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Knowledge Co-production at the Research–Practice Interface: Embedded Case Studies from Urban Forestry

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Abstract Cities are increasingly engaging in sustainability efforts and investment in green infrastructure, including large-scale urban tree planting campaigns. In this context, researchers and practitioners are working jointly to develop applicable knowledge for planning and managing the urban forest. This paper presents three case studies of knowledge co-production in the field of urban forestry in the United States. These cases were selected to span a range of geographic scales and topical scopes; all three are examples of urban researcher-practitioner networks in which the authors are situated to comment on reflexively. The three cases resemble institutional structures described in the knowledge co-production literature, including participatory research, a hybrid organization of scientists and managers, and a community of practice. We find that trust, embeddedness, new approaches by both practitioners and researchers, and blending of roles all serve to recognize multiple forms of capability, expertise, and ways of knowing. We discuss the impacts of knowledge co-production and the ways in which hybrid institutional forms can enable its occurrence.

Keywords Community of practice · Hybrid organization · Knowledge co-production · Participatory research · Urban forestry

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Introduction

While humans have been planting and managing trees in cities over the course of civilization, since the 1960s urban forestry has evolved into a field of professionalized practice that engages numerous actors including government officials, public and private land managers, researchers, professional associations, arborists, activists, and the public (Johnston 1996; Konijnendijk et al. 2006; Ricard 2009; Mincey et al. 2013). Historically, management decisions about urban forests and green spaces were driven by a mix of esthetic preferences, socially progressive intentions, development patterns, and desired environmental benefits (Ricard 2005, 2009; Jonnes 2011; Scobey 2002; Spirn 1984). Science-based decision-making is also being brought to bear as municipal leaders engage in sustainability planning (since the 1990s) and resiliency planning (since about 2010), and invest in green infrastructure to enhance ecosystem services (Young 2013; McPhearson et al. 2014). Concurrently, urban forest researchers have produced studies and tools designed to help support sound management, particularly at the local level, such as characterizing current and possible urban tree canopy, valuing ecosystem services of the urban forest, and identifying and mapping civic stewardship groups involved in caring for the urban environment (www.itreetools.com; McPherson et al. 2005; Nowak et al. 2008; Svendsen and Campbell 2008; Locke et al. 2010). As cities create offices of sustainability that utilize metrics in their goal-setting and implementation, and researchers aim to support adaptive management in real time, the lines between environmental science and decision-making have become blurred and intermingled. Various ideologies, types of professional expertise, and scientific approaches shape knowledge co-production in contemporary urban forestry, but it is not

well understood how these processes function or vary across contexts. Given these trends, we ask the following question: how does knowledge co-production occur at the interface of research and practice in urban forestry?

This paper presents three case studies of knowledge co-production among researchers and practitioners from the field of urban forestry in Sacramento, CA, New York, NY, and an international multi-city network. These cases were selected to span a range of geographic scales and topical scopes; all three are examples of urban researcher-practitioner networks in which the authors are personally embedded. After briefly reviewing the relevant literature on knowledge co-production, natural resource management, and urban forestry, we present the three case studies. These cases present three different approaches to knowledge co-production: participatory research, a hybrid organization, and a community of practice. Then we look across the cases to identify common themes and principles related to knowledge co-production and conclude with a discussion of future directions for research-practice partnerships in urban forestry.

Knowledge Co-production: Participatory Research Approaches and Institutional Configurations

Epistemologies of participatory research and participatory action research (PAR) start from the premise that knowledge co-production between "researcher" and "subject" is of utmost importance (Minkler and Wallerstein 2008). This approach acknowledges there is no such thing as objective, neutral observation in science (Guba and Lincoln 1994; Kemmis and Wilkinson 1998). Thus, in participatory approaches, the researcher is not separate from the subject, but rather is a member of the community of study seeking to foster co-learning and produce useful knowledge (O'Fallon and Dearry 2002; Pain 2003; Kindon 2005). And, vice versa, community members have not only the right to engage in research, but also have much to contribute to its rigor, relevance, and reach (Balazs and Morello-Frosch 2013). Much of the PAR literature is positioned from a normative standpoint, informing researchers on ways in which they can seek to affect change in their (often marginalized) communities. While there are critiques that PAR does not do enough to decenter traditional power hierarchies related to research, the goal of this approach is to work in collaborative modes with community members to co-produce knowledge and social change (Thomas-Slayter 1995; Cameron and Gibson 2005).

In addition to viewing knowledge co-production as a normative goal, for some an ethical commitment, other strains of research have examined the institutional configurations that enable such work. Spaces of co-production can take organizational forms. Boundary organizations "involve the participation of actors from both sides of the boundary…[and] exist at the frontier of the two relatively different social worlds of politics and science, but they have distinct lines of accountability to each" (Guston 2001, p401; see also Clark et al. 2011; Parker and Crona 2012). Bridging organizations are "similar to boundary organizations…but are considered to have a broader scope" (Hahn et al., 2006)" (Berkes 2009, p. 1696; see also Folke et al. 2005). Hybrid organizations are arrangements where roles, responsibilities, and resources are thoroughly entangled across member groups (Fisher and Svendsen 2014). Knowledge co-production can also occur through networks, such as knowledge-action networks (Muñoz-Erickson et al. 2014) knowledge systems (Cash et al. 2003), or communities of practice. The latter is defined as groups of people with a shared concern and engagement in social learning based on that interest (Wenger 1998; Lesser and Storck 2001). Thus, there are a wide range of institutional forms that can potentially enable knowledge co-production, from novel organizational forms, to networks of collaboration among diverse actors across sectors and scales, to communities of individuals with shared interests. These categories are not entirely distinct, however, as communities of practice can take organizational or networked forms; and vice versa, networks can be comprised of communities of practice, individuals, and organizations. Finally, many current environmental problems are extremely complex and cannot be solved through managerial expertise alone; these "wicked problems" required shared knowledge production across numerous stakeholders (Ludwig 2001). It is important to note that this brief review focuses on *knowledge co-production* arrangements that link scientists and practitioners, not the *co-production of knowledge* idiom, which is concerned with how broader social, cultural, and political factors shape and are shaped by the production of scientific knowledge, policy, and practice (Jasanoff 2004; Muñoz-Erickson 2014; Wyborn 2015).

Facilitating Knowledge Co-production in Natural Resource Management

Scholars working from diverse perspectives ranging from political ecology (Neumann 2004; Robbins 2004; Kosek 2006) to social-ecological resilience (Berkes et al. 2003) have critiqued top-down management or scientific expertise that ignores the role of communities in managing their environments. Numerous approaches to natural resource management—including *co-management*, *community-based natural resource management*, *adaptive management*, and *adaptive co-management*, seek to rework hierarchies and engage local residents, government agencies, and researchers in relationships of trust, shared vision, and

collaborative work. Co-management and community-based natural resource management have roots in rural landscapes and acknowledge the importance of the participation of communities in managing ecosystems in partnership with government agencies (Koontz et al. 2004; Berkes 2007). In the field of forestry, community forestry approaches began and proliferated in rural areas in the global south but have, in some instances, been adapted and applied in urban and peri-urban areas (Burch and Grove 1993; Kuchelmeister and Braatz 1993). Adaptive management has been examined widely in the natural resource literature since its emergence in the 1980s (see, e.g., Holling 1978). Overdevest el al. (2004) defined adaptive management as the practice of natural resource management institutions adjusting management objectives to changing knowledge and conditions through ongoing feedback. Adaptive co-management is a more recent approach that unites co-management and adaptive management (Folke et al. 2002). It is important to note, however, that these arrangements are shaped by existing power dynamics, structural forces, and adaptive capacity that determine whose voice is heard in decision-making, which approaches to management are pursued, and how the social-ecological system responds to change (see, e.g., Armitage 2005).

The natural resources literature has examined the relationships, factors, and institutional arrangements that enable knowledge co-production within collaborative management settings. Wynveen et al. (2010) found that "place bonding" can be a platform around which managers and community stakeholders can build relationships of trust in order to develop shared management approaches. Armitage et al. (2011) found that co-management arrangements can help facilitate social learning, with knowledge co-production serving as a mechanism that enables adaptation to environmental change. They also highlight the importance of sustained commitment to building institutions over time as well as a need for multiple modes of communication across partners. Similarly, Berkes (2009) examined the relationships between knowledge generation, bridging organizations, social learning, and adaptive co-management, finding that relationships mature over time through "learning-by-doing" in knowledge partnerships (1699). Bormann et al. (2007) evaluated ten years of collaborative work on the Northwest Forest Plan and the completion of one loop of the adaptive management cycle. They found that "alternative ways to meet management objectives" were required of managers; scientists and managers took a "handshake approach" to finding shared objectives for collaboration and agreeing to complete an adaptive management cycle. Bridging the literatures of knowledge co-production and co-management, Fortmann (2008) describes numerous examples of collaborative research approaches that serve dual aims of promoting conservation and enhancing rural livelihoods. Finally, Olsson et al. (2004) argued that adaptive co-management can promote social-ecological resilience, whereby communities and ecosystems can better adapt to and recover from systemic change. They identified important institutional and organizational dimensions that contribute to resilience, including vision, leadership, trust, legislation, funding, monitoring capacity, information flow, diverse information sources, and collaborative learning. The literature demonstrates that the mutual learning and producing shared knowledge play a central role in collaborations between scientists and practitioners in support of natural resource management.

Urban Forests as Sites for Knowledge Co-production

Urban natural resource management is a broad field that encompasses the practice of managing urban nature across a range of habitats, including street trees, parks, wetlands, woodlots, and community gardens (Svendsen and Campbell 2008). Some practitioners use the terms urban forestry and urban natural resource management interchangeably. Others use the term urban forestry more narrowly to refer to the "art, science, and technology" of managing all the trees within and around the urban matrix (Konijnendijk et al. 2006; Piana and Troxel 2014). As a field of practice, urban forest management is closely tied to professional societies, such as the International Society of Arboriculture (ISA), which offers credentials for certified arborists—the professionals who are responsible for urban tree care (Johnston 1996). Contemporary urban forestry is an arena in which researchers and practitioners often interact, with scientific concepts and researcher-produced tools influencing and being influenced by management practices. One example of this interaction can be seen in the use of the ecosystem services concept among greening nonprofits and municipal arborists (Young 2013; Silvera Seamens 2013) and the development of ecosystem service models by researchers (e.g., www.itreetools.org).

Urban forests and the institutional processes that govern them are apt for examination as complex sites of knowledge co-production. Social ecology research notes that urban forests are human-engineered systems that depend upon collective action at various scales from households, to neighborhoods, to cities (Grove 2009; Roy Chowdhury et al. 2011; Mincey et al. 2013). Moreover, municipal managers are increasingly engaging in both highly technical acts of planning for sustainability and resilience and highly collaborative acts of managing urban forests for diverse constituencies (Pincetl 2010; Campbell 2014; Fisher et al. 2015). For example, through the vehicle of

large tree planting campaigns, managers work hand-in-hand with scientists, decision-makers, and the public (Campbell and Monaco 2014).

Approach and Methods

We applied a comparative case study method to examine complex processes of knowledge co-production in urban forestry. Case studies are an appropriate methodology when detailed and holistic investigation of phenomena is used to build upon existing theory, extrapolating from the "micro from the macro" (Burawoy 1998, p. 5; see also Feagin et al. 1991; Stake 1998; Hyett et al. 2014; Bradshaw and Stratford 2005). As such, we selected these cases as a window into broader processes of knowledge co-production among researchers and natural resource managers. We examined three cases of knowledge co-production operating via different structures and at different scales with which the authors have first-hand knowledge as participants (see Table 1). All three cases focus on urban settings in the global north, with geographic scale ranging from a single city to the international scale. As well, the scope of the inquiry varied from a single-research project with a single-lead researcher to a broad, multi-entity network with multiple themes. The cases provide insights into this growing field of urban forestry and the interactions among the many actors—particularly managers and researchers—that are engaged in these practices.

In contrast to a hypothetical-deductive approach, this is a work of qualitative social research that acknowledges the situatedness and subjectivity of researchers as crucial to shaping the findings (Haraway 1991; Rose 1997; Dowling 2005). Therefore, it is important to note that the three co-authors have been working as researchers in the field of urban forestry and natural resource stewardship for more than a decade and are all currently employees of the US Forest Service. We are deeply embedded in the networks that we reflect upon here. Thus, we build upon traditions of embedded, reflexive research that are used in participant observation and ethnographic methods from anthropology, human geography, and the sociology of science (Pryke et al. 2003; Mansvelt and Berg 2005). In developing the case narratives, we triangulated across data sources, drawing upon published research and gray literature, as well as interviews and field notes collected as part of our own prior research (Roman 2013; Campbell 2013). In striving for reflexivity, we remained attuned to problems, pitfalls, and challenges encountered in each case. Finally, we conducted a "member check" by reviewing draft narratives across the three authors and with practitioner collaborators involved in each case, subsequently revised the narratives, and thereby strengthened the credibility and validity of the analysis (Lincoln and Guba 1985).

Case 1: Sacramento Shade Tree Survival: Participatory Research in Practice

The Sacramento Shade program has distributed over 500,000 trees since 1990 and is the largest and longest-running shade tree program in the United States. Using funding provided by the Sacramento Municipal Utility District (SMUD), the Sacramento Tree Foundation (STF) has distributed free trees to residents in Sacramento County, CA to achieve energy saving benefits during the hot summer months. The success of this program in providing residential energy savings has depended on the long-term survival and growth of the shade trees (Ko et al. 2015), with STF conducting site evaluations and providing tree care information to every property. The foundation and

Table 1 Comparison of cases by key attributes

Case	Geographic scale and location	Time period	Structure and scope	Author role	Approach to knowledge co-production
Sacramento shade tree survival	Single county, Sacramento, CA	2007–2013	Single-research project with narrow topical focus	Roman was PI of the research study as part of her doctoral dissertation	Participatory research
MillionTreesNYC	Single city, New York, NY	2007–2015	Multi-entity campaign, research-practice network with multiple projects and topical foci	Svendsen was co-chair of the research and evaluation subcommittee; Campbell was on the subcommittee and studied the campaign as part of her doctoral dissertation	Hybrid organization
Urban Tree Growth & Longevity working group	Multi-city, national to international (mostly US)	2010–present	Research-practice network with narrow topical focus	Roman is chair-elect of the working group and has lead the monitoring standards initiative	Community of practice

the utility district have a history of collaborating with researchers and incorporating scientific findings into their program: the shade tree energy saving projections used in Sacramento are based upon science published in the 1990s by the US Forest Service (McPherson et al. 1998, Silvera Seamens 2013), and STF has embedded scientific thinking into its organization through a technical advisory board.

The Sacramento shade tree study began with a clear management problem: residential tree mortality. Publicly acknowledging and documenting the extent of potential tree mortality required transparency and openness to self-critique through research on the part of the tree planting entities. There was also serendipitous timing: a University of California, Berkeley (UCB) doctoral student (L.A. Roman) interested in mortality research contacted the foundation when foundation staff members were beginning to brainstorm ideas for initiating a mortality study. STF staff seized the opportunity to embark on a project that they already wanted; so the catalysts for this project were simultaneously both the UCB doctoral student and the leaders of STF. The study developed as a participatory research project (Israel et al. 1998, Minkler and Wallerstein 2008) between STF, SMUD, and UCB, starting in 2006. See Fig. 1 for a diagram of the institutional arrangements involved in the study. This five-year project had a relatively narrow focus on assessing yard tree survival in one county, but the findings have widespread geographic application, as tree survival is an important metric of planting program success for urban greening funders, researchers, resource managers, and local stewards (Roman et al. 2013; Koeser et al. 2014). This project had piecemeal funding from SMUD (in the form of transportation reimbursements to the lead researcher) and UCB (in the form of undergraduate student assistants), with under $10 thousand total dedicated to the project over five years. Overall, the project was a highly cost-effective means to apply rigorous science to the problem of tree mortality, compared with the nonprofit running the study themselves or working with a paid consultant to do the research.

Creating trust between partners was essential to a productive dialog and part of a conscious decision by the lead researcher to not only draw upon the expertise of practitioners at the nonprofit but also to allow for co-creation of a research framework. An essential step in building trust was that the researcher and her main STF contact were open and upfront about the potential for difficult results to arise from the study, especially considering that mortality is viewed as a metric of planting performance (Roman et al. 2013). The researcher sought to frame the Sacramento study results as constructive feedback rather than harsh critique, and STF staff were consistently willing to discuss the sensitive nature of the mortality problem, as part of continuing conversations during and after the study. While research partnerships are often referred to as collaborations between organizations, relationships between individual people are at the heart of effective partnerships. In the course of the survival study, the lead researcher joined community foresters for ride-alongs during their resident site visits and stayed as an overnight guest of STF staff while conducing field work, often bringing along home-made-baked goods to share with colleagues. These sorts of techniques are common in ethnographic methods and social science fields like anthropology (Kusenbach 2003), and the value of building personal relationships with local

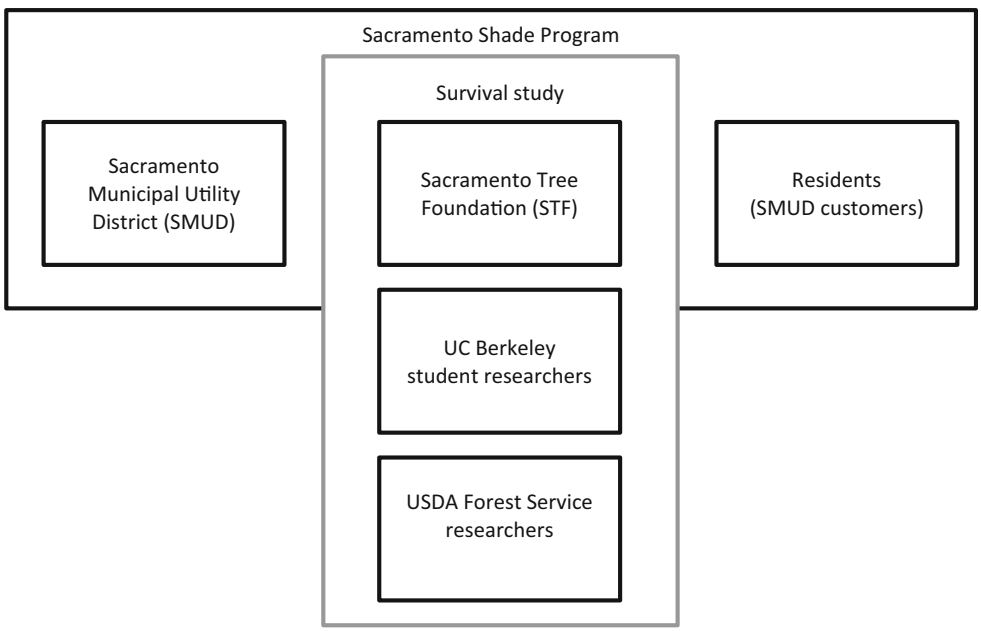

Fig. 1 Parties involved with the Sacramento shade tree survival study and related research projects

collaborators has also been recognized for sustainability science and conservation (Gupta and Kelly 2014; Muñoz-Erickson et al. 2014). In Sacramento, the informal "hanging-out" was crucial to building trust and rapport, especially given the sensitive nature of the tree mortality problem. Building that camaraderie involved recognizing different institutional cultures and needs. The researcher needed to pursue funding opportunities, complete a dissertation on time, and publish manuscripts with dense science writing. At the same time, the nonprofit needed to showcase how research results could be translated into enhancing effective management actions.

The study design evolved over several months to ensure that the final product would be both scientifically rigorous and meet local management needs. Informed by approaches from participatory planning, the lead researcher initiated discussions to jointly set research goals. First, there was an extended listening period (Forester 1999) whereby the researchers learned about program operations and STF study interests. Next, a dozen STF staff members engaged in discussion using the nominal group technique (Van de Ven & Delbecq 1974, Totikidis 2010) to prioritize research objectives. One of the key findings was the realization that researchers and STF staff did not share the same understanding of what constituted tree mortality, as the terms "mortality" and "survival" are often vaguely defined in the urban forestry literature and among managers. Defining "mortality" was crucial both for field data collection and appropriate analysis of distinct life history phases during tree establishment (Roman et al. 2014). Common vocabulary is essential for clear communication in collaborative research (Friedman 2001; Israel et al. 2003); before these differences were clarified, the divergent ways of understanding these terms led to misunderstandings and confusion.

Field methods, sampling approaches, analysis, and writing were shaped via researcher-practitioner dialog. For example, STF personnel drew upon their expertise to develop a composite maintenance score to quantify the level of resident adherence to recommended planting and stewardship actions. These maintenance observations corresponded to specific tree care educational materials that residents received from STF (e.g., watering, mulching, presence of structural support stakes, removal of nursery stakes). Practitioner perspectives were also incorporated into the sampling design; STF staff decided to prioritize results that would be generalizable to the entire population of recently distributed shade trees, rather than focusing more narrowly on a few species or neighborhoods. The researcher presented alternative sampling schemes in order to draw out differences through debate and come to a shared agreement for moving forward. The solution was to take a simple random sample of several hundred trees from over 13,000 trees distributed in 2007. Analysis and writing was an iterative process through a constant back-and-forth dialog between researchers and managers. UCB researchers led the data analysis and manuscript writing, with frequent input from STF staff regarding what factors to include in the analysis and results interpretation. For example, STF had concerns over residents' failure to plant or planting in an incorrect location (i.e., not the location which provided maximum shade benefit). Therefore, the researchers developed a separate statistical model to investigate the failure to plant issue. The distinction between failure to plant and post-planting mortality is a fundamental life history issue for tree giveaway programs, and an issue that would not have been as clearly analyzed without STF input. Preliminary results were shared annually at STF staff meetings and at least monthly through meetings with the Sacramento Shade Director.

The study found that 15.1 % of trees were not planted, and post-planting survivorship at five years was 70.9 %. Homeowner stability was the most important determinant of establishment success, and furthermore, stable homeownership was tightly linked to higher maintenance scores (Roman et al. 2014). Neighborhood educational level was also related to failure to the plant, and species drought tolerance classification was important to five-year survival. Due to the participatory approach, research findings were translated into management practice. Community foresters now call every resident after tree delivery, and automated emails send seasonal tree care tips; such follow-up communication was previously resident-driven and infrequent. STF is also considering targeted outreach strategies for rental properties and properties with changing owners, and alterations to the planting palette with consideration for drought tolerance. This study suggested that direct and targeted communication with residents is necessary in order to ensure proper tree care and ultimately improve the survival rates for Sacramento shade trees (C. Cadwallader, pers. comm.). Indeed, many residential homeowners—when convened in a community meeting to gather input on what could help enhance tree survival—offered that the direct contact with the researcher during her site visits was important to their tree care. This was despite the researcher's concerted effort to focus on data collection, not tree care advice, during the field visits, in order to avoid biasing the sample. Program modifications were also informed by anecdotal evidence from the lead researcher, which supplemented the formal quantitative findings with tangible stories of residents' major life changes and maintenance challenges to provide personal stories behind the numbers.

Because the project evolved through a shared process of development, implementation, and analysis, it deepened the engagement of researchers and managers and attracted

new participants. In addition to the lead researcher (PhD student) and faculty advisors, many UCB undergraduate students were also involved with the Sacramento study, with several completing senior thesis projects on subjects ranging from resident perceptions to the experiences of staff community foresters. Unpublished student contributions were valuable to STF in their decision-making process for program alterations to enhance survival, affirming that knowledge co-production is not limited to the peer-reviewed literature.

This case identifies six key stages in the research-practice partnership. The collaboration began with a clear management problem to be solved, followed by the building of trust between partners. Then the research objectives and study design developed to meet the needs of scientists and managers alike, followed by creation of field methods and sampling approaches that drew upon the diverse expertise of team members. Analysis and writing was iterative, leading to multiple peer-reviewed and non-peer-reviewed products while also exposing students to practices of participatory research. Finally, findings from the research translated to changes in management practices. At all stages in its evolution, the project was open to multiple voices and attracted new participants.

Case Study 2: MillionTreesNYC and the New York City Urban Field Station: Hybrid Organizations at Work

The MillionTreesNYC campaign was launched in 2007 as a public–private partnership to plant and care for one million new trees across New York City. At the outset of creating the city's long-term sustainability plan, the Department of Parks & Recreation (NYC Parks) leveraged scientific evidence to make the case to business-minded leaders in then-Mayor Bloomberg's administration that planting trees was a sound investment that would make the city more livable and therefore more attractive to residents and businesses alike. Indeed, one of the key pivot points for the Mayor's Office was learning that there had been scientific research on the economic and environmental value of New York City's trees conducted by the US Forest Service, including application of the i-Tree Eco and Streets models (McPherson et al. 2005; Nowak et al. 2008, www.itreetools.org). NYC Parks also used the US Forest Service's Urban Tree Canopy research to help provide a context for these numbers and to determine where there was space across the densely built city to plant all these new trees (Grove et al. 2005). Representing a transformative investment in the urban forest, more than $400 million in municipal capital funds were committed to the tree planting initiative via the city's sustainability plan. This public funding was matched by several more million dollars from corporate sponsors, private philanthropists, foundations, and individuals that were attracted through social networks, professionalized connections, and savvy outreach and marketing of the campaign. This funding did not include support for research and evaluation; instead, these efforts were advanced through federal and university scientists' time and research grants.

In addition to the public-facing campaign to plant every available opportunity with street trees, to afforest hundreds of acres of green space, and to create varied opportunities for civic stewardship and engagement, the campaign also triggered a reorganization of the governance of the urban forest (Campbell 2014). NYC Parks and the highly professionalized, nonprofit greening group the New York Restoration Project (NYRP), which had been founded by prominent entertainer Bette Midler in the 1990s, were the lead entities that began to work together through a formal public–private partnership. In addition, the leaders of the campaign created a broad advisory committee of more than 400 individuals from 109 organizations to provide insight and guidance to the implementation of the campaign. This committee included a number of different topical subcommittees: stewardship and education; research and evaluation; public policy initiatives; marketing and public relations; tree planting; and green jobs were added later. A natural resource manager reflected on the role of this network of advisors, "I think the advisory board serves several purposes: breadth and also longevity. So, the advisory board allows us to be able to say in a very real way that it's not just about tree planting; that we want Million Trees NYC to be about creating…an urban forestry movement for planting and care and awareness" (quoted in Campbell 2013). MillionTreesNYC—through its resources, public visibility, timeline, and sense of momentum—became a new organizing framework for the already-existing allies of urban forestry. A Stewardship Corps was created that re-granted MillionTreesNYC resources to greening entities (such as the botanical gardens) across the city in order to help educate and cultivate citizen stewards. This later evolved into the TreeLC program that offered trainings and mini-grants directly to community-based stewardship groups. Existing US Forest Service research on civic stewardship was used to help support this program, as the STEW-MAP database of stewards in New York City provided a list of potential partners to MillionTreesNYC (US Forest Service 2007). A decision-maker in a public agency noted the transformative impact of the campaign, saying "the investment we were able to make, into research, the improvements to our technology, the connections that we've made to academia, other government agencies, other practitioners in the field, it's just been extraordinary" (quoted in Campbell 2013). These transformations in

physical space and in institutional space created opportunities for new research—both collaboratively and individually.

The formal structure of the advisory committee and research and evaluation subcommittee was enlivened by the engagement of the hybrid organization of the NYC Urban Field Station (NYC UFS). The NYC UFS is a partnership between federal researchers at the US Forest Service and municipal natural resource managers at NYC Parks. The NYC UFS serves as a place-based hub, with a mission to improve quality of life in urban areas by conducting and supporting research on social-ecological systems and natural resource management. In addition, the co-director of the NYC UFS (E.S. Svendsen), who is currently a social scientist with the US Forest Service, was previously a program director at NYC Parks, thus she was viewed as a trusted "insider" with whom the municipality could work. Working via the NYC UFS and the MillionTreesNYC research and evaluation subcommittee, scholars from academia and the federal government had productive self-interest in engaging with the MillionTreesNYC campaign. They were interested in accessing data and field sites, conducting new research, and engaging with a lively network of scholars and managers. Co-chaired by a NYC Parks analyst, a NYRP staff member, and a US Forest Service social scientist, the subcommittee had multiple institutional perspectives built into its leadership. See Fig. 2 for a diagram of the institutional arrangements involved in MillionTreesNYC knowledge co-production.

The research and evaluation subcommittee was vibrant and active, particularly over the course of 2007–2011, serving as a space for cross-disciplinary collaboration between researchers and managers. First, the subcommittee held a brainstorming meeting of approximately 50 people in 2008 discussing the role of research in the campaign. Second, members created an urban forestry bibliography free for public download, as an attempt at synthesizing some of the existing research knowledge in the field. Third, the group organized a two-day workshop and field tours of planting and stewardship sites in spring 2009 that led to a report about the effort to integrate research and management practices (MillionTreesNYC Advisory Committee 2009). While the intent was to help foster new research-practice networks, it also illuminated some of the barriers and stumbling blocks to doing just that. Discussions covered motivations, questions, and timelines that drive the work of land managers and scientists: indeed, sometimes questions that managers need answered are not the questions that scientists are interested in exploring, and questions of theoretical import to academia are not always applicable to practice. The workshop report noted, "Practitioners tend to require answers to questions that are narrowly focused. Did the planting succeed? Did the trees survive? Has the stewardship outreach program attracted enough participants? Researchers at universities are drawn to, and tend to be rewarded for, broad and synthetic questions. Answers to their research questions can require significant time and investment. Practitioners can often make decisions (and often must make decisions) with a minimum of information and on short timelines. It can often be reasonably clear when a management action is working or not. Intense and expensive sampling and experimental analysis can seem like a waste of resources" (MillionTreesNYC 2009, 10).

The smaller working group that organized this workshop worked together quite intensively, with meetings and calls on a biweekly to monthly basis. All members acknowledged that their participation was voluntary and outside the boundaries of their normal work tasks, but that the committee had value in helping to advance the field of urban forestry in New York City and beyond. The group curated a research symposium of invited speakers, submitted talks, and poster sessions at the New School in 2010 that was attended by more than 200 people. It led to a special issue of the online open access journal, *Cities and the Environment*, which included research articles and posters from the conference (Svendsen and Lu 2010). The symposium was a milestone in helping to create networks of researchers engaged in MillionTreesNYC and for acknowledging practitioners at NYC Parks as key knowledge producers, including through the creation of jointly authored papers by scientists and managers. At the national level, excitement over large-scale urban tree campaigns such as MillionTreeNYC led to a national call-to-action via the establishment of the Vibrant Cities & Urban Forests task force (Vibrant Cities and Urban Forests 2011). The group was initially convened by NYRP and was comprised prominent professionals from the fields of urban forestry, research, planning, design, policy, health, and education. Vibrant Cities has since been taken up by the Sustainable Urban Forests Coalition, a national alliance aiming to strengthen the urban forestry agenda (www.treesarethekey.org).

Following these two major gatherings, the subcommittee shifted away from its role as a research convener. On one hand, one could critique the subcommittee as 'losing steam,' but on the other hand, one could argue that it served its purpose for a distinct period of time. Instead, individual projects proceeded independently, with interconnections that were often facilitated by the subcommittee or the NYC UFS. For example, a group of university and US Forest Service scientists began National Science Foundation-funded research on changes in stewardship in NYC over 25 years (Connolly et al. 2013; Locke et al. 2014). Others conducted field ecology research on forest restoration initiatives (McPhearson

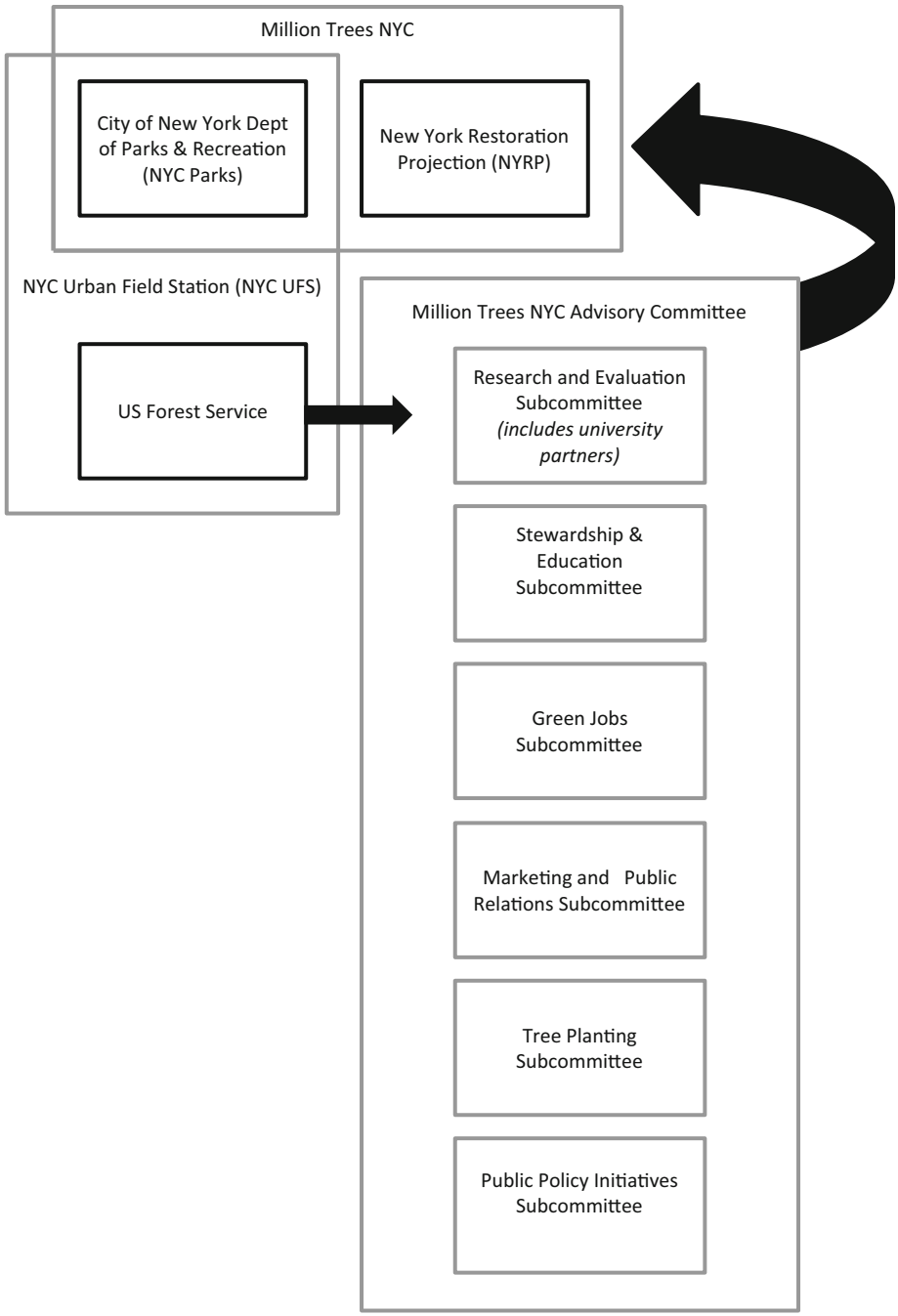

Fig. 2 Parties involved with MillionTreesNYC knowledge production

et al. 2010; Simmons 2010; Falxa-Raymond 2011). Still others examined community engagement, stewardship, volunteerism, and green jobs (Fisher et al. 2011; Moskell et al. 2010; Falxa-Raymond et al. 2013). An internal evaluation of the overall MillionTreesNYC program was taken up by an individual researcher from NYC Parks, with input from committee members. One researcher from the Forest Service examined the politics, discourses, and material practices of the MillionTreesNYC campaign as part of her doctoral dissertation work (Campbell 2013). Another team member published a book linking environmental stewardship and civic engagement based upon interviews with MillionTreesNYC volunteers (Fisher et al. 2015). The UFS reconvened for a final effort at synthesizing the integration of research and practice in the MillionTreesNYC campaign in the form of a print and electronic report that was co-published by the US Forest Service and NYC Parks (Campbell and Monaco 2014).

Looking beyond the timeline of the campaign, which officially ends in 2015, the everyday operations of NYC

Parks have been altered in several ways. First, afforestation research plots have been permanently sited in NYC Parks' natural areas, enabling long-term data collection to answer core questions about how to create and maintain a healthy urban forest (Oldfield et al. 2014). Second, stewardship practices evolved over the course of the campaign to include a more nuanced understanding of how to work with a diversity of volunteers and actively engage neighborhood groups. The campaign developed volunteer activities designed to attract a range of New Yorkers dependent upon their commitment level. Ultimately, this work led to the creation of a new position at NYC Parks. In 2014, a director of stewardship was hired to transfer innovative practices from the campaign to other programs within the department. These management changes were influenced by the knowledge co-production facilitated by the NYC UFS, as well as advocacy and critique led by non-research advisory committee members, and the organizational learning of NYC Parks.

This case reveals the way in which changes in policy and natural resource management create opportunities and openings for research; and vice versa, the way research can influence the practices and policies of natural resource management. First, research was leveraged during agenda setting and was instrumental to the creation of the campaign. Then, the networked structure of the campaign, which included researchers as advisors and the catalyzing presence of a hybrid organization with a core commitment to research-practice dialog (UFS), helped foster new fora for discussion and collaborative work. The voluntary advisory committee and subcommittee existed for a window of a few years, but the UFS has helped to sustain dialogs and networks into future projects. Finally, independent research of individuals with connections to the campaign will carry forth lessons learned into the peer-reviewed and gray literature in order to help inform other cities attempting similar policy goals or management approaches. And NYC Parks' natural resource management approach now has more avenues for engaged, applied, and embedded research.

Case 3: Urban Tree Growth and Longevity (UTGL) Working Group: Learning Together Through a Community of Practice

The mission of the international UTGL working group is to foster communication among researchers and professionals; enrich scientific exchange; and enhance the quality, productivity, and timeliness of research on tree growth, mortality, and longevity (Scharenbroch et al. 2014). Understanding how a multitude of factors interact to influence tree growth and mortality is fundamental to realizing the value of urban forests (Roman 2014, Koeser et al. 2014, Ko et al. 2015). UTGL is a voluntary working group under the Arboricultural Research and Education Academy (AREA), an affiliate of the International Society of Arboriculture (ISA). ISA provides training by awarding Continuing Education Unit credits, which arborists must take to maintain their professional credentials. Arborists earn those credits by attending ISA conferences, and other venues where most of the presenters are scientists.

The UTGL fundamentally reorganized this approach to engagement between scientists and arborists by bringing practitioners and researchers into a common space of dialog and problem-solving. The UTGL encourages broad and open participation by providing free membership, whereas ISA and AREA are dues-based organizations. UTGL is an unfunded, voluntary network that conducts occasional fundraising as needed to support symposia and field trips, and member researchers also pursue collaborative funding to seed particular research projects that emerge from the network. The fact that UTGL did not have any dedicated funding or policy mandate freed participants from power dynamics associated with such mandates. At the same time, the lack of dedicated funding also has presented a potential challenge for the group in advancing their collective ideas. UTGL membership (currently over 200) consists of scientists, urban forestry practitioners, and students. Members are spread throughout the United States, with some international members, mainly in Europe and Australia. The executive committee has been roughly three-quarters researcher and one-quarter practitioner throughout its existence. See Fig. 3 for a diagram of the key actors involved in UTGL.

UTGL was founded in July 2010 after the annual ISA Conference and Trade Show, as several presenters began holding informal conference calls around the topic of urban tree growth and longevity. From these conversations, a clear need to close the gap between research and practice emerged. The informal group of researchers then organized a symposium entitled "Urban Tree Growth" at The Morton Arboretum in Lisle, IL, in 2011. As an independent center for botanical collections, education, and research with a strong national recognition for arboriculture research and training, Morton was well positioned to host an event centered upon research-practice dialog. The attendees—arborists, other urban greening professionals, and students—participated in a facilitated discussion to articulate and prioritize research topics within the themes of tree growth and longevity (Leibowitz 2012). Attendees expressed a shared understanding that research alone was insufficient; there was a need for multi-sector, long-term collaboration around these themes. Several nascent ideas were raised in this setting that might not have materialized in a more controlled and hierarchical setting. For example,

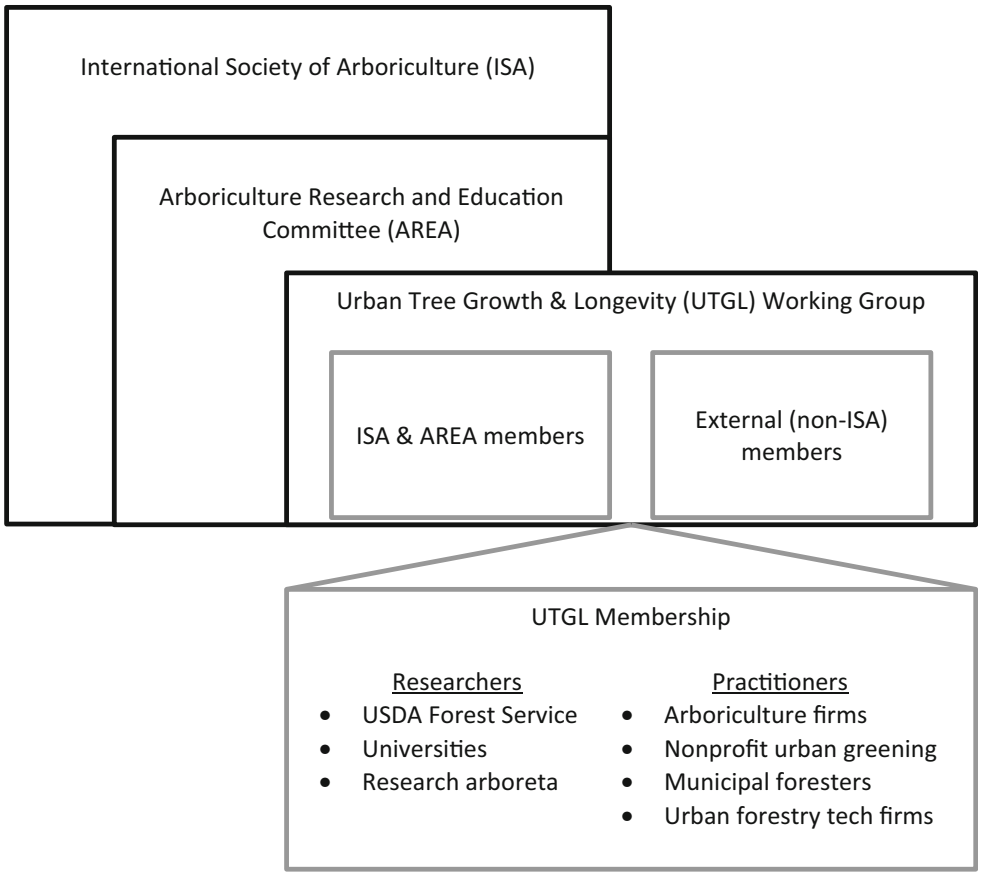

Fig. 3 Structure of UTGL within ISA, depicting the parties involved in the early years of UTGL (2010–2015)

researchers developed a rapid urban site index that was inspired by a practitioner-originated method presented at the 2011 symposium. The site index combined information about the built environment with quick evaluations of soil characteristics and can be used as both a planning tool for planting programs and an analytical tool for studies of tree growth and health (B. Scharenbroch, pers. comm.). The symposium also produced a special issue in *Arboriculture & Urban Forestry*, the peer-reviewed journal administered by ISA, and widely distributed to arborists (McPherson and Scharenbroch 2012; Leibowitz 2012).

The 2011 symposium generated a great deal of momentum for the working group and inspired a new joint endeavor: to establish tree monitoring protocols in response to the new urban tree planting initiatives proliferating around the globe. The symposium attendees recognized an opportunity to monitor the success of these initiatives and produce standard long-term data. Practitioners and researchers continued to work hand-in-hand to shape, guide, and review protocols. This process was fundamentally bottom-up: rather than beginning with researcher-defined project, protocol development reflected the needs and interests of local urban forest managers, beginning with a survey of existing practitioner-driven urban tree monitoring (Roman et al. 2013). UTGL leaders who were passionate about research-practice dialog were important in catalyzing the bottom-up approach. The first UTGL Executive Committee was comprised scientists who partnered extensively with arborists. For example, the first Executive Committee chair (E.G. McPherson) had a track-record as a trusted US Forest Service scientist with decades of experience collaborating with practitioners, and another early member of the Executive Committee was studying participatory approaches in graduate school and made the aforementioned practitioner survey (Roman et al. 2013) part of her dissertation. In addition, this email-based survey of practitioner methods was supported with direct one-on-one phone calls to introduce the UTGL and its goals while getting to know the participants and their needs, which helped to build rapport, buy-in, participation, and engagement. Thirty-two organizations (mostly urban forestry nonprofits and municipal urban forestry units) from across the United States responded. The researchers conducting this survey were pleasantly surprised to identify so many local monitoring programs, and most survey participants were identified through peer recommendations or snowball sampling.

Urban forest managers expressed interest in sharing and adapting protocols and contributing to larger research. The UTGL group made a commitment to be inclusive and to

involve practitioners in an atmosphere of open dialog. For example, the group heard that many protocols are too complicated and academic, creating barriers to use. As one nonprofit program manager remarked, the open approach was appreciated, "This is a great place to start. Update everyone as to your findings and get everyone together to talk about it" (quoted in Roman 2013). A group of over 30 UTGL members continued to work diligently for two years on drafting new monitoring protocols.

This collaborative process recognized the need to balance standardization with customization, leading to a protocol structure that is modular and customizable based on practitioner needs and resources, with a common core of variables necessary for any monitoring project. The first Executive Committee chair reflected on the protocol development process in the UTGL newsletter:

> …it was clear that the protocol needed to be flexible enough to meet diverse needs, but standardized so that data can be easily compared across time periods and project locations to evaluate tree performance. The protocol strives to find this "sweet-spot," but perhaps most importantly, it creates a platform from which researchers can work with practitioners, using science-based findings to improve tree production, site preparation, tree selection, planting techniques and stewardship practices…. The most gratifying aspect of this accomplishment has been the harmonious collaboration of a truly multidisciplinary team (McPherson 2013).

Standard protocols enable more meaningful comparisons of urban forest change across cities and programs, and better assessments of program performance. Existing inventory methods (e.g., i-Tree Eco and Streets) are not optimized for longitudinal data collection and analysis as they provide a single snapshot. Long-term monitoring requires advance planning for locational accuracy and repeated measurements across time with varied users. Monitoring detects change, such as observing mortality as a metric of planting program performance, assessing the balance between new planting and removals, and tracking trees and sites for targeted management. Additionally, some inventory systems are too complex for organizations that rely on minimally trained interns and volunteers. These practical and logistical concerns were all raised during the survey of existing local monitoring programs (Roman et al. 2014), and demonstrate the critical need for new systems to support management needs.

Currently, UTGL members are pilot testing protocols in several cities to evaluate error rates and consistency by field crews with different levels of expertise. These kinds of evaluations of volunteer accuracy have been conducted in other ecological monitoring programs with citizen scientists (e.g., Danielsen et al. 2011). The results of the pilot test are being used to improve the field guide, training materials, and data validation procedures. Partners implementing the pilot test include university and US Forest Service scientists as well as local urban greening nonprofits. This pilot directly responds to management needs identified in the 2011 symposium (Leibowitz 2012) and through the practitioner survey (Roman et al. 2013). By engaging practitioners—who are the intended end-users of these new protocols—throughout the process of methods development and pilot testing, a sense of buy-in is created, which will be essential for successful implementation of the protocol across diverse users.

Other ongoing UTGL activities promote continued dialog among members and recognize the expertise and contributions from diverse membership to knowledge production in urban forestry. UTGL promotes information sharing and encourages collaborations through symposia and free field trips at annual ISA conferences, an emailed newsletter highlighting research and professional projects, a LinkedIn group, and a website (www.urbantreegrowth.com). The unique nature of the group is its sustained, reciprocal dialog among researchers and practitioners. Indeed, urban foresters have long acknowledged the value of such conversations, recognizing the strengths that researchers, arborists, and nonprofits bring to partnerships (Shigo 1976, Dwyer 1987).

This case illustrates how genuine co-learning and knowledge co-production require breaking the paradigm of researchers as experts delivering scientific findings (McKinley et al. 2013, Israel et al. 1998). Engaging practitioners as full participants in the research process also involves power-sharing and continued dedication to communication. The outcomes of this still-young working group have been new and deepened connections between researchers and practitioners who share common interests in a specific subject matter. Scientific projects (e.g., urban site index and tree monitoring standards) were inspired by ideas shared and needs identified by practitioners. Yet engagement did not end with the initial generation of research priorities; as suggested by Israel et al. (1998), engagement continued throughout all steps of the research process. The UTGL has created a dynamic community of practice whereby managers and scientists exchange ideas, solicit feedback on projects in development, and jointly endeavor to produce new research. The collaborative approach to the development of tree monitoring protocols was driven by researchers with a commitment to co-learning with practitioners working in a creative, non-hierarchical space without dedicated funding or policy mandate. Because the UTGL works without dedicated funding, implementation of these protocols may eventually require building top-down support in addition to the bottom-up engagement.

Discussion

This paper presents three case studies of knowledge co-production operating at different scales, via different structures, and encompassing different scopes. As discussed, much of the literature on community-based natural resource management and adaptive co-management focuses on rural, indigenous, or resource-dependent contexts in the global south. However, we find that knowledge co-production for natural resource management exists in urban settings as well, including large metropolitan centers, regional areas, and international networks of cities in the global north. Moreover, co-production can be facilitated by a single researcher working on a narrow topic (as in Sacramento) or via dozens of members of a research-practice network spanning multiple issue areas (as in MillionTreesNYC). We identified three different institutional arrangements supporting knowledge co-production based on the empirical evidence presented here. The Sacramento project follows the principles and practices of *participatory research*. MillionTreesNYC research is facilitated by the *hybrid organization* of the Urban Field Station that focused on long-term arrangements, informing management, and facilitating networks. Finally, the UTGL operates as an international *community of practice* of scientists and managers. In these cases, we find a high degree of variation in the geographic scale, institutional structures, and scope of problems being addressed through working at the research-practice interface. Moreover, capacity and availability of resources alone does not explain the engagement in knowledge co-production, as we see the example of a $400 million public mandate for tree planting in New York City as compared to a utility-sponsored shade tree program with under $10 thousand in student support in Sacramento, and an unfunded, voluntary network working in UTGL. In all three, the complex institutional and physical terrain of urban systems—involving multiple actors, property jurisdictions, and land uses—seems to invite or necessitate collaboration in order to affect change.

Despite clear differences in the scale, scope and complexity of each case, we find several common themes that can serve as guiding principles in knowledge co-production between scientists and natural resource managers (see also Reed et al. 2014). One of our key findings is that trust and embeddedness are crucial to allowing new forms of deep collaboration to emerge and be sustained over time. As well, in each case, we locate new approaches by managers as well as new approaches by researchers, with each partner stretching beyond conventional approaches of their respective fields. Finally, through the blending of roles of researcher-practitioner, we find that the process of knowledge co-production is advancing both the science and the practice of urban forestry. We review each of these principles in turn, as illustrated by the case studies explored here.

Trust and embeddedness are two key attributes necessary to cultivating knowledge co-production. In qualitative social science methods, trust is often discussed in terms of building rapport with gatekeepers, research subjects, and interlocutors. Building rapport is known to enhance the rigor, reliability, and validity of qualitative social science (Dunn 2005; Bradshaw and Stratford 2005). However, the importance of trust is not limited to social science alone—it is also crucial to biophysical scientists and ecologists as they seek to develop research programs grounded in practice (Brown 2003; Vermeulen and Shiel 2007). Trust and common understanding can be built through a range of strategies, including shared ties and personal relationships, open communication, and sustained time spent in the field with participants. In the urban forestry cases presented here, strategies included building upon pre-existing personal and professional relationships, going on ride-alongs with foresters, chairing advisory group meetings, and creating meetings and field trips with opportunities for open discussion and structured feedback mechanisms—rather than traditional lectures. In all three cases, specific trusted individuals helped to span the research-practice divide: in Sacramento, Roman was committed to the participatory approach and studying such methods in graduate school, while STF was similarly committed to getting the research done; in New York City, Svendsen had previously worked as a practitioner in NYC Parks before becoming a Forest Service scientist; and in the UTGL, McPherson's existing reputation and relationships helped foster the young network. We find that embeddedness and trust work in a feedback loop: being embedded in everyday routines cultivates trust, while a certain degree of trust is necessary to be allowed into the planning process. We also found that embeddedness has a temporal dimension. Knowledge co-production necessitates sustained, ongoing engagement of practitioners and researchers, rather than a one-time or short-lived consultation period that can occur in more conventional approaches to research. Although it went well beyond consultation or advisement, the participatory research described in case 1 was tied to an individual researcher's particular study and, as such, the participatory techniques employed for that project did not persist after she completed this work, although the relationships built through that study carried over to inform new projects with the nonprofit partner. In contrast, hybrid organizations (case 2) and communities of practice (case 3) provide an opportunity for ongoing dialog and collaboration. However, we note that these arrangements require ongoing attention and care in order to ensure their persistence and

relevancy, as they are often less formally institutionalized than existing hierarchies or organizational structures.

New approaches by managers are required to enable knowledge co-production. First and foremost, in each case, there was a willingness to allow researchers to enter the managerial terrain that built upon the trust in researchers and embeddedness described in each case narrative. Generally, managers have formal mandates and informal routines that guide their actions; allowing researchers to question, shape, or inform management approaches requires a willingness to take time out of the day-to-day work. Thus, it requires a certain staff capacity to move beyond reactive response toward proactive planning and research design, and it requires patience to work with researchers, who often operate at slower pace than the customary management timeline. We also find that the managers in all three cases were driven by curiosity and creativity as they sought new approaches and solutions to old challenge that in some cases entirely reworked existing modes of operation. This engagement with research means that managers asked questions in new ways so that they both (1) are answerable with scientific studies and (2) have potential to change management practices. An example of (1), the Sacramento case shows managers at STF expanding the scale and scope of their monitoring and research so that it would be statistically valid, generalizable, and replicable. For an example of (2), in the MillionTreesNYC case, managers encouraged research that could transform management approaches—including the biophysical 'designed experiments' and monitoring of afforestation practices as well as the social research on volunteer stewards at tree planting events.

In order for collaborations to evolve into knowledge co-production, managers must be aware of the institutional structures and professional needs of researchers, such as timelines of grant funding and the requirement to publish. At the same time, researchers must be aware and take on the political pressures and day-to-day realities of practitioners and decision-makers. This type of shared understanding can be built through iterative processes of knowledge production among different types of knowledge producers, including scientists, land managers, and policymakers (Dilling and Lemos 2011). That said, building these collaborative ties and new ways of working takes time away from practitioners pursuing their core mandate of natural resource management, and must be understood as adding value over time.

New approaches by researchers are similarly required to work at the science-practice interface and in order to influence policy and practice in lasting ways. Scientists must work beyond the realm of "science delivery," "technology transfer," or even "applied research," wherein scholars transmit and translate research findings to managers (McKinley et al. 2013). Instead, researchers must build in interactions long before the findings-dissemination stage in the pursuit of "actionable science" (Palmer 2012). For example, the Sacramento case began with a "problem-oriented approach" (McNie 2007; Menand 1997). It then employed PAR methodologies, such as nominal group technique (Van de Ven & Delbecq 1974, Totikidis 2010) to build consensus and prioritize research objectives. As well, the UTGL working group began with a survey of practitioners to understand already-existing approaches to urban tree monitoring, thereby building new protocols directly informed by current management-defined objectives and techniques. In addition to early and ongoing communication and co-development of research goals, questions, and methods, researchers can produce insights or preliminary findings throughout all phases of the project. Often, preliminary findings include the creation of shared databases, white papers, reports, informal presentations, and briefing meetings, which are the sorts of outputs that can be put directly to use by managers. The MillionTreesNYC advisory committee produced numerous white papers throughout its life, the Sacramento study led to several student-led reports to inform management in real time, and the UTGL updates members on progress with the new monitoring standards and urban site index via newsletters and webinars; these deliverables complimented the peer-reviewed publications, which are the more conventional measure of research output for scientists. It is important to acknowledge, however, that non-peer-reviewed outputs are less valued within academia. Furthermore, these products must be developed in such a way that they do not jeopardize the ability for scientists to publish their novel research. In a process that differs somewhat from academic tenure review, US Forest Service scientists are evaluated and promoted on both scientific accomplishment and public impact, thereby encouraging both basic and applied research (McKinley et al. 2013), although participatory approaches go beyond this "science delivery" paradigm.

Knowledge co-production occurs when we see the above-described blending of roles between researcher and manager. As a result, we observe a reworking of previously held notions of expertise.[1] This requires an acknowledgement of multiple capabilities and multiple ways of knowing, recognizing what each partner brings to the collaboration. In each case, we see examples where managers are behaving as producers of knowledge, not just consumers. For example, in the MillionTreesNYC case, employees from NYC Parks helped organize and co-host

[1] There is a broad literature on the politics of expertise and the varied roles of scientific experts, policymakers, managers, and the public in generating and using knowledge (see, e.g., Jasanoff 1987; Fischer 2000; Collins and Evans 2002).

the research symposium and co-authored peer-reviewed articles about urban ecology and green infrastructure. Similarly, in the UTGL case, urban forestry practitioners helped drive the development of variables that should be included in the urban site index and the protocols for monitoring urban tree growth and survival, and participated in pilot testing those methods. In the Sacramento case, nonprofit staff articulated research questions, debated sampling schemes, and helped to develop and interpret statistical analyses. Concurrently, we see that researchers are treated as part of the "community" and members of the management system in adaptive co-management (Berkes 2009). In all three cases, we observe these blended networks of researchers and practitioners exchanging ideas and resources. As a result, this networked approach serves dual roles of both advancing knowledge and improving resource management. This occurs through a feedback loop where science informs practice and practice informs science. This feedback loop aligns with changing understanding about the nature of knowledge, "…from 'knowledge as a thing" (which can be given and received) toward 'knowledge as a process' (which evolves over time and is context-specific)" (Reed et al. 2014, p. 342).

Conclusion

Embedded approaches to knowledge co-production can create impacts that go beyond the research arena, occurring over space, throughout time, and crossing scales. Building upon scholarship on participatory research and co-management, in this paper, we found that knowledge co-production in urban forestry can enhance the reach, rigor, and relevance of research, as previously suggested by Balazs and Morello-Forsch (2013). This approach was able to shape natural resource management by providing managers with a new set of science-based tools to measure and reflect the meaning of their work to a larger group of stakeholders. As well, wholly new program areas can be inspired by the feedback loop within knowledge co-production, such as new stewardship programs.

From this work, we learn that urban forestry knowledge generation across space and over time occurs through hybrid organizations and communities of practice that are not exclusively place based, but rather are nested in knowledge networks driven by common questions and concerns. By sharing methodologies and management approaches, researcher-practitioner networks help us move beyond locality-specific approaches to embrace diverse perspectives on a shared problem. For science, this allows for larger-scale comparative research across sites and novel approaches to problem-solving. By cultivating cross-sector partnerships with a shared vision and mandate, hybrid organizations allow for longer-term collaborations that can last well beyond a particular set of political leaders, campaigns, or funding cycles. While political turnover is inevitable in municipal leadership, institutions that foster partnerships between researchers, civil society actors, the private sector, and 'street level bureaucrats' (Lipsky 2010)—public sector natural resource managers who do not change with administrations—create platforms for long-term research and the type of learning that builds upon the past challenges and achievements.

New institutional forms can actively foster knowledge co-production at the research-practice interface, as organizations and actors from different scales and sectors come together in novel ways. These hybrid arrangements can take organizational forms (collaborations, partnerships and bridging organizations) or network forms (knowledge-action networks, knowledge systems and communities of practice). For example, the growing network of Urban Field Stations that has emerged via partnerships between the US Forest Service, municipalities, and nonprofits are examples of hybrid spaces with a public mission. Going forward, there is a need for building science-praxis entities that are designed to draw upon expertise across all sectors. It may be useful to think about these arrangements as hybrid organizations that are place based, but nested in polycentric networks where partners are engaging across local, regional, national, and international scales.

Finally, we must acknowledge who is strikingly absent from the accounts presented here. These collaborative efforts are all led primarily by professionalized nonprofit and municipal managers working with academic and federal researchers. We note that the composition of these groups is generally more highly educated and often, like the current field of urban forestry (Kuhns et al. 2002), over-representative of whites as compared to the populations of the cities in which they are working. As such, the examples of knowledge co-production explored in our case studies may be missing important, diverse perspectives on the urban forest, including different values, beliefs, and knowledges about the resource and how it should be managed. Furthermore, although the urban forestry programs were created in the public interest, with engagement opportunities ranging from tree giveaways to stewardship events, knowledge co-production in our cases has not fully included the residents whom are being served. In many urban forestry and cooperative extension programs, the public is viewed as the client, customer, or recipient of messages and services. As well, they can be viewed as a labor force that engages in stewardship and maintenance activities that help to enhance the health of the urban forest (Campbell 2014). Where the public is engaged as constituents, it is usually through formal processes of consultation, such as structured community meetings (Arnstein

1969; Sipilä and Tyrväinen 2005). What remains an evolving frontier in urban forestry practice is to embrace the ethos of community forestry that first emerged in the global south and rural context of community-based natural resource management, where residents are more substantially engaged in power-sharing and agenda setting. In the US, the ethos of public involvement is well-established with approaches of community-based participatory research in public health (Minkler and Wallerstein 2008) and participatory city planning (Forester 1999); both of these operate in the same landscapes where urban forestry operates.

For researchers, adopting a community forestry ethos means working with the public as knowledge producers through civic science approaches or public participation in scientific research (see e.g., Corburn 2005; Bonney et al. 2009; Shirk et al. 2012; Silva and Krasny 2014).[2] Going forward, there is a clear opportunity for broad-based, digital platforms that enables the involvement of residents as co-creators of knowledge about the urban forest and helps build long-term datasets to enable scientific research. As Muñoz-Erickson et al. (2014) point out, empowering and engaging local residents, in addition to scientists and managers, are crucial to creating robust knowledge-action networks that can help shape cities that are inclusive and resilient. As evidenced from these three cases, knowledge co-production is strengthened through purposeful partnerships that foster critical dialogs, create trust among members, and remain open to new ideas. In the field of urban forestry, there is more room for partnership and inclusion and, perhaps, no end to what we can learn.

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