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A Protocol for Citizen Science Monitoring of Recently-Planted Urban Trees

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A Protocol for Citizen Science Monitoring of Recently-Planted Urban Trees

In this article, we present a protocol for citizen science monitoring of planted urban trees. Informed by social-ecological systems, urban forestry, and tree physiology research, the Planted Tree Re-Inventory Protocol is designed to allow minimally-trained volunteers or citizen scientists to collect data about the factors that influence urban tree survival and growth. We consider characteristics of the tree, the biophysical environment, institutions and management, and the community as factors that influence urban forest outcomes. Here, we reflect on tree planting organizations and their desire and capacity for monitoring. Then we define citizen science and review its use in urban forestry to date. Next we discuss the measurement of urban tree outcomes (survival and growth), and summarize the literature on factors influencing tree success and urban forest outcomes. Finally we present an overview of the main categories of variables included the Protocol. The entire Protocol is available on the Bloomington Urban Forestry Research Group website (http://www.indiana.edu/~cipec/research/bufrg_protocol) and as an Appendix to this paper.

Keywords
Urban tree monitoring, tree growth, tree survival, citizen science, tree inventory methods, Planted Tree Re-Inventory Protocol

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INTRODUCTION

In the last decade, efforts are beginning to converge to monitor the survival, growth, and longevity of planted urban trees. In a comprehensive review of published single-tree inventory methodologies used in urban forestry (including aerial and satellite methods as well as traditional ground survey inventory methods), Nielsen et al. (2014) found that traditional "field survey," or on-the-ground, inventory methods constituted the vast majority of single-tree inventory studies (46 of 57 articles reviewed). Several recent large-scale, single-city tree-monitoring efforts have used field survey methods to measure the survival rates of urban trees. In the summer of 2006, the Parks and Recreation Department of New York City conducted a large-scale young street tree mortality study to examine the many factors in the city influencing the survival of over 14,000 newly planted street trees (NYC Parks 2014). The site assessment tools used in this study included factors measuring the surrounding social and physical environment of each tree (NYC Parks et al. 2010). Other recent regional monitoring efforts include Sacramento, California, where Roman monitored the survival rates over 5 years of over 400 trees that were handed out as part of a utility company tree distribution program (Roman 2013); Milwaukee, Wisconsin, where, most recently, Koeser et al. (2013) use 25 years of monitoring data for a cohort of nearly 800 trees to determine the impacts of a variety of factors on tree survival rates; and New Haven, Connecticut, where Jack-Scott et al. (2013) evaluate the impact of community and other characteristics on survival rates for almost 1,400 trees planted between 1995 and 2007. To our knowledge, large-scale, multi-city planted tree monitoring studies do not seem to exist.

Standards for monitoring tree survival and growth over time are important for comparing the data obtained through different monitoring efforts across multiple locations and years (Leibowitz 2012; Roman et al. 2013; Nielsen et al. 2014). In 2011, the International Society of Arboriculture and The Morton Arboretum convened an international meeting on the subject of urban tree growth and longevity (Leibowitz 2012). This meeting organized four topic areas around descriptive studies of tree growth and longevity, plus three categories of factors influencing urban tree outcomes: tree production and sales, site design and tree selection, and tree and site management (Liebowitz 2012). The Urban Tree Growth and Longevity (UTGL) Working Group that emerged out of this meeting has undertaken to develop of a set of standards for monitoring the survival and growth of planted urban trees, as well as the factors that may influence survival and growth (UTGL Working Group 2014a). The Urban Tree Monitoring Protocol, as these standards are called, considers the factors of the tree, site, community, and management that may relate to tree survival and growth (UTGL Working Group 2014b).

We present in this paper the Planted Tree Re-Inventory Protocol for citizen science-based monitoring of recently-planted urban trees. Although we are members of the UTGL Working Group and the Urban Tree Monitoring Protocol committees, the protocol presented here was originally developed prior to the creation of the UTGL Working Group. Although our protocol and the in-progress UTGL monitoring protocol are informed by one another, our protocol is distinct in that it explicitly presents a data collection methodology for use by non-experts (i.e., citizen scientists) to measure trees in the urban landscape that have been planted relatively recently (trees in the establishment[1] and semi-mature phase).[2]

[1] The establishment phase is typically, 2 or 3 years for trees 3-5 cm (1-2") in caliper at planting.

This paper proceeds as follows: First, we reflect on tree planting organizations and their desire and capacity for monitoring. Then we define citizen science and review its use in urban forestry to date. Next, we discuss the measurement of urban tree outcomes (survival and growth) and summarize the literature on factors influencing tree success and urban forest outcomes. Finally, we present an overview of the main categories of variables included the protocol. The entire protocol is available on the Bloomington Urban Forestry Research Group website (http://www.indiana.edu/~cipec/research/bufrg_protocol) and as an appendix to this paper.

THE TREE-PLANTING ORGANIZATION CONTEXT

In 2010, our research group (the Bloomington Urban Forestry Research Group [BUFRG] at the Center for the Study of Institutions, Population and Environmental Change at Indiana University) was approached by the nonprofit urban greening organization, Keep Indianapolis Beautiful, Inc. (KIB), who was curious about the survival and growth of their planted trees. KIB works with neighborhoods and other groups to plant 1-2" (2-5 cm) caliper trees in the greater Indianapolis and Marion County, Indiana, area. They collect information about the location of each planted trees using global positioning system (GPS) units, and combine this with information obtained from the nursery about the species, planting packaging, and size (caliper, container size, etc.) of the trees they plant using a custom, self-designed Microsoft Access-based data management system. KIB lacked the resources to follow-up and monitor the survival, growth, and condition of these planted trees over the trees' early years (i.e., during the establishment and semi-mature phases before the trees reached their mature size). Their interest was twofold: First, KIB wanted to learn more about the survival and growth of trees they plant, and about the factors influencing the success of these trees. Second, and more importantly, KIB was looking for a way to expand capacity to monitor their planted trees into the future.

With KIB and other urban tree-planting organizations (including citizen groups, municipalities, etc.)[3] in mind, BUFRG embarked on the task of designing a method for re-inventorying recently-planted urban trees that could be used by minimally-trained data collectors, ranging from high school students to casual adult volunteers. That our methods for inventorying planted trees be usable by non-expert individuals with minimal to no training in urban forestry or arboriculture—i.e., *citizen scientists*—was of key importance to our research group and to our main stakeholder, KIB. The resulting Planted Tree Re-Inventory Protocol enables citizen scientists to collect information about planted tree success (survival, growth and condition) as well as the factors that may influence tree success. Usability by citizen scientists makes our Protocol unique from existing urban forestry inventory protocols or standards.

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[2] Therefore, we do not include metrics commonly included in urban forest inventory methods, such as maintenance requirement variables or hazard/risk assessment methods, that may be both difficult for the non-expert to assess as well as not applicable to most immature trees.

[3] KIB is not alone in their interest in tools for monitoring planted trees. In a survey of 32 practitioner organizations already engaged in monitoring efforts, Roman et al. (2013) observed a desire for simple protocols over those that are "complicated and academic" (p. 296). In the same survey, practitioners cited challenges associated with monitoring, including a lack of staff time and dedicated funding, finding and using technology resources, and developing or choosing appropriate protocols (Roman et al. 2013).

CITIZEN SCIENCE

Citizen science, broadly defined, is the involvement of nonprofessional and amateur scientists—the average citizen—in scientific research efforts (Dickinson et al. 2012; Miller-Rushing et al. 2012; Shirk et al. 2012; Bonney et al. 2014). Citizen scientists can be paid interns, temporary workers or unpaid volunteers, and their efforts can augment data collection efforts undertaken by trained researchers, and thus expand the production of knowledge. Citizen science can involve a wide range of activities and various relationships between scientists and the general public. Miller-Rushing et al. (2012) describe three types of citizen science efforts, based on the level of public participation in the research process:[4] *contributory* (public contributes to data collection efforts only), *collaborative* (involving the public in data collection and also some parts of data analysis and results reporting), and *co-created* (public involved in all or most parts of the research process, from generating research questions to analyzing and reporting results).

True citizen science—like all science—involves a research question. Most projects in urban forestry are versions of Miller-Rushing et al.'s (2012) *contributory* citizen science that may or may not involve the processing and analysis of data to answer a true research question. These projects typically involve the public as members of urban forest inventory teams or in other monitoring efforts that might otherwise have been undertaken by urban forestry practitioners and certified arborists. Practitioners undertake inventories for a number of management purposes, including monitoring the success (survival and growth) of a group of trees over time, generating information about survival rates for use planning future tree planting efforts, providing information about the maintenance needs of a tree population, and more. All of these uses of inventory data center on the idea of *adaptive management*. Adaptive management occurs when the strategies used by resource managers are almost viewed as experiments or means of testing predictions about the relationships between management and a desired outcome (Holling 1996). Nonprofits or municipal forester managers that change the management strategies they use to plant or maintain trees based on the observed conditions of the urban forest as seen in urban tree inventory data are using adaptive management.

The use of volunteers to collect inventory data is not new in urban forestry. Tretheway et al. (1999) summarize the results of workshop on "Volunteer-Based Urban Forest Inventory and Monitoring Programs" convened by the U.S. Forest Service Pacific Southwest Research Station in 1999. Workshop participants identified three purposes for involving volunteers (i.e., citizen scientists) in urban forestry: to "provide a direct connection" between the community and the urban forest, to increase public awareness of the benefits and value of the urban forest, and to enhance support for urban forest "planning, management and stewardship" (Tretheway et al. 1999: p. 2). Cowett and Bassuk (2012) make the case for using university students at land grant colleges to conduct inventories; their "Student Weekend Arborist Teams" conducted more than 40 street tree inventories in small communities across New York State. Bancks (2014) discussed a University of Minnesota extension program that trains volunteers in communities of all sizes in urban forest rapid inventory methods, with the intent of assessing preparedness for emerald ash

[4] Shirk et al. (2012) define similar types of citizen science, and their classification also includes *contractual* projects (communities ask professionals to investigate a particular question) and *collegial* projects (non-professional individuals conduct largely independent research which may or may not be recognized by typical scientific authorities.

borer (see also http://mytreesource.com; University of Minnesota et al. 2014). Clarke (2009) describes the use of citizen science to track phenological trends in the urban forest as part of a larger citizen science program, Project BudBurst, managed by the U.S. Forest Service.

When research relies on citizen science for data collection, there can be concerns with the quality of the data collected. Several authors raise concerns about the accuracy of data collected by non-professionals (e.g., Dickenson et al. 2012; Roman et al. 2013). Bloniarz and Ryan (1996) evaluated the accuracy of inventory data collected by volunteers and found it to have similar levels of accuracy and consistency as data collected by certified arborists. In a more recent similar study, Bancks (2014) also found acceptable levels of accuracy for urban forest inventory data collected by volunteers. Future citizen science data collection efforts should continue to monitor the accuracy of data collected to ensure that it meets the quality required for good research.

Citizen science has the potential to substantially expand our ability to not only measure and monitor planted urban trees through time, but to also learn more about the factors influencing tree outcomes. Forty-two percent of practitioner-driven tree monitoring organizations surveyed by Roman et al. (2013) already make use of volunteers. And many tree-planting organizations already keep records with at least some information about the trees they plant (Roman et al. 2013). Rigorous citizen science tools that allow the public to record additional information about planted urban trees could help enhance both the quantity and quality of data on the urban forest available to tree planting organizations, tree managers, researchers, and decision makers. For instance, PhillyTreeMap (http://www.phillytreemap.org) is an urban tree mapping and monitoring project involving collaboration between multiple stakeholders in the Philadelphia area, including Azavea (a geographic information systems software and analysis company), Pennsylvania Horticultural Society (a tree-planting nonprofit organization), and the City of Philadelphia Parks and Recreation department, among other partners (Urban Forest Map et al. 2014). The PhillyTreeMap website and mobile applications allow individuals to enter information about a tree, including species, diameter, and height, and to view the amount of ecosystem services that tree and other trees in the database provide.

The implementation of similar tree-monitoring projects across multiple cities and regions and the integration of data collection methods for more information about each tree would enhance the appeal of volunteer-generated datasets to researchers interested in answering explicit research questions. More direct connections and collaborations between practitioner-driven inventory efforts and researchers would truly launch urban forestry into the land of citizen science. New technologies for monitoring may even allow urban tree monitoring to eventually rival “big data” citizen science projects like Galaxy Zoo (http://www.galaxyzoo.org; Zooniverse 2014) and the Christmas Bird Count (http://birds.audubon.org/christmas-bird-count; National Audubon Society 2014).

MEASURING URBAN TREE OUTCOMES

Whether as trained experts or citizen scientists, when we measure urban forest outcomes at the level of the individual tree, there are two different general approaches: *place-based inventories* and *cohort studies*. *Place-based inventories* aim to capture information about a particular type of trees in a given area (e.g., street trees on a major street, public trees in a single neighborhood, all trees on a particular piece of property). Inventories are the more common approach to measuring the urban forest, and street tree inventories in particular have been the norm for capturing the information necessary to calculate the benefits of the urban forest. *Cohort studies* take a different approach: instead of measuring a particular type of trees in a single area, these studies monitor a cohort—or group of trees planted at the same time—through multiple years or at multiple future points in time. Cohort studies may follow all the trees planted as part of a neighborhood tree-planting project, annual tree-planting program by a municipality or nonprofit, tree distribution program, or other event where multiple trees were planted at the same time, and there is interest in tracking the outcomes of the planted trees over time. For cohort studies, we usually know the actual date, season, or year of planting for each tree, whereas for inventories the date of planting is likely unknown.

Whether tracking a single cohort of trees planted at the same time or inventorying all the street trees in an entire city, we are measuring features of each individual tree in the inventory. At the level of the individual tree, urban forest outcomes can be operationalized several ways: we could measure tree health, vigor, or condition; the amount or value of benefits produced by a tree; tree size or growth rate; or, most simply, whether or not a tree lives or dies. Here, we discuss tree survival (or conversely, mortality) and tree growth rates, as two of the more common tree-level outcomes.

Urban tree survival (and mortality)

A common urban forest axiom is that the expected life of a street tree is only 7 or 10 years, but Roman and Scatena (2011) acknowledge that it's unclear where this life expectancy estimate comes from, and provide a more empirical estimate of 19 to 28 years. There are a number of types of mortality for trees in urban areas. Clark and Matheny (1991) identify three primary reasons that trees die in urban areas: *structural failure, environmental degradation,* and *parasitic attack*. Different types of mortality may be more closely linked to certain stages in a tree's lifecycle, and so another typology of mortality might be establishment-related mortality, damage-related mortality, and age-related mortality. Establishment-related mortality is connected to the tree's failure to establish in the landscape after transplanting, either due to inadequate care (i.e., not watered after planting), poor tree stock, or improper site selection (not the "right tree" in the "right place"). Damage-related mortality is the death of a tree directly due to damage by humans, either during construction of roads, buildings, or other urban infrastructure that results in removal of the tree during or after the construction, or other damage (due to an automobile, lawnmower, etc.) that necessitates the tree's removal. Age-related mortality is the typical cause of death for non-urban trees; age-related death results from the natural senescing process undergone by trees, through which first small branches and then large branches and then the whole tree stop producing new growth or green leaves every season. Age-related mortality is closely connected to mortality caused by pests or diseases, which are more likely to affect declining or already dying trees.

When calculating a mortality rate for a group of planted trees, unless the cause of tree mortality or failure was recorded for each tree (i.e., as in the case of trees in the International Tree Failure Database; ITFD 2014), most of the time we cannot distinguish the types of mortality from one another. Especially in cases where the tree has been removed, the only thing monitors can know is that where there was once a tree, there is no longer a tree. For this reason, defining "mortality rates" for a cohort of planted trees or for an inventory becomes rather muddled. We cannot know, for instance, what portion of the calculated mortality rate is due to the planting of poor nursery stock relative to what is due to activities undertaken (or not) post-planting in the name of tree care. Long-term data on the same trees at multiple points in time generated through citizen science-based monitoring efforts can help fill this gap in our knowledge.

Growth

Urban tree growth is another measurable urban forest outcome. Large, mature trees provide many more benefits than small or immature trees; thus, the faster a tree grows, the sooner it will yield a return on investment (Nowak et al. 1990). Growth rates are measured a number of different ways in the urban forestry literature, including change in tree height (e.g., Stoffberg et al. 2008; Jutras et al. 2009), amount of new shoot growth at the ends of branches (e.g., Solfjeld and Hansen 2004), change in diameter at breast height (e.g., Nowak, McBride & Beatty 1990; Jack-Scott et al. 2013), change in caliper (diameter at 6 in [15 cm] above the first lateral root; e.g., Struve et al. 2000), and the width of annual growth rings as obtained from tree cores (e.g., Iakovoglou et al. 2001). Peper and McPherson (2003) evaluated several methods for measuring leaf area of urban trees that could be used to measure or model canopy growth and change. There are relatively few studies of urban tree growth—particularly longitudinal studies (Liebowitz 2012). And although tree growth has been examined in nursery and experimental settings, few researchers have examined urban tree growth *in situ* in actual cities.

FACTORS THAT INFLUENCE URBAN TREE OUTCOMES

Tree survival (mortality) and growth is influenced by a large number of factors. Several existing organizing frameworks can be helpful in identifying categories of variables that might influence urban tree outcomes. The social-ecological system (SES) framework developed in rural natural resource management settings states that the characteristics of the resource itself (for example, a forest), the resource system (the trees), the resource users or actors (timber harvesters), and their governance system (rules about when and how to cut trees) influence outcomes observed in coupled human-natural systems (e.g., Ostrom 2009; Ostrom and Cox 2010). In urban forestry, the Clark et al. (1997) "Model of Urban Forest Sustainability" states that sustainable urban forest outcomes are predicated on "a healthy tree and forest resource, community-wide support and a comprehensive management approach" (Clark et al. 1997, 17). Tree biologists and plant physiologists also delineate categories of variables that influence plant growth. In *Growth Control in Woody Plants*, Kozlowski and Pallardy (1997) review the numerous factors influencing tree and shrub growth. These authors outline categories of physiological factors, environmental factors, and "cultural practices," and describe how each category influences the reproductive (production of flowers and pollen, fertilization and eventually fruiting) and vegetative (root and shoot) growth of woody plants (Kozlowski and Pallardy 1997).

We combine these ideas into an interdisciplinary[5] social-ecological systems perspective of urban forest outcomes (Table 1, Figure 1). Adapted from SES theory (Ostrom 2009) and the Clark et al. (1997) model, and informed by tree physiology research (Kozlowski and Pallardy 1997), Table 1 presents urban forest outcomes as the product of interactions between the components of the urban forest social-ecological system. Thus, urban forest outcomes—including tree survival, growth, condition, etc.—are influenced by the interactions between the characteristics of the tree itself, the biophysical environment, the community, and the institutions and management strategies (Figure 1).[6]

The following section describes the current state of knowledge for each of the four main categories of variables that influence tree outcomes. This abbreviated literature review uses the three key sources from Table 1 (Clark et al. 1997; Kozlowski & Pallardy 1997; Ostrom 2009) as well as other relevant literature from the fields of urban forestry/arboriculture, urban ecology, natural resource management, coupled human-natural systems, and more.

Table 1. The urban forests as social-ecological systems perspective draws on several organizing frameworks, including the Model of Urban Forest Sustainability (Clark et al. 1997), the Social Ecological Systems (SES) Framework (first developed by Ostrom [2009], but see also Ostrom & Cox [2010]), and Kozlowski and Pallardy's (1997) *Growth Control in Woody Plants*. *"Institutions" refers to the rules and shared strategies (per Ostrom 2005) used by people to manage and maintain trees as well as the surrounding biophysical environment in the urban forest. [Modified from http://www.indiana.edu/~cipec/research/bufrg_about.php).

Social-Ecological Systems Framework	**Model of Urban Forest Sustainability**	**Growth Control of Woody Plants**	**Urban Forests as Social-Ecological Systems**
Resource Units	Vegetative Resource	Physiology	**Trees**
Resource System		Environment	**Biophysical Environment**
Governance System	Resource Management	Cultural Practices	**Institutions & Management**
Resource Users or Actors	Community Framework	--	**Community**

[5] The integration of multiple disciplines into an approach based on the SES framework has been advocated by several authors, including recently Epstein et al. (2013) and Schlüter et al. (2014).
[6] A modified version of the urban forests as social-ecological systems perspective is presented in Vogt et al. (*in review*) and on the BUFRG webpage: http://www.indiana.edu/~cipec/research/bufrg_about.php).

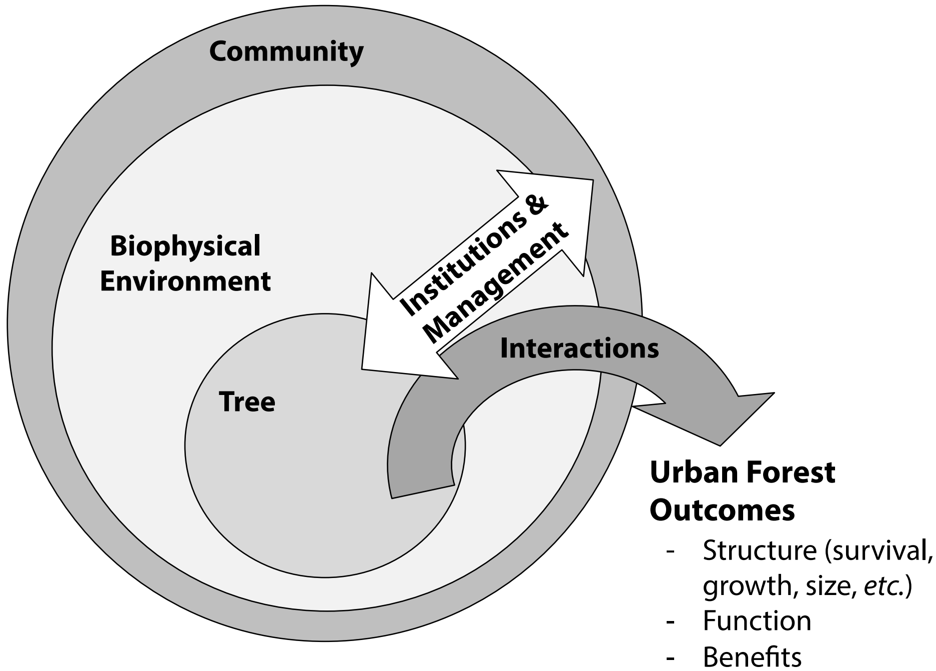

Figure 1. The urban forests social-ecological systems perspective emphasizes that the community interacts with trees and the biophysical environment through institutions and management to produce outcomes in the urban forest.

Characteristics of the tree

The characteristics of the tree itself obviously impact its survival and growth. Clark et al. (1997) use *vegetation resource* to refer to the trees in the urban forest, listing canopy cover, age distribution, species mix, and native vegetation as the key features of the urban forest that influence its sustainability. Here, we focus on the characteristics of an individual tree—including physiology—that influences its success. Kozlowski and Pallardy (1997) discuss the following key physiological processes as they relate to tree growth: production of carbohydrates via photosynthesis, mineral uptake and use, internal water relations and evapotranspiration, and hormone regulation. Clark and Matheny (1991) note that a tree's growth rate depends significantly on the availability of resources (carbohydrates, minerals, water, etc.) and that when resources become limiting growth is reduced. Because these physiological processes that manage resources are clearly connected to tree genetics, it should come as no surprise that different species exhibit different survival and growth rates (e.g., Iakovoglou et al. 2001; Grabosky and Gilman, 2004). For transplanted trees, the physiological processes that impact tree establishment, survival, and growth in the landscape are affected by characteristics of the tree at the time of transplanting. The size of the tree at planting has been linked to subsequent survival and growth (Lambert et al. 2010). Nursery production method and the type of plant packaging can also impact transplanted tree success (Gilman and Beeson 1996; Buckstrup and Bassuk 2000). Trees planted too deeply or with excessive mulch covering the rootball exhibit higher mortality rates than trees planted at the proper depth (Gilman and Grabosky 2004). Tree condition and health are also linked to tree success. Lower tree condition ratings are associated with decreased odds of tree survival (Koeser et al. 2013) and lower growth rates (Berrang et al. 1985).

Biophysical environment

Factors in the surrounding biophysical environment also influence tree outcomes. Environmental factors include variables that might be studied by a plant ecologist, such as light availability and intensity, water relations (including drought and flood conditions), temperature, soil nutrient content and physical structure (e.g., compaction), pollution, and other abiotic (e.g., wind, fire) and biotic (pests and diseases) factors (Kozlowski and Pallardy 1997). The biophysical environment may have a particularly strong effect on urban tree success, and street trees in particular experience stressful growing conditions. The most influential environmental factors are significantly different for trees in urban areas compared to rural, more natural growing environments. Urbanization increases impervious surfaces, buildings, and other built or grey infrastructure, resulting in radical changes in the water, temperature, and other abiotic conditions across the urbanized landscape (Arnold and Gibbons 1996; US EPA 2008). Water stress is commonly cited as a limiting factor for urban tree growth (Kramer 1987; Krizek and Dubik 1987; Graves et al. 1991), particularly in arid regions (Costello 2013; Symes and Connellan 2013). High air temperatures can disrupt tree phenology and reproductive growth, and higher soil temperatures can change seasonal root growth patterns (Kozlowski and Pallardy 1997). Because water availability, temperature, and other characteristics of the biophysical environment vary throughout the year for most locales, the season of planting may also impact tree outcomes (Anella et al. 2008; Solfjeld and Hansen 2004). Additionally, several authors have found that smaller available rooting volume leads to constrained root, trunk, and shoot growth (Krizek and Dubik 1987; Grabosky and Gilman 2004; Day et al. 2010). Competition with other trees for space, nutrients, light, water and more can also limit tree growth and survival (Nowak et al. 1990; Rhoades and Stipes 1999; Iakovoglou et al. 2001). Compounding space constraints are the generally poor soil conditions in urban areas (Scharenbroch et al. 2005; Smith et al. 2001).

The urban forest axiom *right tree, right time, right place* is often on the minds of tree planters, and even sometimes a piece of urban forest policies, plans, or ordinances. Several efforts are currently underway to develop a more empirical foundation to the linkages between tree outcomes and site and soil characteristics, including work led by Bryant Scharenbroch at the The Morton Arboretum (MASS Laboratory 2014). Our protocol includes measurement of variables that are proxies or indicators for available growing space above and below ground and the quality of the site.

Institutions and management

Tree success is also impacted by the institutions—i.e., management strategies and maintenance practices—that arborists, urban foresters and other members of the community use to care for urban trees. Kozlowski and Pallardy (1997) refer to these activities as *cultural practices* that influence tree growth, and their list includes typical tree maintenance activities such as pruning and watering, use of fertilizers, growth regulators, or other chemicals, spacing of trees (both initial arrangement of planted trees and thinning of existing forest stands), and, even protection from freezing. The Clark et al. (1997) *resource management* component includes mostly variables representing administrative or organizational features of city government as these might relate to adequacy of resources for urban tree management: city-wide management plan, funding, staffing, assessment tools, protection of existing trees, species and site selection, standards for tree care, citizen safety, and recycling. The SES framework (e.g., Ostrom 2009) uses the term *institutions* to refer to the formal and informal rules and shared strategies that structure the interactions among individuals and groups of people and between people and their environment (Ostrom 2005).

Much of the research on institutions emerges from studies on common pool resource (CPR) management conducted in the disciplines of political science, economics, and anthropology (e.g., Ostrom 1990, 2005). Theory on CPR management states that several principles are likely to be linked to persistent or sustainable systems, including effective monitoring, appropriate sanctioning of rule-breakers, rules allowing individuals impacted by the resource and rules to change those rules, and strategies for effective conflict resolution (Cox et al. 2010). Institutions as rules have only been cursorily examined in urban ecosystems, and not at all for urban forest outcomes (Mincey et al. 2012). Larson et al. (2008) describe rules of homeowners' associations that limited the appearance and management strategies used for residential vegetation, including pest and water management methods and species composition. Mincey and Vogt (2014) find that watering strategy used by the neighborhood impacts tree survival rates.

Tree maintenance strategies can be characterized by the type of maintenance (e.g., pruning, watering), intensity (how much maintenance is performed, i.e., training pruning, 15 gallons of water), frequency (how often the activity is performed, e.g., annually, once per every week it does not rain), duration (how long the activity is performed, e.g., for the first 5 years after transplanting), and extent (which trees or what part of each tree is maintained, e.g., pruning up lower branches, watering all trees in the State St. right-of-way) (Vogt, Hauer, and Fischer *in review*). Maintenance type, intensity, frequency, duration, and extent all influence tree and urban forest outcomes; the impact of watering (Gilman 2001, 2004), pruning (Whitcomb 1979; Miller and Sylvester 1981; Evans and Klett 1985), and mulching (Gilman and Grabosky 2004) varies depending on the particulars of the maintenance strategy.

Maintenance strategies or institutions or rules about tree care may not always be visible on the tree itself or in the area nearby. Our Protocol includes a few key maintenance practices—pruning, mulching, staking—of which evidence can be seen on the tree itself.

Community

Because urban trees are surrounded by people, the characteristics of the community of people living in and around the urban forest influence tree outcomes. For instance, Boyce (2010) observed that the designation of volunteer tree stewards in the community dramatically reduced urban tree mortality rates. The components of *community framework* included in the Clark et al (1997) model are public agency cooperation, involvement of large private and institutional landholders, green industry cooperation, neighborhood action, citizen-government-business interaction, general awareness of trees as a community resource, and regional cooperation.[7]

Most of the empirical evidence for the influence of community characteristics on environmental outcomes emerges from the research that informed development of the SES framework. Because of its emphasis on rural natural resource management, the SES framework uses the terms “resource users” or “actors” to describe the community of people that manage and use a resource (Ostrom 2009; Ostrom and Cox 2010; Epstein et al. 2013). Features of the community that impact resource management outcomes according to the SES framework include community size (population or number of people involved), history using or managing the system (i.e., experience), demographic or socioeconomic characteristics, individual knowledge (of the resource system), norms (individual perceptions of socially-acceptable practices), and the location of the community (Ostrom 2009; Ostrom and Cox 2010; Epstein et al. 2013).

Some of the resource user or actor characteristics listed above have been examined for urban forest social-ecological systems. Iakovoglou et al. (2002) find no significant difference in growth rates between different-sized communities. Jack-Scott et al. (2013) found that a greater number of participants in tree planting events during a year is associated with higher survival and growth rates. Land use type is a factor partially indicative of the features of the biophysical environment but perhaps more closely captures community characteristics. Several authors have found an effect from adjacent or surrounding land use type on tree success (Nowak et al. 1990; Lu et al. 2011). A few studies have found that demographic characteristics (i.e., variables from the U.S. Census) are related to tree outcomes (Nowak et al. 1990; Grove et al. 2006). Lastly, studies from the field of urban ecology have observed that norms or individual motivations impact landscape outcomes (Austin 2002; Grove et al. 2006; Nassauer et al. 2009).

Like institutions, characteristics of the community of people are difficult to observe during on-the-ground inventory. Our Protocol adapts several of the *stewardship factors* collected by the New York Young Street Tree Mortality Study (NYC Parks et al. 2010) as indicators of a care ethic in the community surrounding the tree.

Interactions and endogeneity

Complex coupled human-natural systems are inherently filled with endogeneity, or simultaneous interactions between variables that complicate and sometimes obscures our understandings of the causal impact of variables on observed outcomes (Liu et al. 2007; Schlüter et al. 2014). The urban forest social-ecological system is no exception: interactions within and between tree, biophysical environment, community, and institutional factors can influence urban forest outcomes as much as the influence of a single factor. For instance, proper, proactive maintenance strategies may actually mitigate the impact of sub-optimal growing conditions. Additionally, alignment between rules, the characteristics of the community and local conditions has been demonstrated to impact common-pool resource outcomes (Cox et al. 2010). And characteristics of the community such as individual preferences and knowledge may impact choice of management strategies. A study of residential yards in Minnesota found that homeowners' application of water, fertilizers, and weed killers, as well as other yard management techniques

[7] However, few of these components have been empirically evaluated to determine their impact on urban forest outcomes (but see Kenney et al. 2011).

was strongly influenced by resident knowledge and perception of the yard as a relatively closed system (Dahmus and Nelson 2013). Additionally, Vogt et al. (*in review*) observed an interaction between watering strategy and planting season.

THE PLANTED TREE RE-INVENTORY PROTOCOL

In light of these four main categories of variables that influence urban forest outcomes, we present here the Planted Tree Re-Inventory Protocol (see the Appendix of this paper for Version 1.1; refined from an earlier version of the protocol: Vogt et al. 2013). The protocol describes standardized methods that can be used by non-professional inventory personnel to gather data necessary to evaluate the survival and growth of recently-planted[8] urban trees, as well as the many factors influencing survival and growth.

Selection of variables to include in the protocol was informed by the literature review summarized above as well as existing urban tree inventory methods, including the i-Tree Eco field methods (i-Tree version 4.0 of the user's manual was consulted for this work), the *Standards for Urban Forestry Data Collection* (IUFRO et al. 2010), and the methods of New York City's Young Street Tree Mortality Study (NYC Parks et al. 2010; results summarized by Lu et al. 2010). Individual variables and values of each variable were debated by members of the Bloomington Urban Forestry Research Group (BUFRG) over the course of a 6-month period following the review of literature and inventory methods. Table 2 lists each of the variables in the final protocol and, if applicable, the original source for their methods. We adapted and modified variables from other inventory methods to make sure that each variable could be successfully assessed by minimally-trained data collectors. To this end, many variables in the protocol require only simple, qualitative, visual assessments of the tree and its environment, and not precise measurements. For instance, a simple presence or absence assessment method, where the data collector only has to determine whether or not a particular feature is present or absent on the tree or nearby surrounding environment, is used for many variables. Variables that do ask for more precise quantification (e.g., measurements of diameter, height, or distance) require use of only two or three simple tools: a diameter tape and a digital range finder (hypsometer) or clinometer and measuring tape.

The protocol was tested by several different parties (Table 3). A preliminary list of variables was tested by members of BUFRG in the summer of 2011. Since the final users of the protocol were to be minimally-trained, non-professional data collectors, high school members of KIB's Youth Tree Team (YTT) tested the protocol during the summer of 2012; YTT used a version of the protocol adapted for use on ESRI's ArcGIS iPhone mobile application to collect data for more than 700 recently-planted street trees. YTT data collection team members were trained in data collection methods during two 6-hour training days, and overseen by a college-aged YTT Leader who had participated in approximately 15 additional hours of data collection activities with members of BUFRG during Protocol development. The YTT training procedures described above are similar to those used in studies that have found high accuracy for volunteer-collected data (Bloniarz and Ryan 1996; Bancks 2014). The protocol was also tested on slightly

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[8] Re-inventorying trees during the establishment and semi-mature phases between approximately 2 and 10 years after planting means that data collection could be combined with any remaining young tree maintenance (mulching, stake removal, training pruning, etc.).

more mature trees planted between 2000 and 2011 on City of Bloomington right-of-ways; IU master's students collected data on over 1,000 street trees using paper-and-pencil in the summer of 2012.

In addition to collection and evaluation of tree data using the protocol, testing also consisted of written daily field notes taken by YTT members (Vogt et al. 2012) as well as extensive informal discussion between members of the YTT team engaging in data collection and the researchers. For instance, the original protocol called for collecting presence or absence information on several different leaf conditions (evidence of insects, rust, chlorosis, and other leaf condition notes); however, based on written field notes from YTT members, we reduced leaf condition variables to just one: chlorosis. We also clarified that to be considered "present," chlorosis must be evident on at least 25% of the leaf surface area of the tree, and provided pictures and sketches of chlorosis to help with identification and estimation. Written field notes feedback also encouraged us to clarify instructions provided for locating each tree. Additionally, at the end of the data collection season YTT members narrated their thinking while collecting data into an audio recorder. This recording was used to verify that data collection methods had not changed between the beginning and end of the summer, and slight modifications were made to variable descriptions and instructions in the protocol based on decisions and strategies that data collectors were using in the field. (For example, narration revealed that data collectors were marking "incorrect mulching" for trees with very old, degraded mulch, where only few bark chips were still visible. The definitions of correct, incorrect, and no mulching in the protocol were updated to clarify that this case would actually better be classified as "no mulch," given the biophysical implications of capturing information about correct versus incorrect mulching.)

Version 1.1 is presented here. In the remainder of this paper, we briefly describe the variables included in the protocol. The entire protocol (in PDF form) is available as a supplementary online appendix to this article, as well as on the BUFRG website (http://www.indiana.edu/~cipec/research/bufrg_protocol.php) in both greyscale and color versions, along with a quick reference guide for the field and customizable and printable data collection sheets.

Tree characteristics

Biophysical variables (tree characteristics and local environmental variables) compose the majority of the variables in most tree inventory protocols, including this one, for a couple reasons: first, factors about the tree and immediate surroundings are most easily observed by data collectors. Second, most tree inventory methods used by urban foresters and arborists are informed by forest mensuration methods used in traditional forestry. Third, as noted above, most research on urban tree survival and growth has emerged from the fields of horticulture and arboriculture, and these fields are strongest in their assessment of the impact of tree and environmental factors on growth.

Table 2. Original sources for variables included in the Planted Tree Re-Inventory Protocol. Complete citations in Literature Cited.

VARIABLE NAME		ADAPTED/MODIFIED FROM *(if applicable)*
Tree characteristics		
Identifying information		
V1	Tree ID#	
V2	Location	
V3	Species	IUFRO et al. 2010: p. 1
Size		
V4	DBH	IUFRO et al. 2010: p. 2-3
V5	Caliper	
V6	Total height	IUFRO et al. 2010: p. 3
V7	Height to crown	IUFRO et al. 2010: p. 3-4
Canopy		
V8	Crown dieback	IUFRO et al. 2010: p. 8
V9	Crown exposure	IUFRO et al. 2010: p. 4-5
V10	Chlorosis	
Trunk		
V11	Root flare	IUFRO et al. 2010: p. 23
V12	Lower trunk damage	
Overall condition		
V13	Other damage	
V14	Overall tree condition	Fischer et al. 2007: appendix
Local environment		
Near tree		
V15	Utility interference	IUFRO et al. 2010: p. 9
V16	Building interference	IUFRO et al. 2010: p. 9
V17	Fences interference	IUFRO et al. 2010: p. 9
V18	Sign interference	IUFRO et al. 2010: p. 9
V19	Lighting interference	IUFRO et al. 2010: p. 9
V20	Pedestrian traffic interference	IUFRO et al. 2010: p. 9
V21	Road traffic interference	IUFRO et al. 2010: p. 9
V22	Ground cover at base	IUFRO et al. 2010: p. 14
V23	Ground cover under canopy	IUFRO et al. 2010: p. 14
Planting area		
V24	Planting area type	
V25	Planting area relative to road	
V26	Planting area width	IUFRO et al. 2010: p. 15-16
V27	Planting area length	
V28	Curb presence	NYC Parks and Recreation et al. 2010: p. 20
Proximity to other things		
V29	Number of trees in 10-m radius	Iakovoglou et al. 2001: p. 75
V30	Number of trees in 20-m radius	Iakovoglou et al. 2001: p. 75
V31	Number of trees in same planting area	
V32	Distance to road	IUFRO et al. 2010: p. 16
V33	Distance to building	IUFRO et al. 2010: p. 9

Table 2 continued.

VARIABLE NAME		ADAPTED/MODIFIED FROM *(if applicable)*
Management		
Maintenance		
V34	Pruning	NYC Parks and Recreation et al. 2010: p. 22
V35	Mulching	
V36	Staking	
Community		
Evidence of care		
V37	Water bag	NYC Parks and Recreation et al. 2010: p. 22
V38	Bench	NYC Parks and Recreation et al. 2010: p. 22
V39	Bird feeder	NYC Parks and Recreation et al. 2010: p. 22
V40	Yard art	NYC Parks and Recreation et al. 2010: p. 22
V41	Trash/debris	NYC Parks and Recreation et al. 2010: p. 22

Table 3. Protocol testing sites, trees, and data collectors. **Living trees* indicates that only trees remaining at the time of re-inventory were assessed using the Protocol. *Planted trees* indicates that all trees planted were assessed (i.e., for trees removed since planting, the Overall tree condition was assessed as "Missing" and only select biophysical environment variables were collected).

Site	Number of trees*	Tree planting years	Trees planted by	Data collectors	Data collection dates
Indianapolis	120 living trees	2006-2007	Volunteers of Keep Indianapolis Beautiful	IU BUFRG researchers	June-Sept 2011
Bloomington	1,097 planted trees	2000-2011	City of Bloomington Parks and Recreation Division of Urban Forestry	IU Master's of Science in Environmental Science students	May 2012
Indianapolis	714 planted trees	2006-2009	Volunteers of Keep Indianapolis Beautiful	High-school aged Keep Indianapolis Beautiful's Youth Tree Team (YTT) members led by a college-age YTT leader	June-July 2012

Identifying information. The most critical information collected in any inventory protocol is basic identifying information about the tree. This includes a *tree identification number*, some sort of *location* information, and *species*. An identification number is a unique value for each tree in the inventory, useful for tracking the same tree over time through multiple inventory years. Location information should include enough information so that the physical location of the tree in space can be found. Location may be an address number and street name of the property adjacent to the tree, geographic coordinates (I.e., GPS latitude and longitude), distance and direction of the tree from the nearest street intersection, or any other way to precisely locate the tree. Species is the biological name for the type of tree that was planted. Species can be detailed, and include the cultivar or variety (e.g., autumn blaze maple, *Acer x* *freemanii* 'Jeffersred'), or could be limited to just the genus (e.g., *Acer* spp.) of the tree planted, depending on the level of detail desired for the inventory and the tree identification skills of data collectors.

Size. In order to measure growth of trees over time, we need information about trees' size. Size information included in the protocol is *diameter at breast height*, *caliper*, *total height*, and *height to crown*. Diameter at breast height (DBH, or diameter measured at 4.5 ft or 1.3 m off the ground) is one of the most commonly used metrics of size for trees in rural or urban areas. The change in DBH over time is one way to calculate tree growth, and DBH can also be used to calculate the total benefits provided by the tree (e.g., carbon storage). Caliper, or tree diameter 6 inches (15 cm) from the first lateral root, can also be used to calculate tree growth. This is a particularly convenient measure for recently-planted trees, because trees are often sold from the nursery by caliper size; comparing current caliper with that from the tree at the time of planting is another means of calculating tree growth. Total tree height and height to crown provide a metric of above ground size, and can be combined to provide a simple proxy for crown or canopy volume and potential for photosynthesis and growth.

Canopy. Tree health and condition includes information about the canopy, trunk, and entire tree. Information about the condition of the canopy (or leafy top of the tree, also called the crown) is important for assessing the health of the tree. Canopy information included in the protocol is *crown dieback* rating, *crown exposure* rating, and presence of *chlorosis*. Crown dieback and exposure are qualitative visual assessments, recorded on simple point rating scales, using methods modified from the *Urban Forestry Data Standards* (IUFRO et al. 2010). Crown dieback is a qualitative assessment of the percent of dead branches in the canopy relative to the total living crown, assessed on a 0-6 scale. Crown exposure is a rating of how much of the tree's canopy is exposed to sunlight, based on how many sides of the canopy are shaded by buildings or other trees, assessed on a 0-5 scale. Chlorosis is a presence or absence metric, where "presence" implies that leaf chlorosis is evident on at least 25% of the leaf surface area of the entire tree.

Trunk. Trunk condition metrics are equally as important as canopy condition in assessing overall health of the tree. Trunk condition is related to the health of its vascular tissue and the ability of a tree to successfully transfer nutrients and water between the root system and canopy. Trunk information included in the protocol is presence of a *root flare* and presence of *lower trunk damage*. A root flare, or gradual taper of the trunk of a tree as it enters the ground, may be indicative of how deeply the tree was planted.[9] The roots of trees planted too deeply may lack sufficient access to oxygen, may be more at risk of water stress (e.g., Gilman 2004) or may be prone to root girdling of the tree. Trees exhibiting lower trunk damage—such as that caused by a lawn mower, weed-whacker, or even animals—may be at greater risk of infection by fungus or disease. Repeated damage over time and on all sides of the lower trunk, such as from a lawn mower, may even girdle the tree, severing the vascular tissue and preventing water and nutrient transfer.

[9] This variable was collected at the suggestion of employees of Keep Indianapolis Beautiful, Inc., who teach volunteers to plant trees at the correct depth by maintaining the root flare.

Tree condition. Presence of any *other damage* and determining an *overall tree condition* rating are the final assessments of tree-level variables, made after both canopy and trunk condition as well as all other aspects of the individual tree have been examined. Other damage to the tree that may impact its health, condition, survival or growth include: broken branches, branches stripped of leaves or bark, damage to the upper trunk of the tree, a wire or other item choking or girdling the tree, etc. Overall tree condition takes into account the condition of the trunk and canopy. A deciduous tree in good health and condition exhibits a full canopy of dark green leaves that are not undersized for the current season, and a growth form appropriate for its species, without dead branches or excessive water sprouts growing out of the base or main trunk of the tree. Conifers in good health have full boughs with dark green needles. Tree condition ratings should consider a tree from all angles and from top to bottom. The protocol condition ratings range from good to dead and include categories for stumps, sprouts, or absent trees.

Local environment

Near tree environment. In the local environment immediately around the tree, we can assess the quality and quantity of growing space by assessing interference with infrastructure (*utility*, *building*, *fences*, *sign*, *lighting*, *pedestrian traffic*, and *road traffic*) and type of ground cover (*at the base* of the tree, and *under the canopy*). Interference with infrastructure is assessed according to whether or not the tree is in conflict with aboveground utility wires or poles, buildings, fences, signs, or lighting at the time of re-inventory. Interference with traffic refers to the presence of branches more than ½ inch (1 cm) in diameter at or below 8 ft (2.4 m) above a pedestrian walkway or sidewalk for pedestrian traffic, or, for road traffic interference, at or below 14 ft (4.3 m) above an active lane of traffic (i.e., not a parking lane). Trees that are located in close enough proximity to infrastructure so as to conflict with it may compete with this infrastructure for aboveground growing space, or may require more frequent pruning to limit conflicts between branches and the built environment. The type of ground cover around the tree is a qualitative assessment of the type of cover (e.g., bare soil, mulch, grass, etc.) at the base of as well as under the canopy of the tree. Ground cover reflects the surface conditions of the belowground growing environment, including potential competition with other plants for water and nutrients, the permeability of the area to infiltration of water, or even the likelihood of surface soil disturbing activities (such as digging in an annual flowerbed).

Planting area characteristics. The quality and quantity of growing space is also related to the planting area *type*, its position *relative to the road*, its *length* and *width*, and the presence of a *curb* at the edge of the planting area. Planting area type refers to the type of physical space in which the tree as planted; types of planting areas include a tree lawn, median, shoulder, tree grate, tree pit, bumpout, front yard, side yard, or other open area. Sketches of each type of planting area are provided in the protocol. The size of the planting area as measured by its surface area (length and width) is a proxy for available rooting space below ground. In addition to the type and size, the position of the planting area relative to the road (i.e., above, even, or below the surface of the road) as well as whether or not the planting area has a curb may impact the quantity and quality of any runoff into the tree planting area.

Proximity to other things. Other living and nonliving things in the larger growing area of the tree can also impact tree success. The protocol considers the *number of trees in a 10-meter*

(33-ft) *radius*, *a 20-meter* (67-ft) *radius*, and the *same planting area,* as well as the *distance to the nearest road* and *building.* The number of other trees near the sample tree influence the amount of competition a tree experiences, both above and below ground, for light, nutrients, water, and growing space. The distance to the nearest road can tell us about potential exposure to factors that may influence a tree's health, condition or growing potential, including the potential for automobile injury or road spray contaminated by fuels, salts and other particles. The distance to the nearest building can tell us about the potential exposure to radiant building or for shading by the building.

Management variables

Most management and maintenance cannot be captured using on-the-ground tree inventory methods, but might be better captured through surveys or interviews of the individuals or groups responsible for the trees. However, some maintenance is visible when looking at the tree during an on-the-ground inventory. The protocol includes variables that consider evidence of *pruning*, *mulching*, and *staking* on the tree, as well as whether the maintenance activity appears to have been performed correctly or incorrectly. For instance, correct pruning cuts should be a smooth, flat cut, made just outside the branch collar for a branch off the main trunk of the tree, or just after the branching for secondary branches in the crown. The protocol includes sketches with examples of correct and incorrect pruning and mulching, and complete text descriptions for correct and incorrect pruning, mulching, and staking.

Community variables

The last suite of variables included in the protocol considers the surrounding community as it is manifested in evidence of care around the tree. The protocol includes four indicators of positive norms of care—presence or absence of a *water bag*, *bench*, *bird feeder*, or *yard art* (adapted from the list considered by the New York City Young Street Tree Mortality study [NYC Parks et al. 2010])—and one indicator of a lack of care—presence of *trash or debris*.

CONCLUSION

Data collected via the protocol has many uses, depending on the end user. Tree planting organizations might use the data to help plan the locations and management of future tree planting efforts. Municipal urban foresters might use data on cohort survival rates to help determine an annual budget for planting new trees. Researchers might use data to better understand the myriad factors that influence urban tree outcomes and to create better models of tree growth and survival over time and to improve estimates of the benefits of the urban forest.

As urban areas continue to develop and redevelop, to expand and infill, the number of non-planted (i.e., remnant) trees in cities will continue to decrease, as relatively natural areas are replaced by designed landscapes of buildings, roads, planted trees, and other infrastructure (both green and grey). While cities and developers often maintain complete and detailed plans of buildings and roads, detailed records of planted trees rarely exist. However, trees are an integral part of urban infrastructure. In order to ensure they continue providing benefits to urban residents, we should keep track of the location, survival and growth of the trees we plant so that they can be efficiently managed and maintained throughout their lifetimes, and then removed and replaced after they die. With better data about planted urban trees, we can more efficiently allocate limited resources for managing and maintaining the urban forest.

The protocol methods presented in this paper can serve as a beginning of a conversation between researchers, urban forestry practitioners, and the public about the measurement of the factors that influence the success of recently-planted urban trees. The protocol will continue to be used and tested by various groups, and accuracy assessments of data collected by citizen scientists should be conducted. We expect to continue to publish new and updated versions of the protocol on the BUFRG website.

APPENDIX

Planted Tree Re-Inventory Protocol, Version 1.1 booklet (PDF available for download here: http://www.indiana.edu/~cipec/research/bufrg_protocol.php)

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