Linking science and decision making to promote an ecology *for* the city: practices and opportunities

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Abstract. To promote urban sustainability and resilience, there is an increasing demand for actionable science that links science and decision making based on social–ecological knowledge. Approaches, frameworks, and practices for such actionable science are needed and have only begun to emerge. We propose that approaches based on the co-design and co-production of knowledge can play an essential role to meet this demand. Although the antecedents for approaches to the co-design and co-production of knowledge are decades old, the integration of science and practice to advance urban sustainability and resilience that we present is different in several ways. These differences include the disciplines needed, diversity and number of actors involved, and the technological infrastructures that facilitate local-to-global connections. In this article, we discuss how the new requirements and possibilities for co-design, co-production, and practical use of social–ecological research can be used as *an ecology for the city* to promote urban sustainability and resilience. While new technologies are part of the solution, traditional approaches also remain important. Using our urban experiences with long-term, place-based research from several U.S. Long-Term Ecological Research sites and U.S. Department of Agriculture, Forest Service Urban Field Stations, we describe a dynamic framework for linking research with decisions. We posit that this framework, coupled with a user-defined, theory-based approach to science, is instrumental to advance both practice and science. Ultimately, cities are ideal places for integrating basic science and decision making, facilitating flows of information through networks, and developing sustainable and resilient solutions and futures.

Key words: *Baltimore; co-design; co-production; ecology* for *cities; long-term ecological research; New York City; Phoenix; San Juan; social–ecological; Special Feature: An Ecology in, of, and for the City; transdisciplinary; urban.*

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Introduction

There is a growing focus on how urban ecology can enhance processes of urban sustainability and states of urban resilience (Pickett et al. 2013, Childers et al. 2014, Tanner et al. 2014). Childers et al. (2015) draw particular attention to the concept of an ecology *for* cities as a transformational nexus to promote urban sustainability and resilience. An ecology *for* cities may be understood as a progression in urban ecology over the past 20 years from an ecology *in* cities, to an ecology *of* cities, to an ecology *for* cities. An ecology *in* cities generally refers to research in specific locations of cities that are analogs to the kinds of rural places where ecologists have usually worked: parks as analogs of rural forests and vacant lots as analogs of fields or prairies. Urban streams and remnant wetlands have been studied with similar scope and methods to those conducted in non-urban landscapes. An ecology *of* cities emerged in the mid-1990s. It is inclusive of and complementary to an ecology *in* cities. However, the ambition and agenda is significantly broader, with a shift in attention to the diverse mosaics of land uses and management of urban regions; integration of physical, biological, and social phenomena; incorporation of spatial, organizational, and temporal complexity; and to viewing urban ecosystems through a holistic social–ecological lens (Pickett et al. 1997, Grimm et al. 2000, Grove et al. 2015*b*).

The "transformational nexus" of an ecology *for* cities builds upon these earlier phases, combining urban ecology, sustainability, and resilience as an inclusive domain and novel frontier for decision making to promote the

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welfare of urban regions. It is an inclusive domain because sustainability and resiliency goals include social (people), economic (prosperity), environmental (place), and equity (justice) dimensions (Pickett et al. 2013). It is a novel frontier for decision making because it requires the incorporation and integration of diverse knowledge in the forms of data, experts, analyses, practices, and standards (Tanner et al. 2014, Grove et al. 2015*a*, Campbell et al. 2016). While there are relatively well-established standards for urban planning and for the administration of land use, zoning, buildings, and land management, only recently have guidelines begun to emerge for establishing and achieving sustainability and resiliency goals. Importantly, many of these goals are associated with high levels of complexity and uncertainty and with threats associated with air and water quality and sanitation that may be chronic or catastrophic. Such threats include floods, droughts, fires, heat waves, and hurricanes (Childers et al. 2015). Critical features to this transformational nexus are the need for place-based, actionable science that includes data, knowledge, and tools (Palmer et al. 2016) as well as the infrastructures and practices to facilitate its use. Ideally, the practices and solutions from place-based science and decision making from one location may be broadly relevant to other locations (Grove 2014, Palmer et al. 2016).

While the need for actionable science based on social–ecological knowledge to advance an ecology *for* cities has been recognized, there remains a great need for specific approaches, frameworks, and practices for such actionable science (Childers et al. 2015, Grove et al. 2015*a*). We propose that approaches based on the co-design and co-production of knowledge can play an essential role to meet this need. The role of co-design and co-production of knowledge has been of newfound interest (Craglia et al. 2012, Cornell et al. 2013, Mauser et al. 2013). However, the antecedents for this philosophy and approach have a long history. Multiple uses for the term "co-production" have evolved from an analytical lens with a long lineage in the fields of history of science and science and technology studies, to a more instrumental goal of linking science and policy through collaborative knowledge production approaches (Muñoz-Erickson 2014, Wyborn 2015). The analytical focus on the co-production of knowledge and society as described by Jasanoff (2004, 2010) refers to the macro-societal interplay between science and governance across a range of socio-political scales and their embeddedness within social, cultural, and political norms. In other words, how science shapes and is shaped by society. The second use of co-production, and the focus of this article, refers to the programmatic process of collaborative knowledge production among diverse science, practice, and policy actors to design and generate knowledge relevant to policy and practice (Van Kerkhoff and Lebel 2006, Vogel et al. 2007, Armitage et al. 2011). Antecedents of this latter approach can be found, for instance, in participatory action research projects ranging from agriculture and forestry to industrial production (Cernea 1991, Whyte 1991).

The integration of science and practice to advance urban sustainability and resilience is different from these earlier antecedents of participatory action research in several ways. The potential number of science disciplines required is much larger. The diversity and number of potential actors from government, business, and civil society sectors is greater. The technological and institutional infrastructures that facilitate co-design, co-production, and practical use of social–ecological knowledge have radically changed with the advent of and increasing access to diverse digital data, the Internet, and its associated technologies. The social relationships connecting distant sectors and actors in the current era of globalization are ever more complex and dynamic. Finally, the need to address sustainability and resilience involves numerous scales—from household to global—and may be one of the defining issues for this century.

Some things have not changed since the emergence of participatory action research approaches some 4 decades ago. For the most part, and we stress here *for the most part*, current science is still organized in a somewhat closed system that is siloed by discipline, guided by self-regulated and autonomously set research agendas, and substantially detached from society, politics, and the media (Cornell et al. 2013). Formidable barriers exist to linking disciplines and practicing interdisciplinary and transdisciplinary research among the physical, biological, and social sciences, and the humanities (Palmer et al. 2016). Often, science is practiced as though scientists are the active producers of knowledge and society is the passive recipient (Mauser et al. 2013). Applied or user-engaged research is frequently perceived by scientists and academia to be of lower value and status than basic or theoretical research (Cornell et al. 2013, Pahl-Wostl et al. 2013). Other non-scientific, yet also credible and legitimate, forms of expertise informing societal decision making are not recognized (Chilvers 2007, Hegger et al. 2012). Thus, to a large extent, and more often than not, old knowledge systems and cultures are still deployed to address new and emerging social and environmental challenges to resilience and sustainability (Cornell et al. 2013). In the next section, we will discuss emerging approaches that move beyond the limitations of this linear, unidirectional approach by addressing the types of science to be produced; the linkages between scientists and decision makers; and the transformational interactions among scientists and decision makers.

Types of Science for Co-design and Co-production: Pasteur's Quadrant

A fundamental question for the co-design and co-production of urban ecological knowledge is to first

Quest for fundamental understanding?		Considerations of use? No	Considerations of use? Yes
	Yes	Pure basic research (Physicist Bohr)	Use-inspired basic research (Biologist Pasteur)
	No	--	Pure applied research (Inventor Edison)

Fig. 1. Stokes categorizes three different types of research. Most research associated with our place-based, social–ecological research in the Long Term Ecological Research and U.S. Forest Service networks is located in Pasteur's quadrant: use-inspired basic research (adapted from Stokes 1997). Although Stokes does not discuss the fourth quadrant, cases where there is no initial consideration of fundamental understanding or of use, there are examples from this quadrant of accidental discoveries that later contribute to fundamental understanding and have great benefit to society. One might call this Fleming's quadrant, for the scientist Alexander Fleming and his accidental discovery and later development of penicillin.

ask, what kinds of science are to be produced? The traditional perspective is to think of science as either basic or applied. Given the potential for dynamic connections between scientists and decision makers, we suggest that this is a false dichotomy that is revealed in Stokes' (1997) analyses and what he calls "Pasteur's quadrant" (Fig. 1). The traditional perspective is associated with two of Stokes' quadrants: "pure applied" research and "pure basic" research. Stokes defines "pure applied" research as science performed to solve a social problem without regard for advancing fundamental theory or scientific knowledge. Stokes labeled this "Edison's quadrant" after the inventor Thomas Edison, who was more concerned with practical scientific questions than with the underlying theoretical implications of his discoveries and inventions. In this quadrant, urban ecologists might work to develop solutions to specific problems such as methods and tools for prioritizing where to plant trees to optimize sustainability goals (Locke et al. 2013). Stokes defines the other traditional quadrant, "pure basic" research, as where science is performed without concern for practical ends. This quadrant is labeled "Bohr's quadrant" after the physicist Niels Bohr's "pure" scientific pursuit of a structural understanding of the atom. In this quadrant, scientists work to understand physical, biological, and social theories and laws that advance our fundamental understanding of the world. In urban ecology, for instance, scientists might seek to understand the relationships between urbanization and biodiversity in terms of three different types of biodiversity: species, phylogenetic, or functional diversity (Johnson and Swan 2014, Pickett et al. 2016). Stokes proposes that there is an alternative quadrant, which he calls, "use-inspired, basic research," as science designed to enhance fundamental knowledge while also addressing a practical concern. This quadrant is labeled "Pasteur's quadrant" after biologist Louis Pasteur, whose work on immunology and vaccination advanced both our fundamental understanding of biology and saved countless lives. In this quadrant, urban ecologists work with decision makers (users) to solve practical problems while advancing scientific theories and methods. For example, scientists and practitioners might work together to ask how ecosystem services, social networks, and collaborative governance interact over the long term to affect urban resilience and sustainability (Campbell et al. 2016, Metcalf et al. 2016)? While some of our long-term, place-based work can be located in each of these three quadrants, a significant proportion of our research resides in Pasteur's quadrant.

Pasteur's quadrant is important to signaling the possibility of and interest in advancing both science and practice. However, our experience suggests that this box is also filled with questions: Which types of linkages among scientists and decision makers might be most effective for promoting "use-inspired, basic research" over the long term; does "basic" research include multi-, inter-, and transdisciplinary research; and who is a "user"? In the next section, we discuss linkages among scientists and decision makers.

Conventional Conceptualizations of the Linkages between Scientists and Decision Makers

There are a number of different ways that scientists and decision makers might interact. We propose a generic caricature of these interactions (Fig. 2), while recognizing

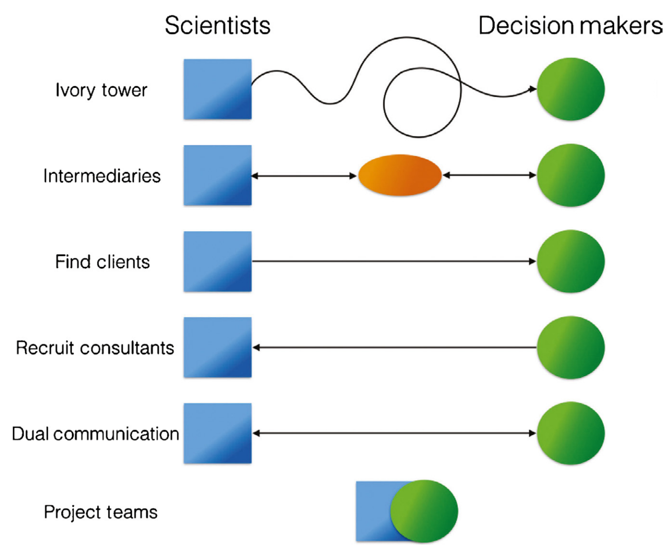

Fig. 2. Six generic types of interactions among scientists and decision makers. An ecology *for* cities will most often involve *Project Teams.* We adopt a broad and inclusive definition of decision makers including public agencies, non-profit organizations, community associations, businesses, and individual landowners.

that these simplistic, linear notions obscure the more dynamic and murky relationships that take place among researchers and practitioners, often in complex forms of connectivity and ways of communication (Vogel et al. 2007). The most traditional approach is what we call the *Ivory Tower* model, where decision makers are passive recipients of knowledge. The *Intermediaries* type includes situations where scientists and decision makers do not directly interact. Instead, a third party might communicate decision makers' needs or repackage science products in forms that decision makers can use. These people are often called science communicators. Scientists might produce data or information and then try to find decision makers who might need the information. We call this the *Find Clients* type. The reverse situation is what we label *Recruit Consultants,* when decision makers search out scientists who might be able to address their needs. *Dual communication* is when scientists and decision makers may exchange information about science products or decision maker needs, but they do not directly work together on a common problem. The final type is what we call *Project Teams*, which involves scientists and decision makers working together on a common problem with one or all of the following behaviors: identifying and framing questions; collecting and analyzing data; interpreting results; disseminating and applying findings; or identifying new questions.

We recognize the possibility that each of these types of science—decision making linkages—might produce user-defined, basic research. However, we propose that Project Teams have the greatest potential to be productive in Pasteur's quadrant and generate actionable science because of its use of co-design and co-production of knowledge. Project teams are more likely to build greater trust, which can lead to better access to new and existing data and diverse knowledge. The close interactions among team members can create greater efficiencies in conducting and analyzing research as well as developing shared products and outcomes. Teams can inspire greater investments in the project through shared intellectual ownership as well as foster innovation through diverse peer-to-peer networks. We suggest that project teams may also be more likely to generate results in what we have called Fleming's quadrant, cases where there was no initial consideration of fundamental understanding or of use, but teams may have accidental discoveries or insights that later contribute to basic knowledge and have great benefit to society. This is because the familiarity of the project team with diverse knowledges and decision needs may predispose them to make the leap from accidents to fundamental understanding and applications.

While Project Teams may have the greatest chance for success, other questions remain. In the next section, we take up the question of how Project Teams might function and the potential for transformation of both science and decision making over the long term.

A Dynamic Framework for Co-design and Co-production: Project Teams

Our experience with long-term, place-based research is that there are a number of different ways that Project Teams might be formed. In Baltimore, for instance, the U.S. Forest Service's Revitalizing Baltimore (RB) initiative in the mid-1990s included a Technical Committee of federal, state, and local scientists and mangers who were responsible for working with local partner agencies, NGOs, and community groups to address knowledge and data needs and develop a shared geographic information system (Pickett et al. 2007). The scientists who participated in the Technical Committee came from a diverse set of biophysical, social, and economic disciplines because the RB initiative sought to integrate community redevelopment with environmental rehabilitation. The RB Technical Committee would subsequently contribute key staff, knowledge, and data to the initial Long Term Ecological Research (LTER) proposal to fund the Baltimore Ecosystem Study.

In the case of the Florida Coastal Everglades (FCE) LTER, academic scientists at Florida International University in Miami, and others at other universities, began the process of writing the original FCE LTER proposal to the National Science Foundation in 1998-1999. From the beginning of this process, scientists from the South Florida Water Management District and Everglades National Park were "at the table" to help formulate the research questions and to help decide on experimental and sampling designs. This is important because these agency scientists were, and are, in direct contact with water and resource managers. Thus, they represent a direct conduit of the knowledge generated by the FCE LTER program to decision makers. This mix of academic and agency scientists, which continues to this day, was not motivated by deliberate intent to co-produce a proposal and an LTER program. In fact, none of the scientists involved even explicitly knew of the concept of co-design and co-production in 1998. Rather, the motivation for what clearly was, and continues to be, the co-production of knowledge about the Everglades came from a long history of collegial collaborations among the group. Having these agency scientists as part of the FCE LTER Project Team (sensu Fig. 2) for the last two decades has assured that research knowledge reaches water and resource managers in near real time because these decision makers rely upon their agency scientists first and, often exclusively, for knowledge to inform their decisions. This model is effectively the same as having the managers and decision makers themselves on the Project Team.

Once project teams are formed, our experiences with long-term, place-based research suggest that they follow a dynamic cycle of co-design and co-production (Fig. 3). This generic illustration begins with the formation of the Project Team with representatives from one or several ecological, social, behavioral, or economic sciences and from managers or policy makers to address a management concern (the left side of Fig. 3). A management or

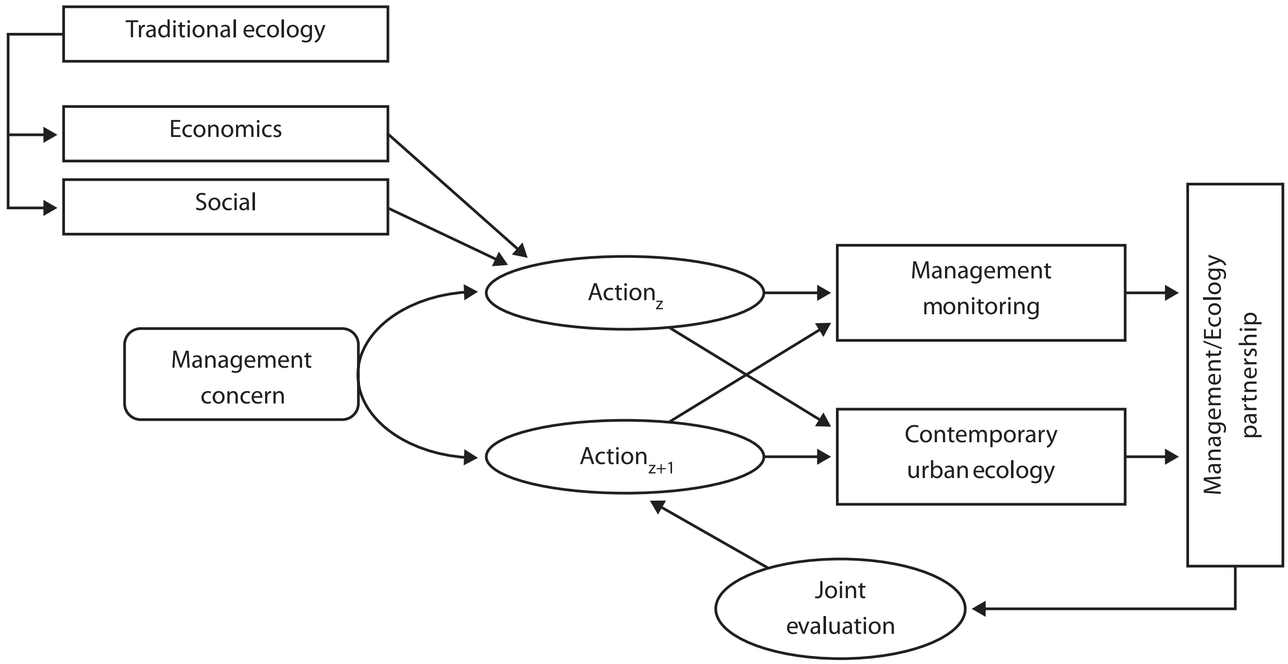

Fig. 3. Dynamic feedbacks between decision making and science (adapted from Pickett et al. 2007). At the end of the first cycle of the dynamic feedbacks between decision making and science, there is a shift from Traditional Ecology, Economics, and Social Sciences to Contemporary Urban Ecology. The partnership between Management and Contemporary Urban Ecology has input into subsequent actions.

policy action (Action$_1$) results from this research-policy co-production. Following the management or policy action, monitoring of the action–outcome is used to evaluate whether the desired result was achieved. At the same time, new knowledge is produced, resulting in a revised and contemporary understanding of the system. Through the joint evaluation of the action and contemporary new knowledge, additional actions might be suggested or required (Action$_{1+x}$), leading to a new cycle of co-design, co-production, and assessment.

Several findings have arisen from our experiences with this generic co-design/co-production framework. Because of the long-term nature of our projects, we have found that this framework is both dynamic and cumulative in terms of both science and decision making. Action$_1$ leads to Action$_2$ and Action$_2$ to Action$_3$, and so on. With each iteration, there is joint learning and new questions for science and decision making (Grove et al. 2015*b*).

For scientists, this dynamic and cumulative process has the potential to transform their work in terms of disciplinary, interdisciplinary, or transdisciplinary knowledge as well as how their science is practiced. This process of transformation and production of transdisciplinary knowledge occurs through "collaboration in which exchanging information, altering discipline-specific approaches, sharing resources, and integrating disciplines achieves a common scientific goal." (Rosenfield 1992). For decision makers, this process also has the potential to transform their practices by increasing the knowledges, information, and data used.

Applying the Framework: Actions, Outcomes, and the Importance of Networks

We have been careful so far to not define who is a user, decision maker, or practitioner in this article. It is an important question, however, because it informs what is "user-defined, basic research" and who is involved in co-design and co-production. On the one hand, we take the inclusive view that "users" and "decision makers" include government agencies, NGOs, community groups, businesses, and individual landowners. On the other hand, we recognize that all these types of actors function in networks and not in isolation. Indeed, urban environmental stewardship has become an increasingly complex process of managing, conserving, monitoring, advocating, and educating the public across a multiscalar geography requiring integrated knowledge and intense coordination among an array of diverse social actors. Further, civic stewardship organizations are becoming more professionalized and embedded in organizational networks as they engage in long-term management of public, private, and community lands and develop strategic relationships with government agencies and private corporations (e.g., Svendsen and Campbell 2008, Fisher et al. 2012).

This inclusive and networked perspective of "users" and "decision makers" is important in several ways. It directs our attention to understand and reflect upon the network flows of information in our locations; to consider other forms of knowledge in our locations; and to evaluate the existing and potential roles that our science institutions can play in our locations. These concerns highlight the crucial importance of "network awareness" so that our science institutions can be as effective, efficient, and equitable as possible for the co-design and co-production of actionable science. In essence, we need to "know where to hit it," which is illustrated by Thompson and Warburton (1985), who recount the story of the motorist,

> "who, having tried everything he can to get his car to start, finally pushes it round the corner to the garage. The mechanic lifts up the bonnet, looks at the engine for a while and then, selecting a large hammer from his tool tray, gives it a hefty clout. "Try it now," he says to the owner, and it starts the first time. "How much do I owe you?" asks the delighted owner. "Ten pounds," says the mechanic. "Ten pounds," says the owner, his face dropping, "ten pounds for just hitting it with a hammer?" "Oh no," says the mechanic, "fifty pence for hitting it with the hammer, nine pounds fifty for knowing where to hit it." (p. 218)

The importance of "knowing where to hit it" through our network awareness has become an important feature of our ability to co-design and co-produce knowledge. Our "network awareness" in New York City, Baltimore, and San Juan includes assessments, mapping, and monitoring of actors in terms of who they work with, where they work, and how they organize their activities (Fig. 4). This enables us to examine the population and diversity of network actors, the connections among actors, which actors are central nodes versus those that are marginally connected, and potential barriers to the flow of information or uptake of new information (Svendsen et al. 2016). The nodes in these networks serve a critical role in environmental governance as meso-scale brokers of resources including information, ideas materials, energy, and funding (Connolly et al. 2013). At the same time, organizations located at the periphery of the network may be vulnerable, nascent, and/or critical innovators of design and application. There is much to be learned about the key functions and behaviors of both nodal and peripheral actors of urban stewardship networks and how they can contribute to the co-design and co-production of actionable science.

Working within this network understanding for co-design and co-production at our urban locations,

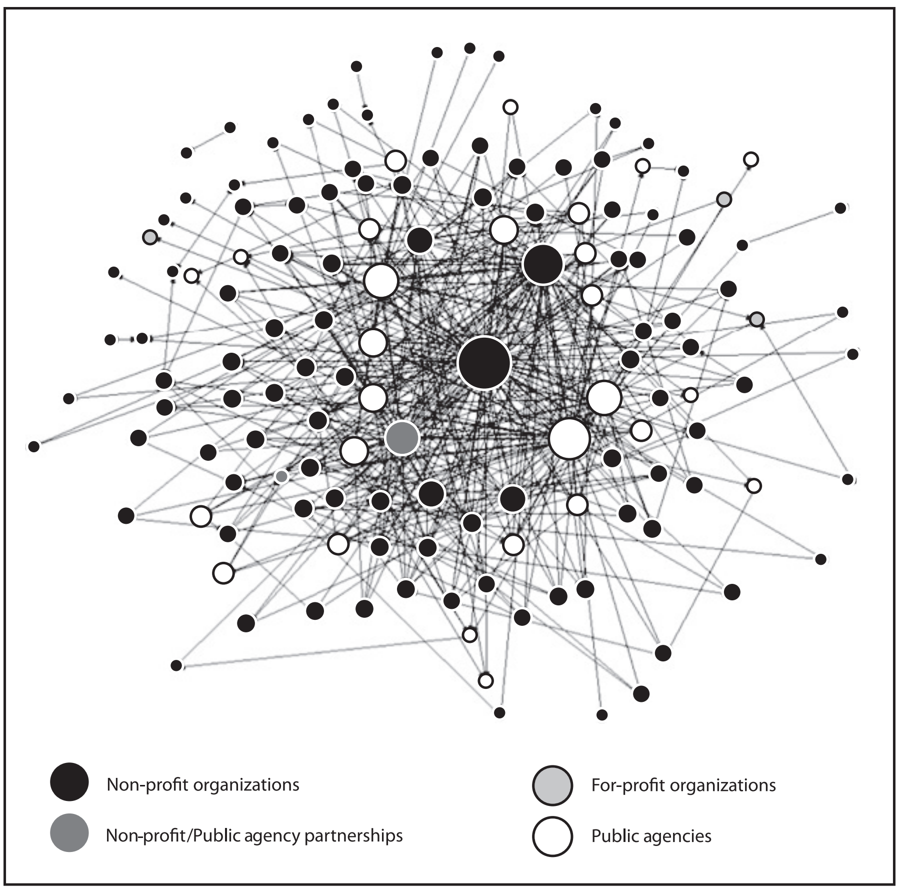

Fig. 4. Illustration of the Stewardship Network in Baltimore, Md., based on information flows (adapted from Romolini 2012). The network contains 390 groups and is dominated by two primary nodes, which are non-profit organizations—The Parks and People Foundation and Blue Water Baltimore; a second tier of nodes, which are public agencies—including local agencies such as the Office of Sustainability and the Departments of Public Works and Recreation of Parks; and an outer constellation of numerous non-profit organizations (Romolini et al. 2016).

our project teams and networks have pursued several strategies for our long-term, place-based work. These strategies are as follows: (1) the use of targeted, traditional forms of communication; (2) the appropriation of generic forms of digital, social media; and (3) the development of targeted forms of digital, social media. For example, scientists and decision makers have worked together to design and produce actionable science using targeted, traditional forms of communication and meeting locations that are familiar and accessible to participants from diverse communities (Cornell et al. 2013:66). Personal engagement through face-to-face interactions and dialog in individual and group settings are crucial for the "give-and-take" exchange of ideas, mutual learning, reflection, epiphanies, and building trust. In Phoenix, for instance, we have worked with the city's Water Services Department to develop infrastructure that is "designed with nature" to take advantage of the services provided by green, blue, and turquoise features in cities (sensu Childers et al. 2015). One example of wetland features that represent turquoise "design with nature" infrastructure is constructed treatment wetlands. These wetlands are designed and built as the final step in municipal wastewater treatment, before effluent is discharged to urban waterways. Since 2011, we have been working in a large constructed treatment wetland operated as part of the largest wastewater treatment plant in the City of Phoenix. During this time, we have also been working closely with the city's Water Services Department to ensure that what we are learning about their constructed treatment wetlands informs the best management and operations of the system, for both the plant and for the city's residents.

In our five years of studying the Tres Rios constructed treatment wetlands ecosystem, we have documented the productivity and nutrient assimilation capacity of the wetland plants and soils (Weller et al. 2016). We have also documented plant-mediated control of surface water hydrology, for the first time in any wetland, in the form of a "biological tide" that is driven by plant transpiration that brings both water and nutrients from the open water areas into the vegetated wetland, where near-complete nutrient removal takes place (Sanchez et al. 2016). This "biological tide" actually makes the Tres Rios constructed treatment wetlands system more effective at its job of nutrient removal compared with similar systems in cooler or more mesic climates.

We use research charrettes as our primary tool for communicating our findings from Tres Rios to the administrators, engineers, and managers in the city's Water Services Department and thus for incorporating our knowledge into their management and operations plans. The planning of these two-hour charrettes begins with a query to Water Services Department staff about what questions they would like to have answered and what challenges they are facing with management of the constructed treatment wetlands. We use this input to structure the presentations of our findings, which are several short (<15 min), general presentations that are often given by students. The content directly addresses the questions and challenges that we received from Water Services Department staff. The second half of these research charrettes is open discussion about the research findings presented and how to best incorporate this knowledge into their management and operations plans. At some charrettes, suggestions are made for future research directions, based on Water Services Department's needs. Using this friendly, collegial, low-impact approach, we are able to co-produce the adaptive management of the Tres Rios constructed treatment wetlands ecosystem to best meet the needs of the Water Services Department, while also maximizing other ecosystem services that the system provides (e.g., wildlife and bird habitat).

In the case of Baltimore, we have developed several practices for the co-design and co-production of actionable science. Working jointly with Baltimore City's Office of Sustainability, we have adopted a strategy of meeting three times per year and a 20/20/20 rule. Meetings are open and include academics, government agencies, NGOs, community members, and businesses interested in local sustainability and resilience issues. Meetings are held for one hour. A scientist presents for 20 min on a collectively, pre-identified topic; decision makers present for 20 min on related policy, planning, and management issues; and for the remaining 20 min, the group discusses how to better link existing science and practice and future opportunities to be pursued. Some of the topics include mosquitoes and vector-borne diseases, urban heat island (UHI) and risk, long-term patterns and processes of environmental justice, and neighborhood greening and redevelopment. The notes from these meetings are shared with the larger Baltimore network of scientists and practitioners through follow-up meetings, e-mail Listservs, and social media. Associated publications and presentations are placed in a shared, online folder. A second, emerging practice is the idea of performing science/decision making cross-walks with the organizations in our network. This includes reviewing various policy, planning, and management documents and identifying science connections in terms of expertise, data, knowledge, models, and tools. This cross-walk matrix can then be used with our network vis-à-vis their decision making documents to determine how existing forms of science may be useful to them and to discuss how new science efforts can be designed and produced to meet their needs. A third practice has been to "share the stage" through forums, co-presentations, and co-authorship. Practitioners have included scientists to participate in their public forums. Likewise, scientists have included practitioners as authors in their journal articles (Locke et al. 2013 and, in some cases, practitioners have been the lead authors (Hager et al. 2013).

In New York City, the stewardship network has formed the basis for engaging with civic organizations and the development of the Science of the Living City (SoLC). The program engages diverse science and practice partners across the city, speaks to a wide professional and public audience, and addresses a variety of pressing issues related to urban social ecology and quality of life in cities. The goal is to explore new ideas and the applications and implications of this information in the urban context as well as to contribute to the co-production of knowledge. Fellowship and internship programs evolve from these exchanges so that there is a shared understanding of the need for both science and practice from the onset. Often, the work of SoLC fellows includes a range of products and outcomes that require the preparation of data and findings in formats that engage an audience of scientists as well as decision makers and, increasingly, the general public.

While traditional forms of communication still work and remain critical, new digital media and communications are increasingly important. Initially, we adopted generic forms of digital, social media using platforms such as Facebook, LinkedIn, and Twitter for dissemination and sustained exchange of ideas. The use of these social networks leads to sharing and resharing of ideas, publications, research results, and decision makers' issues through our network. For instance, research on the relationship between forest patch size and UHI is re-posted on the Facebook and webpages of partner organizations such as Baltimore GreenSpace, TreeBaltimore, and the Office of Sustainability, thereby reaching their network of partners and individual members. Likewise, for example, information about new city initiatives to deconstruct vacant homes and re-green vacant lots is re-posted to the BES Facebook page to share with BES scientists interested in household locational choice research and the effects of dis/amenities. We have also created targeted forms of digital, social media. In addition to subject specific blogs, we built digital libraries and information systems with our local partners to address several goals: (1) support scientific research, (2) facilitate more open participation in science, (3) promote increased use of science in decision making (also see Craglia et al. 2012), and (4) inform scientists of local issues and management concerns. Our strategies and systems are designed so that data and digital media, what had been traditional "print media" such as journal articles, book chapters, maps, charts, and graphs, are easily available and in forms that can be incorporated into decision makers' documents and presentations. In addition to these digital forms of traditional media, we participate in partners' digital data systems. In Baltimore, for instance, our data are included in the Baltimore Neighborhood Indicators Alliance, whose goal is to strengthen Baltimore neighborhoods by providing meaningful, accurate, and open data at the community level by producing reliable and actionable quality of life indicators.

In New York, the stewardship mapping project team has created integrated visualization tools through which users can access and interact with the data through different geographic and temporal scales. The development of these visualization tools highlights the idea that project teams may require and be ideally suited for developing new forms of expression and knowledge dissemination. Working effectively across disciplines and sectors requires a shared understanding of a grand storyline and program design that can support outputs at multiple stages and for different audiences. For example, project teams often develop a working style designed to produce communication and knowledge throughout the life of a project rather than at the end. Our work in New York also highlights the long-term dynamics that arise. Often, a project team does not end but evolves, overtime, to become deeply embedded in a network of scientists and practitioners. This embeddedness enables both scientist and practitioner to reach more people and ideas as well as go deeper and wider in understanding and impacting complex social–ecological conditions.

Conclusion

The challenges for the co-design and co-production of long-term, place-based ecology *for* the city research and decision making can be daunting. It involves diverse disciplines, sectors, scales, and complexity. To meet these challenges, there is a growing demand for education, training, and experiences for both scientists and practitioners. It also involves a subtle but profound shift in "who's in charge" from the traditional research project, governed by a specified group of lead scientists, to a project team model where we embrace and embed ourselves in networks. Ideally, this enables Project Team members, composed of scientists and decision makers, to be more efficient, effective, expansive, inclusive, and better leveraged and resourced. However, a Project Team approach can be time-consuming and does not always lead to quick outputs and outcomes.

Rather than assume that co-design and co-production through Project Teams is superior to other approaches, there is a need for evaluation and reflection. For instance, evaluation and reflection might ask how long-term, place-based Project Teams affect scientific advances and productivity of scientists. Furthermore, given that the performance review of scientists has traditionally focused on the output of peer-reviewed publications in "high impact" journals, how can evaluations include a scientist's contributions to decision maker's needs? At the same time, evaluation and reflection may also consider the usefulness of knowledge and data from Project Teams to inform decisions.

It is important to acknowledge that there will continue to be linear models of interactions among scientists and decision makers, meetings big and small, phone calls, and e-mail. These practices are still valuable. But it is also significant to recognize that long-term, place-based research in the ecology *for* the city will increasingly involve transformations of science and decision making through dynamic, cumulative models of interactions among scientists and decision makers, awareness of and participation in networks, and novel practices. These activities involve major changes in culture, commitments, and resources for both scientists and practitioners.

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