Modernizing National Park Service Plant Records Management

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ABSTRACT — The National Park Service (NPS) stewards one of the greatest collections of plants in the world. However, unless information about these plants can be aggregated and accessed, their greatest potential remains untapped. Currently, there is no digital tool available to NPS employees to manage plant records. This paper presents an overview of digital plant records management and the ways it can enhance plant care, public education, and research. In 2016, the NPS Olmsted Center for Landscape Preservation assessed the capabilities of plant record management databases. The project team selected four leading software applications – the ArcGIS Public Garden Data Model, BG-BASE, BRAHMS, and IrisBG – to evaluate, along with the NPS Facility Management Software System (FMSS). A needs assessment, conducted with staff at partner parks, identified key criteria for evaluation. The project team used sample data from partner parks in trials of each software application to assess capabilities in data fields, maintenance, mapping, interpretation, and research, as well as learning curve and cost. This research, combined with insights from software developers, scholars, and key users of plant records management databases at allied institutions around the world, offered insights into the applicability and value of plant records management software to national parks and other institutions that manage plant records data.

INTRODUCTION

Plants are a cornerstone of life on Earth. As such, they are also the cornerstone of America's national landscapes. Not only do plants provide living, tangible links to the past, but they also possess great ecological and scientific value. Many national parks, including Yellowstone, Great Basin, and Haleakalā, are home to endemic plant species. A greater number provide habitats for endangered plant species critical to pollinators and other at-risk wildlife. Landscapes stewarded by the National Park Service (NPS) reflect the nation's historical and ecological diversity. Wise management and use of information about plants in these landscapes is central to a sustainable future.

Plants in national parks are enjoyed by visitors and cared for by park staff for their aesthetic, cultural, historical, and scientific significance. Plant records form the basis for effective stewardship, and ready access to them is essential. The utility of records is limited if access is impeded, impractical, or insufficient. The availability of plant records and documentation of the history, condition, and care of wild and cultivated plants are also essential to understanding these life-giving organisms. This understanding leads to a wider appreciation for park landscapes and their long-term preservation. In a microcosm, this is the NPS mission: to preserve America's natural and cultural heritage for public enjoyment, education, and inspiration.

Plant records management databases are capable of organizing plant records to inform stewardship and science, and adapting nonsensitive information for public access on the web and mobile platforms. Plant records management databases integrate data about vegetation in the landscape, seed collections, herbarium specimens, and greenhouse operations. When aggregated, this information makes data-driven stewardship decisions and an expanded understanding of the natural world possible.

There are many digital tools to aid in plant recordkeeping, management, research, and education. Yet there is currently no tool available to NPS employees to manage interdisciplinary plant records data for both internal management and external research and education. Plant records management software presents NPS with an opportunity to join the community of scholars and scientists who have long benefitted from the use of plant records management software. Given ongoing global climate change and habitat destruction, the value of an interdisciplinary database for use in plant inventory, management, research, and interpretation cannot be understated (Figure 1).

As NPS moves into its second century, social and environmental changes require NPS to think critically and creatively about the manner in which landscapes are managed. These challenges are not unique to the NPS but are also faced by land management organizations around the world. Institutions that care for plant collections are turning to technology to enhance their stewardship, interpretation, and research potential and to invite new opportunities for collaboration. Although not glamorous, digitizing plant records is the first step in this process.

This paper introduces readers to plant collections, plant records, and records management, the leading software programs available for use in plant records management, and the ways in which digital plant recordkeeping can enhance plant maintenance, interpretation, and research. In 2016, the NPS Olmsted Center for Landscape Preservation assessed the capabilities of plant record management databases. This research—combined with insights from software developers, scholars, and key users of plant records management databases at allied institutions around the world—offered insights into the applicability and value of plant records management software to national parks and other institutions that manage records data.

Plant recordkeeping is much more than a didactic exercise. The understanding that sound plant records afford underscores the relationship between people and plants, food, medicine, shelter, and fuel, along with the impacts of individual and collective actions on the environment, including human-induced climate change. While the technologies and techniques for plant recordkeeping outlined in this paper may be new to NPS and many other readers, their purpose—enhancing data collection and application to inform maintenance decisions, inspire and engage the public, and support scientific research—has been reflected in the NPS mission for over one hundred years. Strategic incorporation of technologies to conduct science and engage the public is central to successful resource stewardship in the twenty-first century.

WHAT ARE PLANT COLLECTIONS?

The term *plant collection* refers to vegetation that is cared for by national and state parks, public gardens, and arboreta for a defined purpose and categorized by geographic, taxonomic, thematic, or ecological significance (Botanic Gardens Conservation International 2016a). Plant collections provide for public enjoyment and education, maintain culturally and historically significant species, and benefit scientific research and conservation efforts.

Broadly speaking, there are two types of plant collections: living collections and preserved collections. Living plant collections are actively grown in the landscape or in related greenhouses and nurseries. Preserved plant collections consist of plant materials gathered by botanists and researchers. They serve as representative specimens from fieldwork or from plants grown in an institution's living collection. These may include the whole plant or individual parts, such as leaves, flowers, seeds, fruits, and wood. Preserved plant collections are generally pressed and mounted on large sheets of paper, dried and stored

Fig. 1. NPS staff compare digital fieldwork tools for managing vegetation at Minute Man National Historical Park in Concord, Massachusetts, 2017 (Courtesy of NPS).

in boxes, or submerged in a preservative fluid. Specimens are generally organized and maintained in herbaria, which serve as libraries for preserved plant collections.

Living Plant Collections in National Parks

Plant collections are found throughout the country in designed, ethnographic, and vernacular landscapes at historic sites and within designated wilderness areas. While plants in national parks may look the same as those at public gardens and arboreta, development goals render them different. Most public gardens and arboreta have articulated objectives for the development (most often expansion) of their plant collection. In national parks, collection development is not a primary objective. Rather, collection development occurs through the removal or replacement of failing vegetation that does not align with the historic character, or natural and cultural resource management goals, of the park.

Many public gardens and arboreta are affiliated research institutions and prioritize the biological significance of the specimens in their collections. On the other hand, developed areas of national parks (i.e., nonwilderness areas) are largely managed to reflect their historical significance. Accordingly, collection development for these areas tends to prioritize the objective of perpetuating historic character. Cultivated and wild plants are both considered collections; yet they may not necessitate the same records management approaches.

Preserved Plant Collections in National Parks

Only a handful of national parks maintain herbaria on site or in collaboration with an academic partner. A notable example is Yellowstone National Park, which houses nearly 20,000 vascular and nonvascular plant specimens. The herbarium preserves unique lichen and fungi populations associated with the park's geothermal systems, as well as a comprehensive collection of aquatic plants that are often underrepresented in herbaria. These specimens are important for research, because they preserve both genetic information and physical characteristics of plants at different points in their development. They can be used to study changes

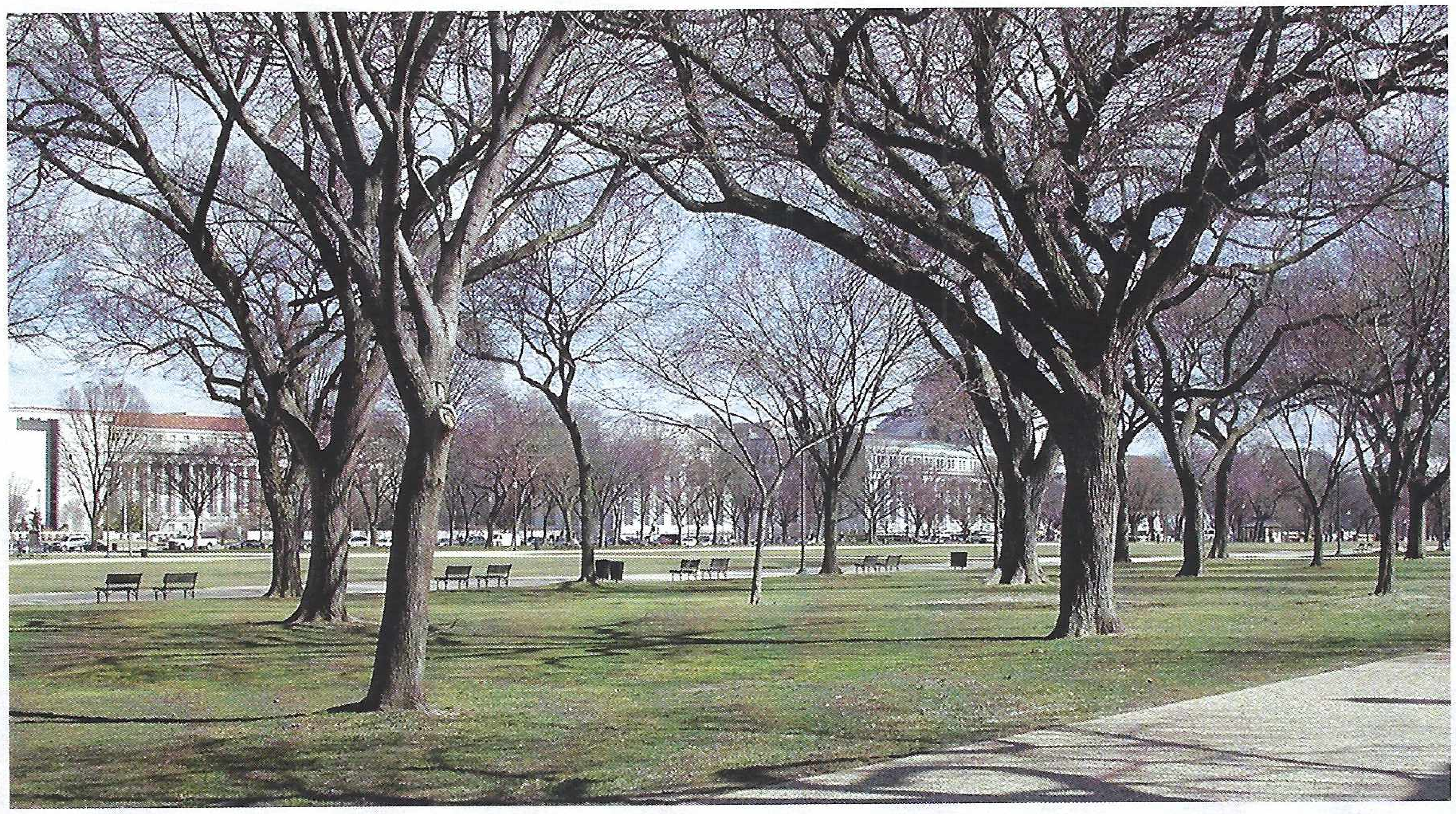

Fig. 2. Elm trees growing on the National Mall, including descendants of the Dutch elm resistant Jefferson elm discovered here (Courtesy of NPS).

CASE STUDY: THE JEFFERSON ELM ON THE NATIONAL MALL

On the National Mall in Washington, DC, over two hundred American elms (*Ulmus americana*) have succumbed to Dutch elm disease since 1952. In the intervening years, NPS has replaced American elms lost to disease with a range of elm species, including many Dutch elm disease–tolerant cultivars of the American elm. One of these cultivars, the Jefferson elm (*U. americana* 'Jefferson'), is defined by a unique genetic characteristic—three sets of chromosomes rather than the traditional four in American elms—that confers natural tolerance to the microfungus (*Ophiostoma ulmi*) that causes Dutch elm disease.

While widespread planting of the Jefferson elm is new, the original Jefferson elm was discovered on the Mall in the 1970s (Figure 2). Unknowingly, it had been purchased from a nursery in New Jersey and planted across Jefferson Drive from the Freer Gallery of Art in 1935 during implementation of the McMillan Plan. When park staff noticed that this specimen was not suffering from Dutch elm disease like its neighbors, they began monitoring the tree.

Collaborative screening was conducted by scientists James Sherald (NPS) and Alden Townsend (US National Arboretum). In 2015, the cultivar was released jointly by NPS (US Department of the Interior) and Agricultural Research Service (US Department of Agriculture). It is now available at wholesale nurseries across the country and was recently used to replace the iconic Olmsted Elm at Frederick Law Olmsted National Historic Site (see the Mapping case study).

A plant records management database could have helped in the screening of the Jefferson Elm by tracking genetic information and the sharing of this information with interagency collaborators. As the tree was propagated, the location and condition of propagules could have been traced in connection with the parent tree on the Mall. If discovery of the Jefferson Elm had occurred today, the provenance information included in a plant records management database would be useful in meeting the requirements of *Director's Order #77-10: NPS Benefits Sharing* (US Department of the Interior 2013), since NPS would stand to benefit from the discovery of a commercially viable plant on public land.

in vegetation over time or species distribution and track environmental responses to climate change.

Plant Collecting in National Parks

Incorporating wild collections, or those collected where the plants grow naturally, is often an important aspect of plant collection development. Species that have a varied natural range often display slight genetic differences that benefit botanical and conservation research (Toomer 2010, 69). To access this genetic diversity, arboreta organize wild origin collection expeditions centered on their mission. For example, members of the Arnold Arboretum undertook an expedition in 2015 to collect paperbark maple (*Acer griseum*) seeds and DNA in alignment with their commitments to developing their Acer collection and cultivating specimens of high conservation value (Dosmann 2008, 16).

Within the National Park System, active collecting is typically limited to within park boundaries and does not include introduction of plant material collected from outside of the park. For instance, seeds collected in Yellowstone National Park are used for vegetation restoration efforts within the park (Renkin 2014). However, visiting researchers and scientists can collect plant materials from national parks, working through the NPS Research Permit and Reporting System. NPS is also a partner in Seeds of Success, a national native-seed collection program led by the Bureau of Land Management. Material collected for the Seeds of Success program is used for research, such as plant germination trials, to aid in restoration conservation (Byrne and Gordon 2009, 21).

WHAT ARE PLANT RECORDS?

Plant records encompass all information about the history, condition, and care of plants, including acquisition and maintenance histories, condition assessments, genetic profiles, images, maps, and documentation of outstanding maintenance needs. They are the backbone of plant collections, providing greater meaning and research value to a plant in the landscape or a reference specimen in a herbarium. It is important to understand that the information contained in a plant record is both a resource and a product (Hohn 2008, 72). As we shall discuss later, the specific value of plant records can be found in how and what information is documented (Hohn 2008, 74).

Basic plant records are standardized at many institutions and include an accession number, taxonomic information, and provenance. Accession numbers are generated in a standardized format so that staff across disciplines and over time can retrieve and update information easily. Many institutions create accession numbers based on the year and order in which a specimen was accessioned. For instance, the fifth plant added to a collection in 2017 might be accessioned as 20170005. Taxonomic information includes plant families, genera, species, subspecies, and cultivar or variety according to accepted nomenclature. While many records also note common names for ease of communication, such as "scarlet oak" for *Quercus coccinea*, scientific names are important because they have fixity to a particular organism based on the rules of botanical nomenclature. This allows staff to understand specific maintenance needs or likely pests and allows for enhanced biodiversity-related research across institutional and political boundaries. Provenance refers to the origin of an accession, which could be wild, cultivated, or unknown. This information is useful for both recordkeeping and research involving genetic diversity or distribution studies.

However, plant records often include much more than this basic information. Enhanced data may include condition assessments and maintenance histories, phenologic data, location within the herbarium or landscape (GPS coordinates), images, or tags to thematic collections, such as oak trees of New England. Enhanced data depends on the goals and capacity of the managing institution. For instance, an arboretum that is affiliated with a research institution and has a large staff and budget likely keeps different and more extensive information about plant specimens than a small public garden staffed primarily by volunteers and with a focus on public educational programming.

Records Management in the National Park Service

There is currently no standard method for managing plant records in the National Park System. Park staff use a combination of the data organization strategies detailed above that generally focuses on organizing task-specific information. This presents difficulties when sharing information across disciplines and can result in data duplication. For instance, a park horticulturalist may have a digital spreadsheet of plants and their related maintenance requirements, such as how to treat invasive bittersweet. A natural resource manager may have a geographic information system (GIS) map of invasive species throughout the park, including bittersweet. Neither, however, necessarily has access to the other's information without a records management system.

Several NPS databases include information on plant records, including the Cultural Landscapes

Table 1. Types of plant records management systems

System purpose	"Lite"	"Regular"	"Extra strength"
Plant Records	Index cards Notebooks	Excel spreadsheets Access (flat file)	ArcGIS Public Garden Data Model BG-BASE BRAHMS IrisBG
Maintenance	Written work orders Calendar records Word of mouth	Digital work orders Excel spreadsheets	Multilevel integrated systems (FMSS) Map-integrated relational databases (see list above) GIS reports for workflow management
Interpretation	Signage Printed flyers	Interpretive rangers Guided tours Reenactments	Interactive digital tools Mobile applications
Mapping	Hand-drawn Printed from the Internet (reference only)	"Heads up" digitization (drag and drop/drawn on screen) ArcGIS (basic license)	ArcGIS (standard or advanced) Digital base maps Accurate GPS data captured with digital tools (Trimble, etc.)
Research	Pen and paper inventories Basic calculations Hand-drawn maps	Basic digitized reports Plant records accessible for internal research Baseline spatial analysis (ArcGIS standard license)	Sophisticated GIS analysis (ArcGIS advanced license) Integrated literary resources (relational database) Web-accessible plant records for external researchers

Source: Adapted by the authors from and courtesy of Mary Burke, University of California, Davis, Arboretum; David Michener, "Collections Management," in *Public Garden Management: A Complete Guide to Planning and Administration of Botanical Gardens and Arboreta*, ed. Donald Rakow and Sharon A. Lee (Hoboken, NJ: John Wiley & Sons, Inc., 2011), 264.

Inventory (CLI), Facility Management Software System (FMSS), NPSpecies database, the Integrated Resource Management Applications (IRMA), and the Public Lands Flora project. Yet none of these include comprehensive information on a specific plant specimen or group, or has the capacity to aggregate different types of information, such as taxa, cultural history, maintenance history, and biological data.

WHAT IS RECORDS MANAGEMENT?

Records management consists of "everything that is done to take care of collections, develop the collections, and make the collections available for use" (Simmons 2006). There are many appropriate ways to manage plant records, ranging from card catalogs to digital spreadsheets to relational databases. For an overview of the range of plant records management options, see Table 1.

Pen and Paper

Card catalogs and written notes can be used to answer simple questions like "When was the red maple (*Acer rubrum*) planted?" They are most useful for a collection accessed by a small number of knowledgeable staff that primarily use the information internally. Card catalogs and written notes must be organized according to a standardized system to be useful. Hand-drawn maps commonly accompany narrative records at small sites. They are most useful when they contain a clear key and directly reference related catalog cards or ledger notes.

Preliminary Digitization

Using a well-formatted digital spreadsheet can help to answer more complex questions such as "What percentage of the tree collection is red maple (*Acer rubrum*)?" Digital spreadsheets provide an additional level of utility by allowing for more advanced queries and flexibility to work with other computerized systems. Fields in digital spreadsheets are often designed to allow only unique entries, organized into discrete and thematic columns such as genera or species. Quality control measures, such as drop-down menus for inserting standardized values, can improve the accuracy of digital spreadsheet records.

With some experience, digital spreadsheets can also be loaded into a Structured Query Language (SQL) server or a GIS, which offers enhancements over hand-drawn maps. Risks associated with the loss or destruction of hard copy (pen and paper) records are reduced through preliminary digitization and data backup.

Relational Database

Relational databases are designed to recognize relationships in stored information. For this reason, they are the most powerful records management tools. The ability to link data tables together based on common factors, such as genera or location, gives relational databases the most complex and flexible querying potential. A relational database can easily answer complex, multifactor questions such as, "How many *Acer rubrum* were planted in the south lawn after 1950?" Many modern relational databases used to manage plant records can also store images and link directly to interactive maps, providing additional levels of data visualization and analysis. Many can also interface with web and mobile platforms to allow use in the field and expand access to new and remote audiences.

Like digital spreadsheets, relational database software provides a level of permanence that written records lack. Database software also adds an additional level of security by allowing for functions such as flexible user restrictions, two-step deletion, and other safeguards that help prevent erroneous data entry or loss. Ultimately, plant records management databases streamline stewardship efforts by providing a centralized home for digitized asset information that can be accessed across disciplines.

OVERVIEW OF LEADING PLANT RECORDS MANAGEMENT DATABASES

The following provides an introduction to the five plant records management databases evaluated for this paper. These applications were selected based on a survey of currently available software and discussions with institutions that currently use digital tools to manage plant records.

ArcGIS Public Garden Data Model

The ArcGIS Public Garden Data Model was created collaboratively by Esri (Environmental Systems Research Institute) and the Alliance for Public Gardens in 2011. Their objective was to build a GIS system that parks and gardens could use to map and record plant data without requiring each institution to build an ArcGIS data frame from scratch.

The Data Model is a modular system built on a base map that is georeferenced to a real world coordinate system. The initial three modules include (1) basic plant record, (2) tree assessment, and (3) facilities and infrastructure. The first module records individual plants and mass plantings with related taxonomic information; the second records comprehensive health, hazards to, and benefits of trees; the third records information about hardscapes and circulation. All three modules can be used simultaneously or users can select only the options pertinent to their landscape.

Version 1.0.4 of the Public Garden Data Model was evaluated for this paper, but has since been superseded by the Parks and Gardens Information Model 2.0, which is available as an ArcGIS Solutions product from Esri. The current version of the model includes expanded capacity for asset management, dedication management, utilities, and plant records management.

Learning to use the ArcGIS Public Garden Data Model itself is fairly straightforward. The Alliance for Public Gardens GIS has created comprehensive training resources that make using the data model easy. Along with the seven-part training video posted on their website, nearly fifty instructional videos and conference recordings are available on their public YouTube page. They have also created a twenty-seven-page written document that includes step-by-step instructions with descriptive screenshots.

Using the data model requires a firm grasp of ArcGIS for setup, data entry, and analysis. ArcGIS is a large and complicated program; however, there are many resources available online through Esri and third-party organizations that offer free step-by-step training. The Alliance for Public Gardens offers free online Esri training to member institutions, and Massachusetts Institute of Technology's OpenCourseWare program has several free online courses.

Ensuring that a specific site's data model is well designed within ArcGIS from the beginning will make it easier to maintain and train new staff members in the long run. The latest version of the ArcGIS Public Garden Data Model can be hosted entirely on ArcGIS Online to reduce the learning curve associated with ArcGIS Desktop products.

BG-BASE

BG-BASE was developed in 1985 by a team of programmers at the request of the Arnold Arboretum of Harvard University to address the issue of storing large amounts of complex data in a unified, query-optimized program. BG-BASE consists of seven linked modules which each contain their own subset of tables. The modules are (1) living collections, (2) preserved collections, (3) conservation, (4) education, (5) propagations, (6) ArcGIS Connector, and (7) HTML/web. Users and administrators can customize or restrict particular modules on a user-by-user basis.

BG-BASE is an immense and powerful system that can initially be intimidating for users without previous database experience. Purchase of BG-BASE comes with two days of off-site training in either Dallas, Texas, or Portland, Maine, as well as a year of unlimited technical support through phone, email, remote access, and discussion forum. Continued technical support agreements can be purchased after the first year. For an additional charge, in-person training and retraining can be arranged, as well as training seminars that are offered regularly in Portland and Dallas. The software developers have created a comprehensive seventy-two-page written document with step-by-step instructions and descriptive screenshots and provide it free of charge. The database also includes a "search by field" function that opens a pop-up help window that explains the functions of a particular data field.

BRAHMS

The Botanical Research and Herbarium Management System (BRAHMS) was developed in 1990 by the Department of Plant Sciences at the University of Oxford as an affordable and practical means of managing collections. BRAHMS includes various integrated modules that can be enabled or disabled depending on need. Within each module are thematic relational tables, such as the accessions, plants, and events tables found in the living collections module. Information can be viewed and edited either on a classic spreadsheet or through forms. Users or administrators can customize or restrict particular modules on a user-by-user basis. BRAHMS v7 was evaluated for this study, but BRAHMS v8 Alpha was released in February 2017. The newest version includes major functional and aesthetic upgrades, including self-documentation, and more flexible extension options, such as enhanced linked file structures and more diverse mobile and web capabilities. It will also be extended to manage fauna, as well as flora, data.

Learning to use BRAHMS is fairly straightforward for basic functions but the development of customized functions, such as creating linked files, can be difficult. Purchase of BRAHMS comes with support via Skype and email provided by advisory group members. A three-day training course can be arranged in-house or at the University of Oxford for an additional charge. The software developers have created a free eighty-eight-page written training guide with step-by-step instructions and descriptive screenshots that can also be accessed as a live digital document.

Fig. 3. Park maintenance staff and interns care for the parterre planting beds in the Falling Gardens at Hampton National Historic Site in Towson, Maryland, 2015 (Courtesy of NPS).

FMSS

For the past four decades, NPS has implemented use of computer-aided facility management software to manage park infrastructure and track associated costs. The latest is the Facilities Management Software System (FMSS), a customized version of IBM's Maximo Asset Management. FMSS uses enterprise asset management principles to inventory facilities and infrastructure, plan for and track maintenance needs, and report on actual resource inputs, such as labor hours and costs. Assets are tracked in FMSS based on a hierarchy of site, location, and asset. FMSS is used primarily by park maintenance staff for inventorying facilities systems and components, identifying work, tracking and reporting maintenance activities, and securing funding.

Learning to use FMSS can be challenging due to the complexity of the system and its broad focus on all components of facility inventory and maintenance. In addition, users cannot customize their experience, meaning the amount of available information can often be overwhelming for those executing simple vegetation maintenance tasks. The majority of the available FMSS courses available on DOI Learn are not offered regularly, including the two courses related specifically to cultural landscapes: "Cultural Landscapes and FMSS—Asset Inventory" and "Cultural Landscapes and FMSS—Work Identification and Planning." Because much of the data entry for FMSS requires knowledge of NPS conventions, the system can be confusing without proper training and reference documents.

IrisBG

IrisBG was developed in 1996 by Digital Forvaltning AS in collaboration with the University of Oslo Botanical Garden to increase plant records management database usability for employees while maintaining comprehensive records. IrisBG is primarily accessible in form view and relies on a series of integrated modules to connect related tables of information. These include the standard plant records data, such as taxa, images, accessions, and tasks. From a basic package, IrisBG can be built out to include additional functionalities, such as mapping

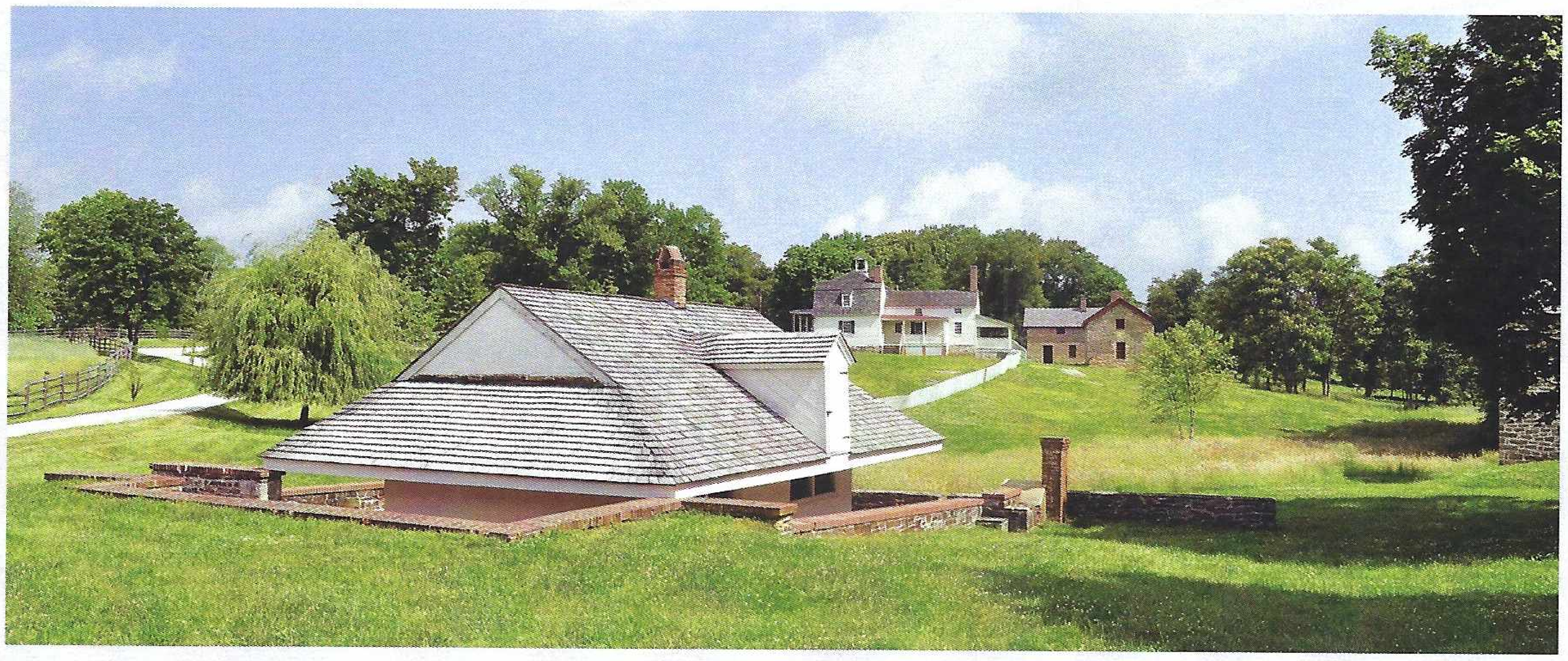

Fig. 4. The Farm Complex at Hampton National Historic Site in Towson, Maryland, with ash trees now threatened by emerald ash borer, 2016 (Courtesy of NPS)

CASE STUDY: EMERALD ASH BORER AT HAMPTON NATIONAL HISTORIC SITE

The emerald ash borer (*Agrilus planipennis*) is an exotic wood-boring beetle that threatens green (*Fraxinus pennsylvanica*), white (*F. americana*), black (*F. nigra*), and blue (*F. quadrangulata*) ash tree populations across the country. The beetle typically kills infested trees within three to five years of infestation. In 2015, emerald ash borer was identified in Baltimore County, Maryland, home to Hampton National Historic Site. Hampton National Historic Site preserves a 62-acre portion of a once-vast residential, agricultural, commercial, and industrial enterprise that was home to the Ridgely family for nearly two centuries (Figure 4). The park landscape includes forests, fields, specimen trees, and formal gardens, with a great diversity of exotic and native tree species, including some 210 ash trees grown in both ornamental and forest settings. Together, these ash trees comprise about 10 percent of the total open-grown landscape trees within the park.

With the arrival of emerald ash borer in Baltimore County in 2015, the park began planning for management options, including chemical insecticide applications, biological controls (i.e., natural insect enemies of the borer), tree removal and replacement, and no action. The park worked with the US Department of Agriculture to develop a biological evaluation for emerald ash borer and also collaborated with the NPS Olmsted Center for Landscape Preservation and the NPS Northeast Region Integrated Pest Management Coordinator to develop a response strategy using vegetation inventory data from a recently completed cultural landscape report. This response involves treating high priority, historic open-grown landscape trees with insecticide to protect them from emerald ash borer while monitoring forest trees and planning for replacement upon decline.

A plant records management system would be useful in inventorying trees for emerald ash borer susceptibility and infestation, and categorizing trees for distinct treatment approaches based on species, location, size, and historical significance. Detailed assessment information may also reveal if any specimens show resistance to emerald ash borer. Like the Jefferson Elm on the National Mall, such a fortunate discovery could lead to a new introduction to the nursery trade. Throughout treatment, the database could be used to track insecticide applications on open-grown trees and monitor condition of forest trees in conjunction with the park's Integrated Pest Management program. Upon loss and replacement of susceptible forest trees (with substitute species), the database would provide a record of the forest's preinfestation composition to inform both the historical record and planning for the enhancement of ecological values. Through web-publishing capabilities, a plant records management database could also be used to communicate with the public and park partners as specimens require treatment, conditions change, or replacement is required.

Fig. 5. A NPS research associate collects GPS data for a vegetation inventory map of the Boston Harbor Islands, Massachusetts, 2016 (Courtesy of NPS).

and publishing data, and technical support, such as web hosting.

IrisBG was intentionally designed to be user friendly and minimize training time. Purchase of the database includes free, self-paced online training as well as a question and answer session with a product team member at the beginning and end. For an additional charge, in-person or live web training can be arranged. The software developers have also created an online video education series organized into introductory, intermediate, and advanced trainings, as well as a thirty-one-page written document that includes step-by-step instructions with descriptive screenshots. Additionally, the manager of IrisBG holds an informational question and answer session on the first Thursday of every month.

BENEFITS OF PLANT RECORDS MANAGEMENT DATABASES

A plant records management database provides for unified storage of information and allows users to query and display information pertinent to their specific needs. Aggregated information remains accessible for use across disciplines, parks, and regions of the National Park System. As a shared resource, a plant records management database encourages interdisciplinary collaboration and makes possible data-driven stewardship decisions.

Maintenance

Maintenance applications of a plant records management database usually comprise inspections, such as inventories and pest monitoring, and tasks, which include historic and requested treatments. Depending on the database, maintenance can often be linked to information related to accessions, taxa, or locations. For instance, maintenance tasks can be tied to a specific scarlet oak (*Quercus coccinea*) that requires pruning or to an area of invasive goutweed (*Aegopodium podagraria*) that needs to be removed from a particular area of a field.

Fig. 6. The South Lawn and original Olmsted elm at Frederick Law Olmsted National Historic Site in Brookline, Massachusetts (Courtesy of NPS).

CASE STUDY:
HISTORIC AND CONTEMPORARY PLANS OF FAIRSTED, FREDERICK LAW OLMSTED NATIONAL HISTORIC SITE

Frederick Law Olmsted National Historic Site preserves the final home and office of Frederick Law Olmsted Sr. (1822–1903) and the offices of the successor firms that operated from the site until 1979. The 1.75-acre grounds of Fairsted, as the property is known, currently reflect their appearance from about 1930, at the height of the firm's operation (Figure 6). The grounds embody the design characteristics of Olmsted Sr.'s most noteworthy landscapes, including the key concepts of scenery, suitability, style, subordination, separation, sanitation, and service.

As the primary repository of the firm's records for over 6,000 projects, the Olmsted Archives include 160 plans related to the firm's work at Fairsted, a fraction of the approximate 138,000 plans and drawings in the archives. Olmsted Sr., and later his sons and successor firms, developed the property's landscape from the time of purchase in 1883. This included removing selected preexisting plantings and making extensive additions. As the site's building complex grew, garden areas were redesigned to accommodate the burgeoning design firm. Accordingly, garden areas and plantings were redesigned throughout the historic period. Since Olmsted Associates vacated the property in 1979, the work to restore the site to its 1930 appearance has involved planting plans that detailed the removal of vegetation that postdated 1930 and installation of new plant specimens to replace those removed between 1930 and 1979.

With nearly two hundred plans tracing the development of Fairsted from 1883 to the present, a plant records management database would provide a georeferenced platform for managing information about changes to the site's planting over the past hundred and thirty years, including details of ongoing efforts to preserve historic plantings and replace missing historic specimens. This information would be useful to park gardeners, horticulturists, landscape architects, and historians who seek to understand the evolution of the landscape and reasons for plant viability in order to inform future management decisions. Web publishing makes information about the historical development of the site's plantings accessible to visitors who are experienced researchers or learning about Frederick Law Olmsted Sr. and the field of landscape architecture for the first time.

Maintenance records can be queried by creating a filter comprising multiple concurrent data fields. For instance, querying "prune," "open," and "Quercus" simultaneously would return all the oaks scheduled for pruning. Maintenance histories are also recorded in chronological order in most databases, so users can quickly see the complete work history when viewing a record. This offers practical assistance and preserves institutional memory through staff turnover.

Many plant records management databases also include a fieldwork option for maintenance. At the most practical level, this allows employees to collect, edit, and access information about specific plant specimens or management areas, such as location or water requirements, from the field. This information can be synchronized with the main database in real time over a mobile data connection or Wi-Fi, or later through an Internet or USB connection. This allows employees to conduct field assessments, update GPS coordinates, and access and update records for maintenance inspections or tasks efficiently without taking field notes and having to enter them into the database in the office later. Many fieldwork applications allow employees to capture and upload photos as well. This can be useful for monitoring pest issues or documenting phenologic changes (Figure 3).

Based on evaluation of the five systems under review, BG-BASE, FMSS, and IrisBG were found to offer the greatest work tracking and work planning potential, followed by the ArcGIS Public Garden Data Model and BRAHMS.

Mapping

Landscape and vegetation mapping is important on a practical level for both internal applications, such as maintenance, and for external applications, such as visitor wayfinding. Georeferencing vegetation improves the accuracy of maintenance tracking and execution and allows visitors to orient themselves in a landscape. Mapping is also a powerful tool for planning, research, and interpretation, particularly when paired with GIS or another dynamic mapping system. Mapping the trends in a particular landscape can assist in planning decisions by showing change over time.

Most plant records management databases are capable of interfacing easily with one or more mapping platforms. These range from free basic options like Google Earth to complex licensed programs, such as ArcGIS and AutoCAD. All of the evaluated plant records management databases with mapping capabilities allow information to be selectively exported or displayed using stored GPS coordinates. Drawing from one data field can create a simple map, whereas drawing from multiple data fields can create a complex map. Once data is available in a dynamic mapping system like a GIS, information can be manipulated using the program's analytical tools (Figure 5).

The results from the evaluation of the five systems under review indicate the ArcGIS Public Garden Data Model, BRAHMS, and IrisBG have the strongest mapping capabilities and ease of use, followed by BG-BASE.

Interpretation

Expressing the complex cultural histories of living landscapes along with their aesthetic and ecological value is an important aspect of interpretation. Preserving cultural and natural resource information together in a database helps streamline the interpretation of these disciplines. For instance, information about vulnerable species can be easily queried in a plant records management database. This information, including photos, could be printed and shared with a school group learning about conservation efforts. Alternatively, ethnobotanical information could be saved in a plant records management database, and information about how plants are traditionally used or spiritually significant to indigenous people could be shared with visitors (Figure 7).

There are many ways to store interpretive and educational information in a plant records management database. Images, including historic photos and maps, photographs of pollinator activity, and images of phenophases, can be attached to plant records. Thematic collection tags, such as "native trees," can be used to quickly generate public programs like nature walks or citizen science days. Many databases are capable of exporting information for physical markers in the landscape, ranging from metal tags to QR Codes, which ensures that information shared with the public is standardized and accurate. In an increasingly digital age, most plant records management databases include connections to web publishing platforms that allow organizations to share selected information. Most commonly, these include a search function for identifying nonsensitive records by taxon or common name, interactive maps, images, and seasonal programs, such as a "what's in bloom?" map.

The results from the evaluation of the five systems under review indicate BRAHMS and IrisBG offer the most streamlined web-publishing and mobile-optimized interpretive capabilities, followed by the ArcGIS Public Garden Data Model and BG-BASE.

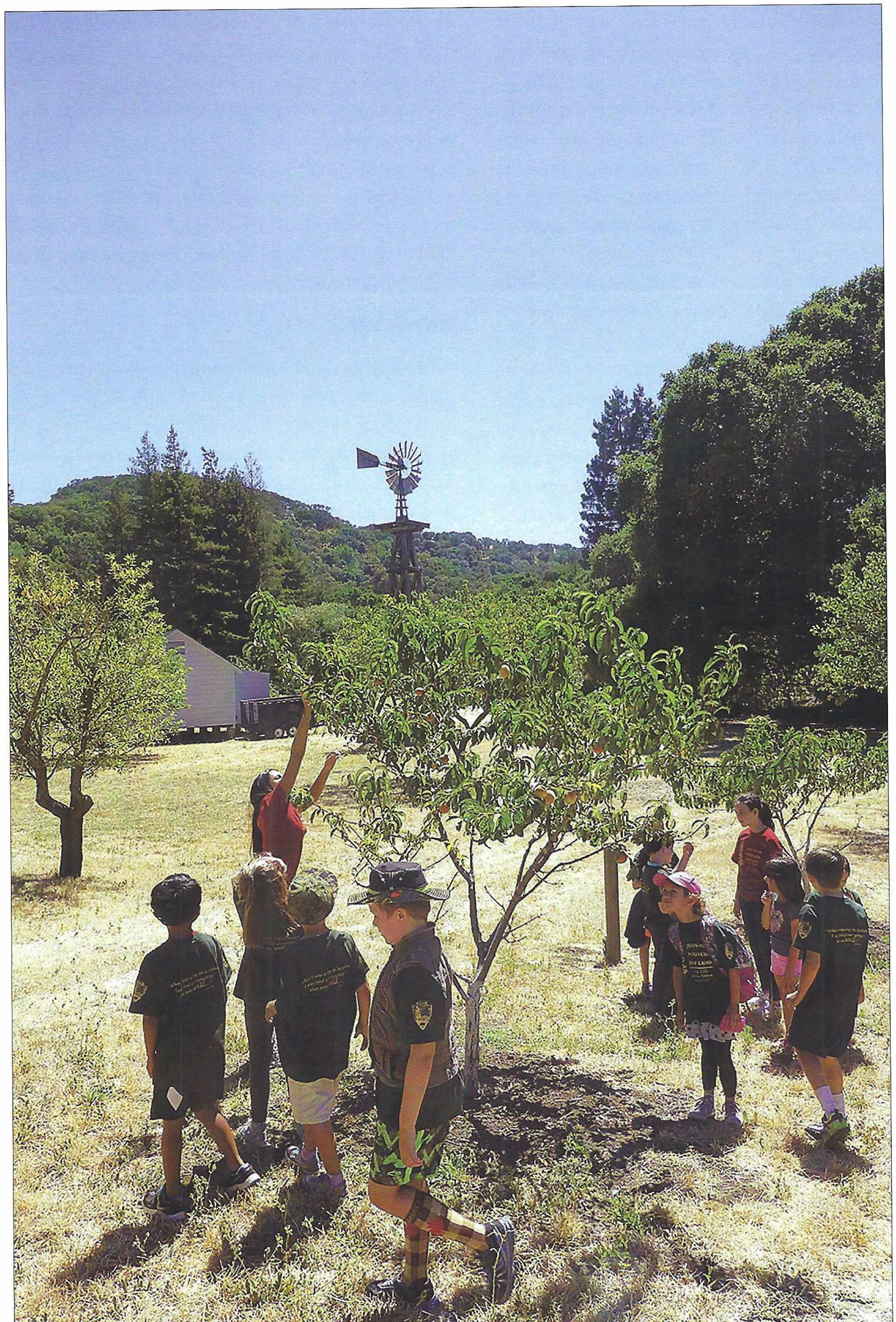

Fig. 7. Participants in a youth education program learn about and pick peaches in a historic orchard at John Muir National Historic Site in Martinez, California, 2016 (Courtesy of NPS).

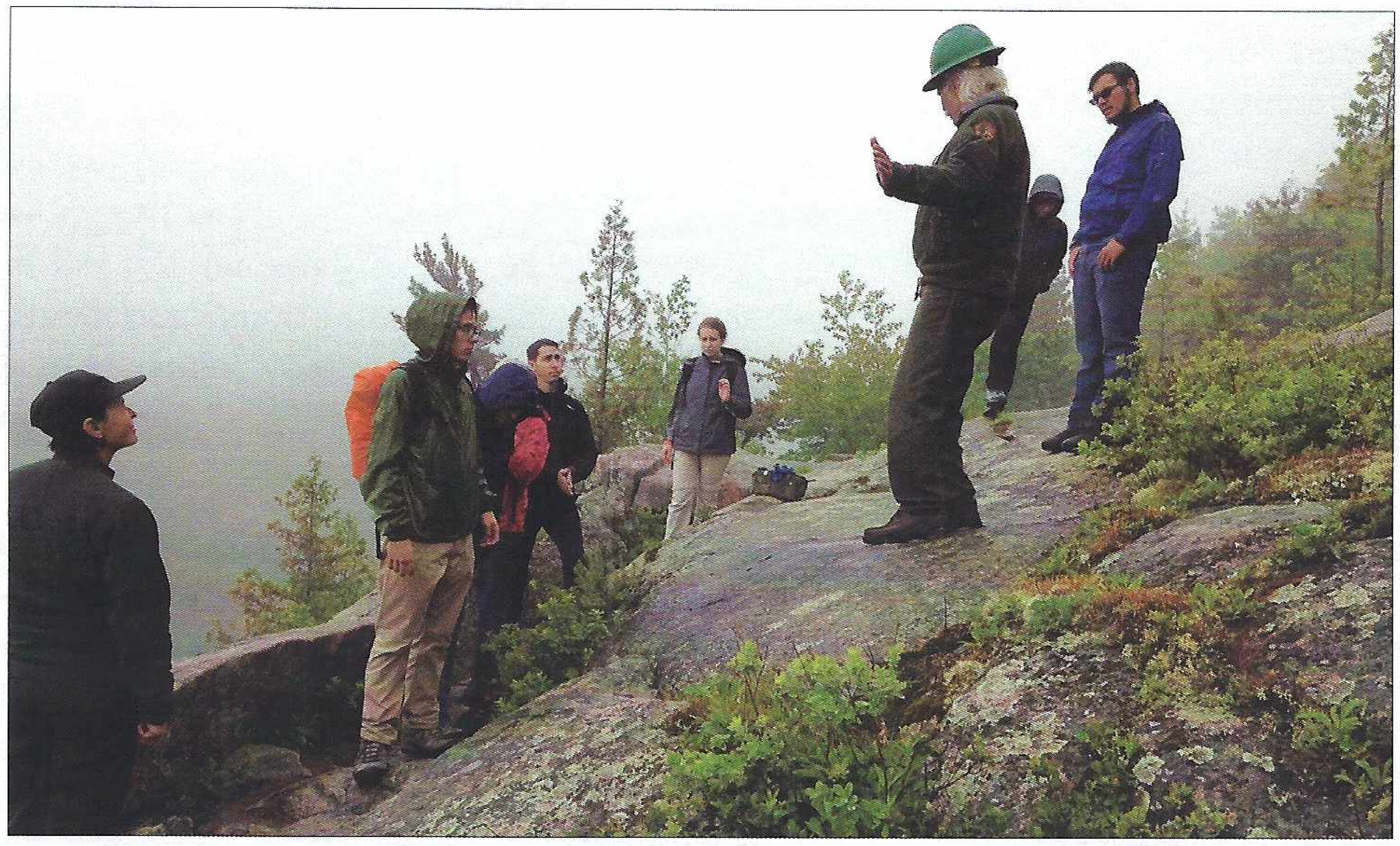

Fig. 8. NPS associates conduct research about the unique mountaintop ecosystem in Acadia National Park, Maine, 2015 (Courtesy of NPS).

CASE STUDY:
PHENOLOGY AT JOHN MUIR NATIONAL HISTORIC SITE

Phenology is the study of cyclic or seasonal biological events, such as plant leaf-out and flowering, insect emergence, and animal migration. Understanding the frequency and change in frequency of these events informs climate science, pest and invasive species management, plant and animal migration patterns, and agricultural practices, among many other activities.

John Muir National Historic Site in Martinez, California, preserves the home and orchards of America's most famous and influential naturalist and conservationist. In addition to nine acres of orchard blocks planted with almonds, apricots, cherries, peaches, pears, European plums, Japanese plums, and black and English walnuts, the park includes a 236-acre natural area, replete with native trees and wildflowers covering a 600-foot ascent named for one of Muir's daughters, Wanda.

Beginning in 2010, John Muir National Historic Site partnered with the USA National Phenology Network to initiate the California Phenology Project. Designed to assess the effects of climate change on California's biodiversity and natural resources, the project involves seven units of the National Park System. Working with the University of California, Santa Barbara, the partnership has identified over sixty high-priority plant species for phenological monitoring in California, eight of which grow at John Muir National Historic Site.

The work has engaged students from the Martinez Unified School District and local citizen scientists in the collection and interpretation of phenological data, encouraging visitors to observe the world around them through a new lens. The park also created ethnobotany cards that foster visitors' appreciation for California Native Peoples' knowledge and uses of plants.

A plant records management database would provide a framework for gathering, sharing, and analyzing phenological data from all seven units of the National Park System involved in the California Phenology Project. Through use of the database's administrative controls, volunteers, interns, and park staff could all access the database at varying levels to update and verify phenological data. The public could also view web-published plant information to enhance the parks' interpretation of native and cultivated vegetation, phenology, and climate change impacts. Networked across several parks—or even the entire nation—phenological data aggregated in a plant records management system would be even more impactful, systematically expanding our understanding of climate change through indicator data. Over time, georeferenced plant records data may also reveal secondary climate change impacts, such as species migration.

Research

According to a 2016 report from Botanic Gardens Conservation International, only an estimated five percent of threatened plant species are currently included in recovery and restoration programs around the globe (Botanic Gardens Conservation International 2016b, 22). Protecting areas that support threatened species requires developing detailed inventories and surveys that document what is growing in the landscape, where, how, and in concert with what other species. Based on this information, parks can facilitate climate change and biodiversity research at the park, regional, and national levels (Figure 8).

The reporting and analytical tools built into plant records management databases allow researchers to compile and compare complex data sets. Many plant records management databases are capable of linking to reference sources, such as the US Department of Agriculture PLANTS Database, to ensure data standardization. Library resources, such as journal articles or publications that reference park research, can also be stored in many plant records management databases and linked directly to specific plant specimens or areas of the landscape. Research project data can also be stored in plant records management databases, allowing for the long-term storage of information that may typically fall outside the purview of routine data collection for a particular park. For instance, information currently being gathered for the Denali National Park and Preserve tree ring analysis project could be imported into a plant records management database for future use, eliminating the need to duplicate the same data collection effort in the future.

The results from the evaluation of the five systems under review indicate BG-BASE and BRAHMS have the strongest support for research applications, followed by the ArcGIS Public Garden Data Model and IrisBG.

CONCLUSION

Digitizing plant records data is the way of the future. The terrestrial and aquatic area protected by NPS has grown to 84 million acres over the past one hundred years, spanning all fifty states, the District of Columbia, American Samoa, Guam, Puerto Rico, and the Virgin Islands. These lands and waters are the life support for all living organisms and a reflection of the way the Earth is changing. The documentation we keep is a priceless repository of cultural and botanical knowledge that will help us navigate and adapt to those changes.

Dedication to unifying data and collaborating with other organizations that are leading the way in plant collections management can have a significant impact on public engagement and global conservation. As Botanic Gardens Conservation International notes in their *Global Strategy for Plant Conservation*, "of urgent concern is the fact that many plant species, communities, and their ecological interactions, including the main relationships between plant species and human communities and cultures, are in danger of extinction" (Botanic Gardens Conservation International 2012, 11).

NPS's *Director's Order #100: Resource Stewardship for the 21st Century* recognizes the stewardship goal of NPS as

> manag[ing] NPS resources in a context of continuous change that we do not fully understand in order to:
>
> - preserve and restore ecological, historical, and cultural integrity;
> - contribute as an ecological and cultural core of national and international networks of protected lands, water, and resources; and
> - provide visitors and program participants with opportunities for transformative experiences that educate and inspire. (US Department of the Interior 2016)

These actions include the following:

- Strategically incorporating emerging technologies, when applicable and feasible, into park resource management to conduct sound science and engage the public.
- Participating and collaborating in interagency and nongovernmental efforts to promote connectivity that, in particular, address climate change. These efforts may include large land or seascape conservation efforts, regional networks of protected areas, and wilderness preservation.
- Establishing partnerships with educational and scientific institutions to identify, encourage, and promote scientific and scholarly research needed to better understand the complexities and uncertainties of the future.
- Conducting or facilitating scientific and scholarly inquiry that is directly applicable to current or expected resource management challenges.
- Developing and maintaining broad and inclusive public engagement strategies to identify and understand long-term public interest and foster co-stewardship of natural and cultural resources.

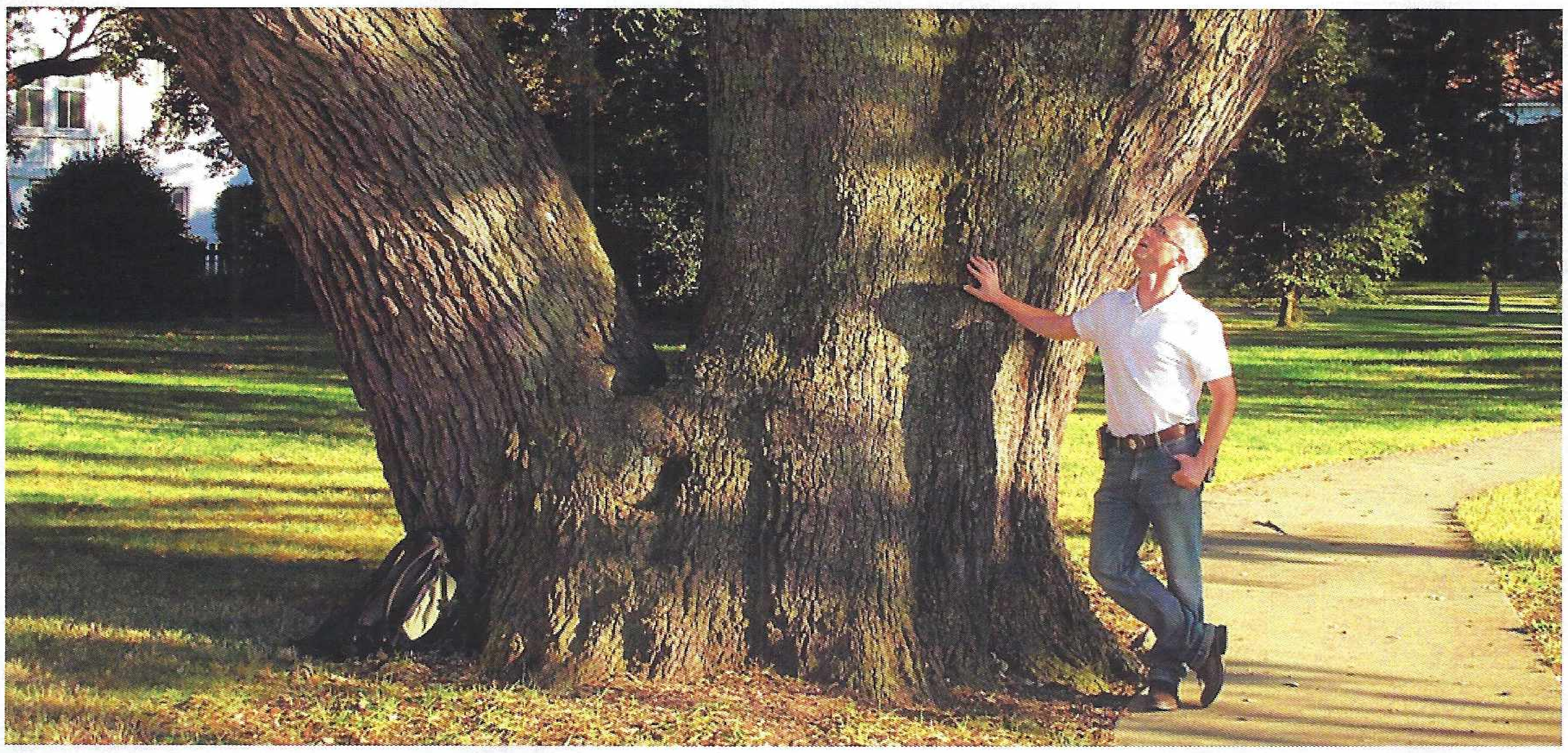

Fig. 9. This 500-year-old live oak tree at Fort Monroe National Monument in Hampton, Virginia, bore witness to key moments in American history and is of particular scientific interest, 2013 (Courtesy of The Arnold Arboretum of Harvard University).

CASE STUDY: THE ALGERNOURNE OAK AT FORT MONROE NATIONAL MONUMENT

Fort Monroe National Monument in Hampton, Virginia, is one of America's newest national parks. Strategically located at the mouth of the Chesapeake Bay on a 565-acre peninsula known as Old Point Comfort, Fort Monroe is a place of astounding beauty and inspiration. The northern stretch of the peninsula is largely open, with over three miles of Chesapeake Bay beachfront. At the southern end of the peninsula, an imposing 63-acre stone fort is the focal point of the park.

Within the moated walls of the fort, a large parade ground is bordered by historic buildings and a striking collection of mature live oak trees (*Quercus virginiana*). One particularly majestic specimen, known as the Algernourne Oak, is estimated to be nearly 500 years old—Algernourne being the name of the first fort on Old Point Comfort (1609–12). These trees are living witnesses to events that shaped both our nation and millions of individuals' lives: Old Point Comfort saw critical events that led to both the beginning of slavery in England's American colonies and the end of slavery in the United States.

In addition to its cultural significance, the Algernourne Oak is the subject of scientific interest. It grows far north in the geographic range of the species and is thus particularly cold hardy. In 2012, the Arnold and Morris Arboretums completed a joint collecting trip to the Virginia Tidewater region to gather acorns from live oak trees. Read more about this in "The Quest for the Hardy Southern Live Oak" in *Arnoldia: The Magazine of the Arnold Arboretum* (Figure 9) (Dosmann and Aiello 2013, 12–24).

Aggregated, genetic and phenologic information about live oaks in units of the National Park System along the mid-Atlantic and southeastern seaboard offers opportunities to better understand genetic variation among live oak populations and trace the effects of changing climate on a specific plant population over a large area. In conjunction with the NPS Research Permit and Reporting System, a robust plant records management database could also support the reporting requirements of Scientific Research and Collecting Permits. A plant records management database has the capacity to track papers and findings associated with research on specific plant specimens, populations, and species by linking to third-party repositories, such as *Arnoldia*, referenced above. Through web publishing, information on the scientific value of park resources could be made available to the general public.

Fig. 10. Elementary school students learn about flower structure at Biscayne National Park, Florida, 2014 (Courtesy of NPS).

Plant records management systems, particularly networked (enterprise) databases, enhance communication by providing a unified platform for data sharing and analytical decision making. Associated web and mobile publishing tools allow information to be shared with the public and third-party researchers, empowering NPS to reach broader audiences and participate in global discourse on research, climate change, and biodiversity science with greater confidence and impact. Adopting the use of digital plant records management tools is fundamental to NPS leading the way in twenty-first-century resource stewardship, science, and interpretation (Figure 10).

Four of the leading plant records management databases assessed for this paper—ArcGIS Public Garden Data Model, BG-BASE, BRAHMS, and IrisBG—all have potential to advance these goals significantly. Yet the efficacy of each varies broadly across national parks and other institutions that manage plant records data. A single leading database cannot be identified, as the strengths and weaknesses of each application differ depending on the needs, nature, and resources of each site. Therefore, in Table 2, the four software programs are rated comparatively based on management of standard data fields, effectiveness with respect to key uses, and administrative considerations. The summary presents the strengths and weaknesses of each application and is intended to guide the selection of a database that is best suited to a particular park landscape and staff.

Further research is needed to develop standard practices for units of the National Park System for collecting and managing data about living plants; networking

MODERNIZING NATIONAL PARK SERVICE PLANT RECORDS MANAGEMENT

Table 2. *Summary Comparison of Plant Records Management Databases*

	ArcGIS Public Garden Data Model	BG-BAS	BRAHMS	FMSS	IrisBG
Data Fields	ʌ	ʌʌ	ʌʌ	v	ʌʌ
Maintenance	ʌ	ʌʌ	ʌ	ʌʌ	ʌʌ
Mapping	ʌʌ	ʌ	ʌʌ	vv	ʌʌ
Interpretation	ʌ	ʌ	ʌʌ	vv	ʌʌ
Research	ʌ	ʌʌ	ʌʌ	v	ʌ
Learning Curve	ʌ	–	–	v	ʌ

Key	
Excellent	ʌʌ
Good	ʌ
Fair	–
Poor	v
Not Applicable	vv

enterprise data across multiple organizations for use in collaborative scientific research; uniting distinct parks' web-published data for general public access; and integrating information about other living-collection types, including animals and microbes, into a comprehensive living-collection records management system. These challenges present compelling opportunities for further investigation by academics, public servants, and the private sector alike.

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