Involving Ecologists in Shaping Large-Scale Green Infrastructure Projects

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Cities are implementing green infrastructure projects to provide ecosystem services such as storm water mitigation. The efficacy of these projects at providing services is rarely evaluated. Embedding research into project design provides a mechanism for both evaluation and development of the ecological knowledge needed to improve infrastructure for services provision. Ecologists must navigate the politics, economics, and social constraints of working in cities. Additional skills and practices are needed to develop new relationships and improve credibility, to define project roles, to identify new funding, and to integrate multidisciplinary knowledge. We examine a large-scale green infrastructure project that integrates hypothesis-driven experimental research and baseline monitoring with park design, implementation, and maintenance. Drawing on this case study, we recommend strategies to facilitate the inclusion of research ecologists in green infrastructure projects by enhancing the professional certification process, establishing research ecologists as consultants, and integrating ecology and design in graduate programs.

Keywords: applied ecology, urban ecology, green infrastructure, urban design, designed experiments

Cities implement green infrastructure projects to sequester carbon, improve air quality, reduce storm water runoff, and enhance native biodiversity (Nowak et al. 2007, James et al. 2009, McHale et al. 2009, Pincetl 2010). The provision of these ecosystem services, which we refer to here as *performance*, by urban green infrastructure projects is rarely evaluated (Pickett et al. 2011a, Tratalos et al. 2007). When projects are evaluated, it is often revealed that they do not supply the ecosystem services that they were designed to provide (Pataki et al. 2011). To ensure that green infrastructure projects do provide their intended ecosystem services, designers and land managers must construct ecosystems containing plant, animal, or soil microbial communities that meet performance criteria and that are resilient to disturbance (Hobbs et al. 2006, Lundholm and Richardson 2010). Systematic observation and research is crucial for assessing and understanding the performance and resilience of these constructed ecosystems. Short- and long-term monitoring programs are increasing in number, but most catalog observations such as pollution levels (e.g., the International Stormwater Best Management Practices Database, *www.bmpdatabase.org*). Instead, a guarantee of performance and resilience requires ecological knowledge of how species persist and grow in the context of the urban environment (Pickett et al. 2011b). Studying resilience in ecological processes, such as competition, dispersal, and recruitment, is crucial if we are to evaluate how ecosystem service provision and ecology are linked in a changing climate (e.g., Robinson and Handel 2000, Millar et al. 2007). We must also understand how people and institutions influence the ecosystem services and ecological dynamics of green infrastructure projects (Williams et al. 2009, Shirk et al. 2012).

Knowledge gaps in the ecological understanding of green infrastructure performance and resilience arise because projects are typically designed and constructed primarily to address factors of infrastructure cost, durability, maintenance, safety, and aesthetics (Foster et al. 2011). As urban areas increasingly rely on green infrastructure to provide ecosystem services, a failure of projects to perform—because of a lack of understanding of their functioning—could be costly and environmentally detrimental. Developing hypothesis-driven research to achieve a rigorous analysis of these constructed ecosystems will add to our body of knowledge and will allow safe urbanization in a way that accounts for the health, safety, and welfare of residents and their environment. Research ecologists can play a crucial role in the science needed to develop the sustainable city (Pickett et al. 2011b). Specifically, ecologists can engage with designers and engineers to help convert crucial management questions into testable hypotheses and then to integrate research projects into the design, construction, and monitoring of green infrastructure. This emerging approach in ecology builds on recent arguments, including *Earth stewardship*, for ecologists to shape trajectories of social–ecological change alongside studying them

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(Chapin et al. 2011). These goals demand a proactive strategy for operationalization in order to integrate ecological research with drivers that structure human environments (Evans 2011). Designed experiments offer one approach toward this goal; they allow ecologists to situate research experiments as part of the built environment, melding scientific analysis with urban planning, design, and engineering (Felson and Pickett 2005). Research results can be used to improve existing green infrastructure and to provide ecological understanding to guide future projects.

We focus on the New York City Afforestation Project (NY-CAP), an ecological research project within the MillionTreesNYC initiative, as a case study to illustrate the process and challenge of establishing urban experimental research through the designed-experiment approach. We build on this case study to recommend formal mechanisms for the engagement of research ecologists in large-scale green infrastructure projects (Chapin et al. 2011, McKinley et al. 2011). We acknowledge that environmental consultants, engineers, planners, designers, and land managers play a crucial role in green infrastructure (Forman 2008, Steiner 2008). They may monitor performance, but they do not typically conduct experimental research as a part of their involvement. We then use the term *ecologist* in this article to refer to research ecologists, whose expertise is hypothesis-driven research, and discuss how they can bring this expertise to green infrastructure projects.

NY-CAP case study

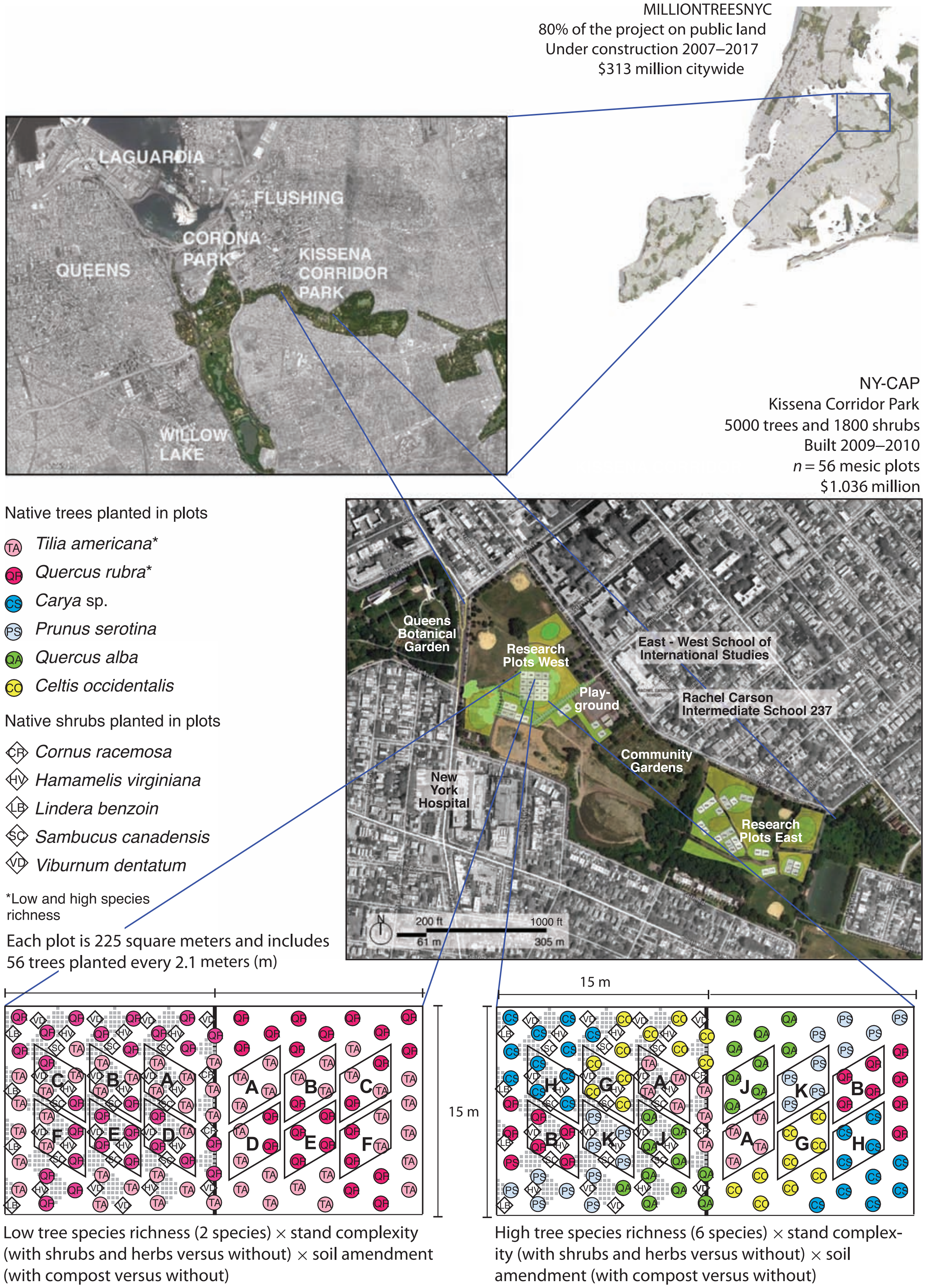
Situated in public parkland, the NY-CAP is part of New York City's sustainability-driven agenda, PlaNYC 2030 (*www.nyc.gov/html/planyc2030/html/home/home.shtml*). For the NY-CAP, the designed-experiment approach provided a framework for the collaboration of designers and ecologists that allowed each to employ their respective expertise and, at the same time, inform and complement each other's role (Felson and Pickett 2005). The ecologists proposed experiments that would generate knowledge on the performance and resilience of urban forests. The designers, in turn, incorporated these experiments into an urban aesthetic and functional park design (figure 1; *www.milliontreesnyc.org/html/urban_forest/planyc_reforestation.shtml*). The designed-experiment approach offered (a) a new platform for ecologists to design and situate hypothesis-driven research in urban areas on sites that have been historically inaccessible to ecological experiments; (b) a new method for generating replicable scientific data about the ecological processes of constructed urban ecosystems; (c) a new framework for connecting ecologists with stakeholders, including city agencies, contractors, and park users; and (d) a new means for designers and park maintenance staff to update their underlying assumptions informing urban land management and to expand their ecological knowledge.

The NY-CAP experiment tests three central questions: (1) How do urban environmental stressors (e.g., pollution, vandalism, drought) affect the health and survival of planted trees? (2) How does tree health and survival respond to management and planting practices, such as increased plant diversity and organic soil amendments? (3) Will planted trees recruit to form the urban forest of the future, or will this constructed forest instead be overwhelmed by invasive species? These questions derive from the fact that few data exist on how planted native vegetation survives and functions in urban settings (Robinson and Handel 2000, Lundholm and Richardson 2010, Oldfield et al. 2013), although planting natives is seen as a way to promote the native regional biodiversity of plants and animals (McKinney 2006, Burghardt et al. 2009, Ordóñez and Duinker 2012). Situating ecological research as a component of green infrastructure presents an opportunity to fill these knowledge gaps. Many cities around the world are adopting large-scale native afforestation programs (e.g., Auckland, London, Los Angeles, Philadelphia), which highlights the need for urban forestry experiments such as the NY-CAP to provide answers to questions about the ability of native trees to persist in the urban environment and the management strategies that facilitate their persistence (Oldfield et al. 2013).

To establish the NY-CAP, ecologists conceived the central research questions and replicated the study design, and landscape designers integrated the plots as amenities within public parkland (figure 1). To elaborate on ways in which ecologists can establish experiments to inform future green infrastructure projects and assess their functionality, we break down the NY-CAP project into a series of steps (figure 2) and elaborate on three crucial areas: (1) recognizing research opportunities through collaboration between designers or planners and ecologists, (2) securing research funding, and (3) balancing research goals with design opportunities and constraints.

Recognizing and establishing opportunities for research. The research opportunity for the NY-CAP arose from a request for proposals under the MillionTreesNYC initiative within PlaNYC 2030, which called for ecological monitoring to track reforestation success and resulted in the publication of a full report (PlaNYC 2007). Mayor Bloomberg allocated $313 million over 10 years to the New York City Department of Parks and Recreation (NYCDPR) to plant 800,000 trees, including hundreds of hectares of forest restoration across the five boroughs (*www.milliontreesnyc.org/html/urban_forest/planyc_reforestation.shtml*). The selected team was composed of designers and ecologists who proposed to incorporate basic and applied research into the project's design, going beyond the usual postimplementation monitoring of tree mortality and survival. The group proposed an assessment of urban forest ecosystem development and performance (McHale et al. 2009). Incorporating research into the overall project design was promoted as crucial to advancing the understanding of the effects of trees on the urban environment and necessary for identifying best practices to ensure the successful growth of the plantings.

The NY-CAP experience suggests that, in the absence of formal mechanisms for engaging ecologists in the design


MILLIONTREESNYC
80% of the project on public land
Under construction 2007–2017
$313 million citywide
LAGUARDIA
FLUSHING
CORONA PARK
QUEENS
KISSENA CORRIDOR PARK
WILLOW LAKE
NY-CAP
Kissena Corridor Park
5000 trees and 1800 shrubs
Built 2009–2010
n = 56 mesic plots
$1.036 million
Native trees planted in plots
TA Tilia americana*
QR Quercus rubra*
CS Carya sp.
PS Prunus serotina
QA Quercus alba
CO Celtis occidentalis
Native shrubs planted in plots
CR Cornus racemosa
HV Hamamelis virginiana
LB Lindera benzoin
SC Sambucus canadensis
VD Viburnum dentatum
*Low and high species richness
Each plot is 225 square meters and includes 56 trees planted every 2.1 meters (m)
Queens Botanical Garden
Research Plots West
Play-ground
East - West School of International Studies
Rachel Carson Intermediate School 237
Community Gardens
New York Hospital
Research Plots East
200 ft
61 m
1000 ft
305 m
15 m
15 m
Low tree species richness (2 species) × stand complexity (with shrubs and herbs versus without) × soil amendment (with compost versus without)
High tree species richness (6 species) × stand complexity (with shrubs and herbs versus without) × soil amendment (with compost versus without)

process, ecologists must actively seek out green infrastructure projects for which funding is available for ecological input (Felson 2013, Felson et al. 2013). This strategy involves advocating that ecological research is an added value to the project. Ecologists are increasingly challenged to contribute to social–ecological change through initiatives including Earth stewardship (Chapin et al. 2011) and actionable science (Palmer 2012). These initiatives involve integrating ecological research with drivers that structure human environments. An impediment to this integration is operationalizing the approach (Chapin et al. 2011). Our experience suggests that green infrastructure projects provide an operational mechanism. In particular, they place ecologists in an arena in which they can affect the structure and function of the built environment, but to operate in this arena, ecologists must forge new partnerships, align research objectives with management goals, and acquire new knowledge through interdisciplinary science in order to contribute to sustainable practices (Ostrom 2009, Pielke 2012).

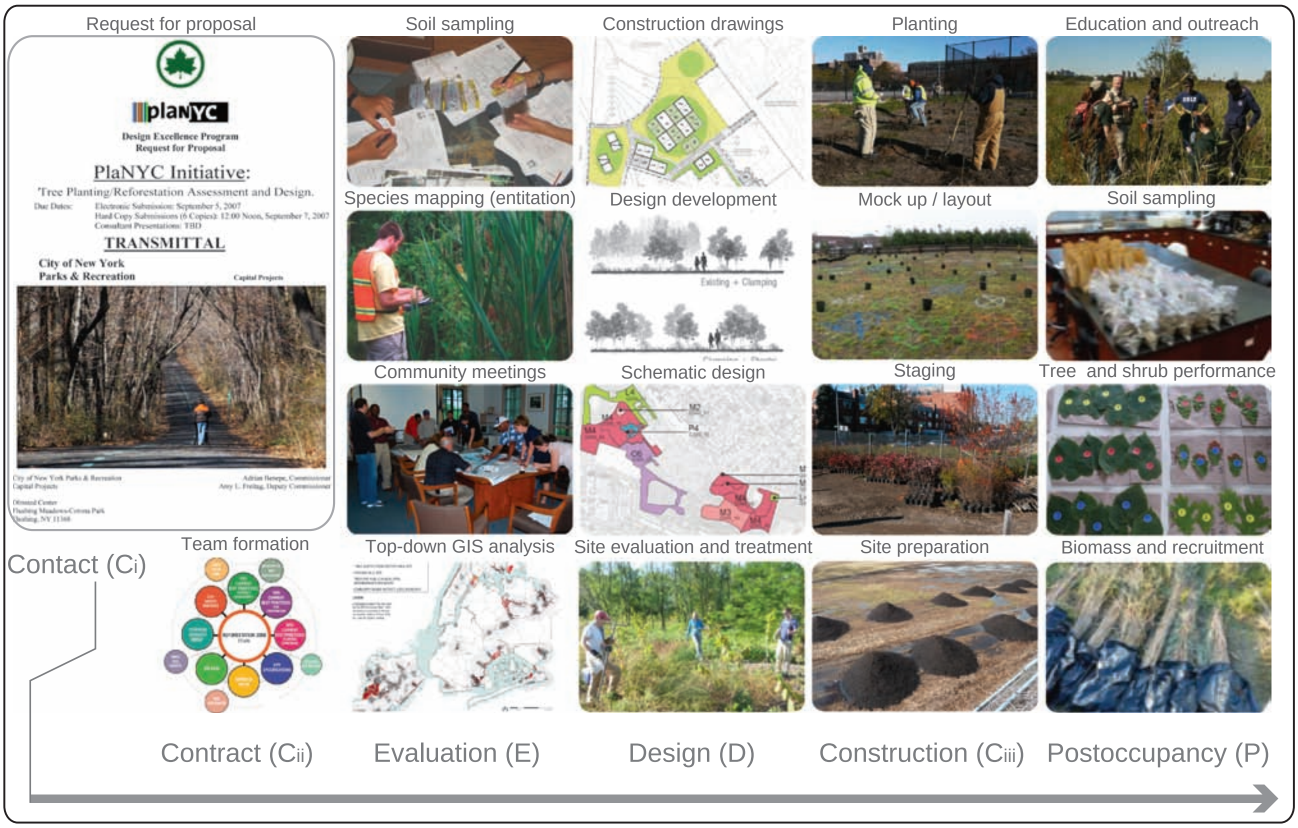
Funding the research. The NY-CAP team directed the funds allocated for the design and implementation of Kissena Corridor Park (one of two sites where the NY-CAP is located)—amounting to $1.036 million—to build a designed experiment that functions as a public park and research site (figure 1; PlaNYC 2007; also see *http://urbanomnibus.net/2013/03/experimental-landscapes-alexander-felson-on-ecology-and-design*). By using the designed-experiment approach, the ecologists could access research funds and locations not available through traditional funding sources of academic science. Funding for urban infrastructure and design projects are made available through different mechanisms (e.g., requests for proposals targeted at engineers and designers). From fiscal years 2002 through 2009, New York City allocated $17.6 billion for PlaNYC environmental protection capital projects, including treatment systems and other infrastructure (NYC DEP 2010). This amount dwarfs the US National Science Foundation's (NSF) 2013 fiscal year budget for biological sciences of $711.6 million and $762.7 million for engineering (*www.igert.org/public/about/history-and-mission*).

In pursuing green infrastructure funding opportunities, ecologists need to reconcile their interest in addressing gaps in scientific understanding with the client's objectives for a project. This reconciliation, if it is achievable, will entail compromises in the experimental and infrastructure design (McShane et al. 2011). The NY-CAP, for example, includes a research component that was not anticipated under the original request for proposals. Consequently, there was no funding to support the development of the experimental design, so scientists worked on a voluntary basis through a science advisory board. The board met with NYCDPR managers, landscape designers, and ecologists to identify crucial management issues, translate these into basic research hypotheses, and establish a design to test these hypotheses.

Funding for the collection of research data is also challenging and is not usually invited in the proposal calls for green infrastructure projects. Instead, research is often viewed as costly and not directly applicable to project objectives (Palmer 2012). Funds for monitoring city infrastructure are increasingly available to consulting firms but are notoriously inadequate (see *www.sustainablesites.org*). The NY-CAP then provides a precedent for funding the design and setup of an experiment, under a model that provides new opportunities for researchers across academic institutions but not funding for data collection. However, because NY-CAP is already established as a well-replicated experiment in public parkland, it has attracted researchers from the US Forest Service, Yale University, Columbia University, the Cary Institute of Ecosystem Studies, and The New School (e.g., McPhearson et al. 2010). The research has been funded, however, through a variety of small grants from the different institutions. Formal mechanisms for research funding need to be included in proposal requests for green infrastruture projects if the performance and ecological resilience of these projects is to be assessed and improved. One would not build a wastewater treatment plant if it did not achieve water-quality standards, so why plant an urban forest without knowing that it performs the intended function?

Balancing research goals with design opportunities and constraints. When developing a designed experiment, the ecologist must strike a balance between the applicability of results to design and management practices and the specifics of the scientific investigation. For the NY-CAP, it was crucial to ensure that the project incorporated basic scientific research that also benefited landscape management without compromising and while, ideally, enhancing the space's use as a public park (figure 1). The development of

Figure 1. The New York City Afforestation Project (NY-CAP) is part of the MillionTreesNYC initiative, a green infrastructure project intended to enhance human and environmental health through large-scale tree planting efforts. To balance the interests of stakeholders (e.g., land managers, park users, the general public), the NY-CAP was, from the outset, designed to generate useful results for guiding decisionmaking about land management issues. The 56 research plots, which are embedded within public parkland, are separated into eight different treatments, consisting of a factorial arrangement of tree species richness (six species versus two species), stand complexity (with shrubs and herbs versus without), and soil amendment (with compost versus without). Plot treatments break down as follows: high diversity, shrubs, compost (n = 9); high diversity, no shrubs, compost (n = 9); high diversity, no shrubs, compost (n = 5); high diversity, no shrubs, no compost (n = 5); low diversity, shrubs, compost (n = 5); low diversity, no shrubs, compost (n = 5); low diversity, no shrubs, compost (n = 9); low diversity, no shrubs, no compost (n = 9). Source: The maps were adapted from Google Earth.



Ci
- Follow the money and target urban projects (e.g., green infrastructure) and practitioners to build experiments.
- Package and market ecological information, research, and monitoring as deliverables for urban projects.
- Differentiate the role of research ecologists from environmental consultants and develop new scopes of work.

Cii
- Negotiate early, and balance research goals with cost savings, ease of construction, and maintenance.
- Expand the budget and timeframe to establish research and monitoring during and after evaluation.
- Ensure that a research program and additional funding are secured to support postoccupancy research.

E
- Add scientific rigor while balancing research objectives with project goals and social investments.
- Build stakeholder consensus, which can help ensure the longevity and support for the project, while considering that involvement increases transaction costs and reduces control over the project scope.

D
- Participate in key stages (e.g., design reviews, cost estimation, value engineering, punch list).
- Integrate controlled experiments shaped as urban landscapes (e.g., designed experiments).
- Advocate for the critical components of the experiment while compromising on others.

Ciii
- Befriend the contractor early and solicit feedback on designing and building the experiment.
- Stake a claim to the work and integrate experimental goals and adaptive management into the design.
- Build mock ups to explain how to construct experiments and to improve the design.

P
- Ensure that the rigor going into data collection and modeling of urban areas is in-depth and peer reviewed.
- Develop robust metrics and establish a process for experiential, mutual, and adaptive learning for academics, practitioners, and community participants with feedback between experimental results and design solutions.

Figure 2. An overview of the New York City Afforestation Project (NY-CAP) process with general recommendations for involving research ecologists in urban green infrastructure projects. Those responsible for the design and implementation of green infrastructure typically include engineers; designers; natural resource managers; horticulturalists; and environmental consultants, whose practices are often not supported by ecological research. Photographs: AECOM (the first three columns), Emily E. Oldfield (the second and third photographs in the last column), Alexander J. Felson (all others).

the NY-CAP's experimental design then required the involvement of multiple stakeholders, including land managers, naturalists, community members, park users, politicians, and designers. Involving stakeholders early on with opportunities to codesign the research provided the ecologists with a more informed understanding of community needs and opportunities to frame results in ways accessible to nonscientists. This involvement does, however, reduce the level of control that the ecologist has over the experimental scope and research methods. For example, the design of the NY-CAP plots had to facilitate research and serve as an aesthetic amenity. This dual demand required a reconceptualization of the standard gridded research plot as a more naturalistic plot, with patches of trees and shrubs in an offset grid. The plots then had to be stitched back into a more traditional parkland identity, using a picturesque planting (figures 1 and 2). Finally, to defuse concerns that densely planting trees would limit public access, inaccessible zones of invasive species were targeted for the research plots in order to meet the aims of the larger initiative for tree planting and invasive species control.

Establishing a replicable research project requires the core scientific team to retain sufficient control to ensure the quality of the experimental design. Generating stakeholder investment, however, and so giving up some control, can help ensure that the project is both implemented and financially supported in the longer term (McShane et al. 2011, Shirk et al. 2012). Achieving this balance is crucial if we are to assess and advance the resiliency and sustainability of human-dominated systems (Ostrom 2009) and an interdisciplinary science that engages multiple stakeholders (Lélé and Norgaard 2005).

Recommendations for promoting the involvement of ecologists in large-scale green infrastructure projects

The NY-CAP case study highlights challenges and opportunities involved in incorporating research into green infrastructure projects. We have used the lessons learned from our experience with the NY-CAP to develop a set of recommendations for facilitating designed experiments through a formal approach that will engage the broad community of ecologists interested in urban systems (box 1).

Dialogue and formalization. Studying the evolution of the dominant US institution for academic ecologists, the Ecological Society of America (ESA), reveals changing relationships with preservation, policy, and practice that are relevant to other countries with similar professional societies. From the beginning, the ESA debated whether to focus solely on ecological research or whether to include the preservation of natural areas. The Committee on the Preservation of Natural Systems for Ecological Study was founded in 1917. The Ecologist Union was formed in 1946 to take action in conserving natural areas. When its members were unable to reach a consensus on whether to embrace preservation of natural areas as a central agenda of the ESA, the group separated from the ESA and was incorporated as The Nature Conservancy in 1951 (*www.esa.org/history/docs/BurgessHistory.pdf*). Within the ESA, the Applied Ecology Section was formed in 1971 to provide a venue for communication about "applying ecological principles to solve practical environmental problems" and to encourage interdisciplinary exchange (*www.esa.org/applied/ESA_Applied_Ecology_Section/home.html*).

The ESA established a professional certification program in 1981, responding to state and federal agency demands for certified ecologists on environmental projects. The program provides "ready access to professional ecologists for advice and technical guidance on public policy and regulatory issues facing society." The certification process is procedural, based on one's credentials and experience. Certified ecologists must meet "a minimum set of standards in education and experience" and "adhere to high ethical standards" (*www.esa.org/careers_certification/about.certification.php#about*). Membership is around 6% of the 10,000 ESA members (*www.esa.org/careers_certification/directory*). The ESA notes that the program needs further promotion to increase participation, but for those ecologists working on urban design projects, it establishes their credibility (Michener et al. 2007).

The ESA's certification program provides a roster of ecologists certified to participate in professional practice, but it does not position the ecologist as a crucial component of urban projects. That is, the presence of a mechanism to certify the credentials of ecologists does not mean that they will be included as consultants. Building on the certification program is one step toward inclusion by enhancing the interface between ecologists and urban practitioners. This enhancement would require the ESA to implement an institutional support structure to forge deeper integration of ecologists into design. Toward this goal, the ESA has increasingly sought collaborations with other professional societies and has most recently proposed Earth stewardship (see box 1; *www.esa.org/earthstewardship*). The proposal asks ecologists to influence the trajectory of social–ecological change by integrating ecological research with drivers that structure human environments (Chapin et al. 2011). A national approach under the banner of *stewardship* could include marketing campaigns and lobbying efforts to educate the public on the need to address the lack of data about the performance of large-scale green infrastructure projects. The ESA might also consider establishing an institutional platform or internal coordinator to interact with other societies and professionals to facilitate matching certified ecologists with urban practitioners on design projects. This matching would foster the formalization of cross-disciplinary approaches at the professional level and would replicate the relationships already established across other professional societies (e.g., between lead design or engineering firms and their subconsultants).

Defining a distinct identity. Regular inclusion of ecologists in green infrastructure projects will benefit from distinguishing research ecologists from environmental consultants. Currently, environmental consultants serve as the main contributors of applied ecological knowledge to land development and design projects and rely mostly on monitoring and rapid environmental assessments to gain information about a site and to then provide expert opinions. They are able to fill the demand for environmental guidance based on regulatory requirements and developer needs. That is, environmental consultants have a defined role on design teams. The role of research ecologists must then also be defined and distinguished from that of environmental consultants, because they

Box 1. Required actions to develop a more formal methodology for the inclusion of ecologists as essential components of large-scale green infrastructure projects.

Dialogue and formalization

Improve the professional certification program. Promote the Ecological Society of America's professional certification program to increase participation. Add educational resources, training, and testing of this knowledge to elevate the professional quality of the professional certification program. Add areas of expertise and team configurations and precedent projects (illustrating how ecologists have been involved) to the online networking database as a tool for selecting and linking ecologists to projects. Increase the stature of the professional certification program through national and international marketing and lobbying efforts.

Establish ties with other institutions and urban design teams. Establish productive exchanges with other professional societies such as the American Society of Landscape Architecture, the American Institute of Architects, the American Planning Association, and the American Society of Civil Engineers. Establish an institutional platform with a professional negotiator and support structure to work with other societies and design teams to facilitate matching certified ecologists with urban practitioners on design projects.

Perform national to international marketing campaigns. Establish marketing and lobbying campaigns nationally and internationally to highlight the lack of data on green infrastructure performance and the role that professionally certified ecologists can play. Highlight other problems that would benefit from ecologists' contributions.

Defining a distinct identity

Distinguish between ecologists and environmental consultants. Differentiate the role of ecologists on urban design projects from environmental consultants' in order to complement and expand on the environmental scope and to establish a targeted contribution to meet specific demands. Focus on redressing the data shortage through urban experimentation and by developing standard means for translating data into applied practices.

Package ecologists' contributions (e.g., experiments, monitoring, review) into valued products. Define the roles that ecologists can play within the design process and determine the labor and material costs for each of these contributions along with the deliverables. Expand the role of ecologists into previously unchartered areas in which research scientists can make tangible contributions (e.g., targeted site analysis for high-value ecosystems through monitoring, or design the review to assess ecosystem services and disservices).

Establish roles for ecologists on par with the engineering and architectural professions. Engage in a legal effort to frame a contributing role for ecologists in reviewing and approving design documents. Work with regulators and lobbyists to establish specific contributions.

Education

Educate graduate research ecology students interested in urban design. Develop integrated design and ecology programs through grassroots efforts (e.g., interdisciplinary relationships among faculty) building on the growing funding options. Develop distributed graduate courses that combine expertise and resources across universities to improve knowledge exchange. Seek interdisciplinarians who can communicate effectively across the disciplines and can help construct and maintain successful programs in urban and human-dominated ecosystems, while engaging with social–ecological systems.

Train interdisciplinarians who hybridize design and ecological research. Expose students to both science and design in order for them to manage both the quantitative and theoretical components of ecology, in addition to the ability to work within the design process. Emphasize the value of pursuing dual degrees at universities that have both quality ecological sciences and urban planning or design programs. Seek students who hold complementary interests in ecological and urban design goals, without overcompromising on either agenda.

perform rigorous scientific research to answer basic questions about the ecological performance on which the success of many green infrastructure projects rely.

Research ecologists involved in urban green infrastructure could be complementary to the environmental consultant by redressing the data shortage through urban experimentation and by developing standard means for translating the resulting data into application. To achieve such a goal, we recommend that ecologists follow other professional societies (e.g., architecture, engineering) to develop legal forms and contracts that define the relationships and terms involved for ecological research on design and construction projects and a more rigorous certification process focused on knowledge assessment and the provision of educational resources and training options. This formalization could further elevate the professional identity of the certified ecologist to the level on par with that of other professions actively engaged in green infrastructure. Research ecologists then take on many traits of a consultant and, even if their involvement is purely academic, such formalization may be necessary for the ecologists to be recognized as equivalent to other professionals during the design and implementation of green infrastructure projects.

Education. Education is a crucial area for advancing the integration of research with design in green infrastructure. Ecologists seeking urban research opportunities are typically not trained in urban policy, city planning, design, or other areas that provide insight into urban systems (Forman 2002, Felson et al. 2013). At the same time, designers and planners typically have little scientific training and rarely focus on ecological research (Felson and Pickett 2005). To demonstrate the relevance of ecological science to urban design, planning, and landscape architecture, one can look back at developments such as the sanitary city in the early twentieth century. Public health risks due to a lack of wastewater treatment and water purification facilities were addressed directly through a combination of science, technology, design, and planning (Evans 2011, Pickett et al. 2011b). This notion of the experimental city is gaining in popularity and relevance as society seeks resilience, adaptability, and sustainable urbanism (Evans 2011). To further advance this idea of the experimental city, dialogue is an essential step.

It is necessary to inform scientists and designers about the theory, methods, and application in each other's disciplines before they can appreciate how collaboration can lead to success (Forman 2002). There are at least four audiences to target for further education in order to accelerate the development of designed experiments: (1) ecologists who are interested in urban design and social–ecological systems, (2) research ecologists interested in consulting, (3) designers interested in partnering with ecologists to develop ecological experiments, and (4) trained interdisciplinarians who hybridize design and ecological research. Each category requires considerable elaboration, but we focus here on the first and fourth, given our present focus on the involvement of the academic research ecologist.

For graduate students interested in studying urban ecosystems and interdisciplinary research, the last 20 years have witnessed an expansion in funding options and support. In the United States, the transformation is apparent in various NSF programs, including two NSF-funded Long Term Ecological Research Network projects (called *urban LTERs*) launched in 1997 in Baltimore, Maryland, and Phoenix, Arizona, and more recent initiatives, including the Dynamics of Coupled Human and Natural Systems program, started in 2007; the Urban Long-Term Research Areas: Exploratory Awards, initiated in 2009; and the National Socio-Environmental Synthesis Center, initiated at the University of Maryland in 2011. With the development and continuation of these programs, there are at least a handful of federally funded basic science programs that explicitly target urban ecological research—meaning that the research monies are in place to train and engage students in urban ecology.

With funding opportunities in place, academic and scientific institutions are recognizing the need for interdisciplinary education to prepare scientists to participate in and contribute to solving complex social–ecological challenges (CFIR et al. 2005). A number of universities have already adopted interdisciplinary courses and programs (Rhoten and Parker 2004). We advocate that future interdisciplinary programs be focused on the integration of design and ecology. Tapping into existing funding sources, such as the NSF's Integrative Graduate Education and Research Traineeship (IGERT) program, can facilitate this move, with its focus on promoting "new models for graduate education… for collaborative research that transcends traditional disciplinary boundaries" (*www.igert.org/public/about/history-and-mission*). We recognize that, notwithstanding IGERT, the advancement of programs for the integration of ecology and design will depend largely on individual efforts and, above all, on effective communication across disciplines.

For the interdisciplinarians, we argue that a new hybrid designer–ecologist will facilitate the development of designed experiments to augment urban ecological research. Designer–ecologists can provide an essential link between the practical and logistical challenges of working with stakeholders, the many constraints of urban systems, and the robust demands of experimental research. Such a hybrid would need to have substantial exposure to both the science and the design professions in order to manage both the quantitative and the theoretical components of ecology in addition to the ability to work through drawings and design. What kind of educational background and exposure would facilitate the development of a hybrid designer–ecologist?

In practice, students of this hybrid field will need both traditional ecological training, emphasizing the development of hypothesis-driven research and fieldwork, and a reputable design degree. The hybrid practitioner needs to have an understanding of the implications of spatial form and aesthetics and experience with integrating social dynamics as drivers of the design. To this end, they will likely need to pursue dual degrees or joint degree programs. A critique of joint programs is that too much attention is paid to the area of integration and not enough on the development of the knowledge base within each discipline (Graybill et al. 2006). We suggest that dual—as opposed to joint—degree programs are where institutions should start. Dual programs would provide the necessary depth of coursework and experience in both design and ecology.

The role of the hybrid designer–ecologist would be to seek complementarity and trade-offs between ecology and design goals without overcompromising on either agenda (McShane et al. 2011). The hybrid practitioner would aid other ecologists in establishing experimental designs, ensuring the quality of the research while also considering ways of framing the research and organizing it to fit into the constraints and expectations of urban clients and stakeholders. Universities that have both ecological sciences and urban planning or design degree programs seem ideally placed to begin to train such hybrid designer–ecologists.

Conclusions

The inclusion of research ecologists in green infrastructure projects requires a combination of enhanced dialogue, education, formalized frameworks, and funding for their participation. We have proposed a formalized framework that should expedite the translation of scientific knowledge into the construction of ecosystems and services for urban areas (box 1). Doing so establishes long-term research sites and produces new urban landscapes. A central goal of the framework should be to merge urban design and ecological research to address the need for performance data on green infrastructure projects.

Through the NY-CAP case study, we outlined several necessary actions for ecologists to participate in urban design projects: They must make contacts and partnerships, be opportunistic, negotiate and compromise, and seek novel funding sources. We also recommended ways to promote the involvement of ecologists in green infrastructure projects, primarily by improving the interdisciplinary dialogue between designers and ecologists, formalizing relationships between professional societies, and focusing on interdisciplinary education.

Our case study demonstrates the crucial role that urban ecologists can play when they collaborate with urban designers. In the ongoing dialogue, ecologists learn how to structure research that responds to urban design challenges, whereas designers learn how to incorporate ecological practices and methods into their design. The long-term aims of such collaborations are to advance ecological understanding of urban ecosystems and to enhance the performance of large-scale green infrastructure initiatives to improve human and environmental health.

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