version Evaluated: TreeKeeper 7.7

Summary: TreeKeeper is tree management software focused on managing tree inventories, tracking work management activities, and creating reports.

Notes:

- As a proprietary system, product information for TreeKeeper is available online and pricing information is available upon request. It is a subscription-based system geared towards tree inventory and works management but includes tree valuation and eco benefits as well.
- Native mobile apps are available for Android, iOS, Windows phone, and Windows tablet. All mobile devices can also open a mobile browser-enabled version of TreeKeeper. There are costs relative to the number of mobile users, which could impact plans for use by large numbers of volunteers and interns.
- The product primarily focuses on data collection by arborists or other trained professionals. myTreeKeeper is a separate product that is available as a read-only public engagement site for viewing tree and aggregate forest data. An administrator can also enable guest access for TreeKeeper to provide read-only or editing access to selected tree data.
- Administrators can request additional data attributes be added by Davey Tree. Once the data field is added, the administrator can customize field choices.
- Location of trees is stored spatially and can be viewed in a map interface.

Overall - TreeKeeper

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request	⛔	
Tech Support Available	Help documentation, online forums, phone or email support	✅	Topic specific help available when using system. If click "help" within a task, user will go directly to that section of the help documentation.
Web-Based	Supports use in the field or office	✅	
Cloud-Hosted Data	Data not stored just on local device or computer network	✅	Several deployment options available
Mobile Access	Native app or web app	✅	Native Android, iOS, Windows phone, and Windows tablet applications available. Mobile browser-enabled access available via all mobile devices.
Offline Mobile Access		⛔	
Free Version Available		⛔	
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years	✅	Customizable fields and data choices are available and could be used to match the minimum data set. Completing all fields is not mandated and a comments field is available.
Relational Database with Distinct Tables for Trees and Other Information		✅	Can also export data as Access database
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically	✅	Supported by Davey Tree and regularly updated based on client requests

User Experience and Management - TreeKeeper

UTM Feature	UTM Desired Feature Details	Supports UTM Data	Software Specific Notes

		Management Needs	
Supports Multiple Users at One Time		✔	
Tracks User Name of Person Entering Data		✔	
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc	✔	An administrator can enable guest access to provide read-only or editing access to selected tree data
Administrator Can Customize Data Fields		✔	Davey will set up additional data fields as requested by the client. Clients can edit the list of choices available in drop-down menus at any time.
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event	⚠	Work is managed under “projects” which can be a set of tasks deployed to a specific group of people. Users can access work order that shows the specific trees associated with that project. Event management (inviting people to an event via an email, checking them into the event and confirming they attended) is not available although users will receive notifications when they login.
Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc	✔	A work project can be customized to include completing certain fields on select trees. Administrators can access work order to view all tasks completed as part of the associated project.
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data	✔	Custom queries of audit log available

Data Gathering Features - TreeKeeper

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes

Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees	✓	Administrator can grant access to any user and assign them read-only or customized editing privileges. Access may be dependent upon number of users supported by the purchased plan and data collection is often completed by Davey arborists and employees of the client.
Tree Assigned a Unique, Non-Duplicable Identifer		✓	
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map	✓	
Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location	✓	
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool	✓	myTreeKeeper appears to have map and satellite data
Photo Upload		✓	
Interface for Editing Data on Single or Multiple Trees		✓	Users can edit data on a single basis, apply global edits to a group of trees, or create “rules” to regularly apply a set of edits. For example, an administrator can create a “stump” rule that automatically changes certain values (risk rating, condition, etc) on a tree if user selects the “stump” rule. Users can also apply rules while in a work order to update the group of trees associated with the work order or select from “rules” that could include copying details from previous tree.
Users Can Flag Trees for Additional Data Review		✓	Administrator can view list of flagged trees and confirm or cancel edits
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees	✓	

	for use in ongoing data collection or reporting		
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		Could print the screen showing data fields for a site but would not have access to choice lists for data fields
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc		Work specifications set orders for how fields should be completed but stored in a separate document
In-context Training Materials	Help icons near a data field, embedded videos, etc		Some public facing sites have help icons near data fields and topic-specific help available when entering data in a field
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only select options from a list, etc		
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		Administrator can view data by user and date using search filters and defined choice lists prevent errors when entering data. There is no specific page that displays data automatically flagged based on rules in the system.
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is tracked, surveys are distinct from each other, etc		“Tree Sites” can be surveyed multiple time and an archive system supports viewing data from a previous survey via a query on the Site ID number
Select Data Fields Limited to Certain User Groups	Administrator can limit the ability to access certain fields based on different user roles		Administrator and crews have different roles and can be granted the ability to edit only certain fields

Data Analysis and Export Features - TreeKeeper

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS	✓	Options for an automated shapefile export to an FTP site
Export as CSV		✓	
Export in i-Tree Eco Format		△	Could set up data attributes that align with i-Tree Eco fields and then export the resulting data
APIs Available to Support Interoperability with Other Systems		✓	Data from TreeKeeper can be shared with an external works management system and tree location information can be made available as a WMS layer
Metadata Persists in Export	How fields should be completed, how data is stored, etc	△	Metadata is available in the work specification. Davey can also prepare and provide a data dictionary to the client.
Administrators Can Sort and Filter Data		✓	
Administrators Can View and Edit Data Gathered by Field Crews		✓	
Dashboard and Data Summary Information Available		✓	Dashboard available with pre-set reports. User can also customize reports and view a summary or detailed version, save the reports, and associate them with a customized layout. Reports are based on live queries of the data rather than static snapshots.

Tree Plotter

Data Management for Urban Tree Monitoring (UTM) - Software Evaluation

Legend	
	Fully Meets
	Partially Meets
	Does Not Meet
	Unknown

Creator: Plan-It Geo
Product: Tree Plotter
Website: http://www.planitgeo.com/#!new-tree-plotter/c12n
Version: Tree Plotter 2.0

Summary: Tree Plotter is a tree inventory application that provides software tools for organizations to inventory and manage trees and make planting and management decisions based on that information.

Notes:

- Entirely web based and data is centrally managed as a service with manual exports available in a variety of formats.
- Data fields are customizable when signing up for the application. Plan-It Geo can add fields at a later point by request from the client.
- Tree locations are created by placing and moving markers on a map.
- Tree Plotter LITE is a limited version of the Tree Plotter software that makes several features available for use and valuation at no cost.
- Tree Plotter is available at three subscription levels with optional add-on features and customizations available.
- The application includes helpful charting with options for basic and detailed analysis and customized reporting of the data.

Overall – Tree Plotter

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Open Source	Code available online or by request		Uses open source technologies but the Tree Plotter code base is not available as open source. For custom projects, the code could potentially be available for further development by the client.
Tech Support Available	Help documentation, online forums, phone or email support		Videos, webinars, and help documentation available online. Phone and email support available based on subscription level.
Web-Based	Supports use in the field or office		
Cloud-Hosted Data	Data not stored just on local device or computer network		Cloud-based hosting with annual fee to cover hosting, maintenance, and support
Mobile Access	Native app or web app		Web-browser based access is optimized for desktop, tablets, and smartphones
Offline Mobile Access			Data can be exported to a tablet or smartphone, edited in the field while offline, and then synced to the full cloud-based application when back online
Free Version Available			Tree Plotter LITE is available at no cost and includes a subset of the full Tree Plotter functionality and data fields
Compatible with Urban Tree Monitoring Protocols	Fields can be customized to meet minimum data set and support adding data on same tree over several years		Plan-It Geo can add custom fields to match UTM minimum data set
Relational Database with Distinct Tables			

for Trees and Other Information			
Sustainable for Long-Term Use	Software has ongoing development and support from a business or group of users and is updated periodically	✔	Plan-It Geo provides ongoing support for Tree Plotter and regularly updates the software

User Experience and Management – Tree Plotter

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Supports Multiple Users at One Time		✔	
Tracks User Name of Person Entering Data		✔	Tracked based on the user login
Supports Levels of User Access	Access options may be different for volunteers, staff members, research scientists, etc.	✔	Multiple levels of user access are available based on subscription level or as a selected customization. Access levels can be adjusted to meet the needs of customized projects.
Administrator Can Customize Data Fields		✔	Clients select data structure during the initial set-up of the application. Plan-It Geo can customize data fields at a later point upon request.
Includes Event Management	Setting up tree monitoring events, creating lists of trees or blocks to assign to attendees for monitoring, tracking work completed as part of an event	△	The Work Order Management module (described below) could be adapted for event management. Event management (inviting people to an event via an email, checking them into the event and confirming they attended) is available in custom applications but not standard in Tree Plotter.

Supports Works Management	Designating maintenance crews, tracking maintenance completed, setting dates when next maintenance is due, etc		A Work Order Management module can be added to the application and supports receiving, creating, editing, printing, and tracking service requests, inspection information, and work orders by administrators, staff, and crews.
Supports Workflow to Gather Data for Use in Scientific Research	Audit log visible to administrators that tracks changes to data		A full audit log is visible in the Work Order Management module or can be included in a custom application.

Data Gathering Features – Tree Plotter

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Data Collection User Experience Accessible to Volunteers and Interns	Does not require login credentials only available to employees		Visitors not logged into the site have read-only privileges by default (which can be turned off to skip login credentials) and clients or administrators can set up limited access to select data fields
Tree Assigned a Unique, Non-Duplicable Identifier			
Ability to Enter Geospatial Data for Tree Location	Adding GPS coordinates or placing a pin on a map		Tree locations identified by placing a point on a map and location does not require GPS access
Ability to Enter Tree Location Information	Indicate an address, site code, or other notes regarding location		
Map or Satellite Data Available within the Software Tool	Does not require accessing a mapping system outside of the app or other software tool		Multiple street or imagery base maps available

Photo Upload			
Interface for Editing Data on Single or Multiple Trees			Data can be edited for a single tree via a pop-up form or the data table. Editing multiple trees is available in a specific interface for Tree Plotter and the Work Order Management module.
Users Can Flag Trees for Additional Data Review			Via a custom field or the Work Order Management module
Ability to Print Map Showing Existing Trees	Administrators may print a map showing the locations of known trees for use in ongoing data collection or reporting		
Supports Gathering Data Via Paper	Software provides a paper worksheet or supports data entry while not in the field		Paper forms not included but data can be added while not in field or imported as an existing spreadsheet
Existing Data Bulk Uploads	Spreadsheets of existing data can be bulk uploaded rather than entering data on each tree individually		Import data from csv files or shapefiles
Supports Setting Metadata	Info on how fields should be completed, how data is stored, etc.		Tool tips, an “About” panel, and “Take a Tour” slides are provided, and certain fields include validation. Details on how each field should be completed are not a standard feature.
In-context Training Materials	Help icons near a data field, embedded videos, etc.		Hyperlinks and hover text available via customization
Data Validation Built into System	Automatic checks prevent entering certain species or diameters, users can only		Includes species look-up table, limitations on date formatting and certain numeric values, and select choice fields.

	select options from a list, etc		Customization options available for additional validation rules.
Quality Assurance Procedures Built into System	Administrator can review data in order to determine error rates		There is no specific page that displays data automatically flagged based on rules in the system but could be added based on a customizations to the data fields
Supports Gathering Data Across Time via Multiple Surveys	Trees can be surveyed multiple times, time of data gathering is tracked, surveys are distinct from each other, etc		Trees may be edited but changed data not tracked as a standard feature in Tree Plotter. Status changes are tracked in the Work Order Management module.
Select Data Fields Limited to Certain User Groups	Administrator can limit the ability to access certain fields based on different user roles		

Data Analysis and Export Features – Tree Plotter

UTM Feature	UTM Desired Feature Details	Supports UTM Data Management Needs	Software Specific Notes
Export as Shapefile	For use in GIS		
Export as CSV			
Export in i-Tree Eco Format			Could set up data attributes that align with i-Tree Eco fields and then export the resulting data
APIs Available to Support Interoperability with Other Systems			Web services could be quickly setup to support customized access between online systems
Metadata Persists in Export	How fields should be completed, how data is		

	stored, etc		
Administrators Can Sort and Filter Data		✔	
Administrators Can View and Edit Data Gathered by Field Crews		✔	
Dashboard and Data Summary Information Available		✔	Preset reports available for display as pie or bar charts and custom chart creation tool also available