Understanding and Working with Urban Biodiversity: The Baltimore Ecosystem Study

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HUMAN ECOSYSTEM			
BIOPHYSICAL FOUNDATIONS		SOCIAL CULTURAL FOUNDATIONS	SOCIAL SYSTEM
Energy Assimilated Thermal Source	Biodiversity Identity Source Evolution Guilds	Cultural Resources Organisations Beliefs Myths	Institutions Health Justice Faith Commerce Leisure Governance Sustenance
Water Path Rate Quantity	Soil Structure Chemistry Carbon	Socio-Economic Resources Information Population Labour Capital	Order Identity Norms Hierarchy
Nutrients Source Form Level	Vegetation Structure Regeneration		Cycles Psychological Individual Organisational Institutional
Materials Toxics Biomass Trace gas	Patch Mosaic Disturbance Configuration		
Air Quality Advection Stratification			

FIG. 1. The components of any human ecosystem (Source: BES LTER diagram, modified from Machlis et al., 1997).

Introduction

The Baltimore Ecosystem Study (BES) examines urban biodiversity through its integrated, long-term research in an urban social-ecological system. The project includes scientific research, education from elementary to post-graduate levels, and engagement with the Baltimore, Maryland, US community. Established by a National Science Foundation (NSF) competition in 1997, it partners academic institutions, non-governmental organisations (NGOs), and government research and management agencies (Pickett et al. 2011). The breadth of the partnership is reflected by the authors of this article who represent eight different organisations. Support comes mainly from NSF and the US Department of Agriculture Forest Service.

Because BES is so intellectually and geographically diverse, shared conceptual frameworks are vitally important. BES research uses three related frameworks: 1) the human ecosystem, 2) the watershed, and 3) patch dynamics (Cadenasso et al. 2006). These frameworks allow a flexible and adaptive programme of research and education that has evolved to examine the emerging transition from the sanitary to sustainable city (Grove 2009). This essay will explain the frameworks and exemplify how they contribute to understanding urban biodiversity.

Community engagement, the third component of BES, is as important as research and education. Consequently, the project has devoted great effort to working with governmental agencies and with NGOs, ranging from informal community associations to non-profit institutions. Indeed, BES was built on a decade of work in Baltimore by the Parks & People Foundation and the Urban Resources Initiative of Yale University.

Conceptual Frameworks

Urban systems, which encompass interacting cities, suburbs, and the exurban or periurban fringe, have been conceived as largely or even entirely human artefacts. The role of nature and of bioecological processes has seemingly been erased in much of urban discourse and urban practice. Our three frameworks were selected to counter this erasure and to facilitate interdisciplinary work among physical, biological, social, and economic researchers, and to promote connections with decision makers and citizens.

The human ecosystem

This framework originated with social scientists (Machlis et al. 1997). It is an inclusive statement of the components of the systems in which humans act. The framework is not a model, but rather a repertoire of potential causes, interactions, and constraints that can operate in all human influenced or inhabited places (Fig. 1). It is founded on the biogeochemical resources the system requires. Such resources can also be labeled as ecosystem services. The biogeochemical component of the system converts sunlight to biologically useful energy, cleans and stores water, generates soil, cycles nutrients required by plants and animals, and modulates extremes of climate, for example. These biogeophysical processes result in a spatial template that affects the functioning of the plants, animals, and microbes in the system, as well as the location, vulnerability, desirability, and productivity of human habitats and constructions.

The human ecosystem framework also identifies social-cultural resources as a critical component. These are the kinds of capital that allow social processes to operate and adapt. Cultural resources include organisations or institutions, as well as beliefs and myths. Socio-economic resources include the population, the information it possesses, the pool of labour for intellectual and physical work, and the capital embodied in finance, buildings, and infrastructure.

The social system itself is the final component of the human ecosystem framework. This subsystem describes how people interact. It encompasses the institutional arrangements for sustenance, health, justice, faith, commerce, leisure, and governance. Social order, a necessity for the social system, is provided by social identity, formal and informal norms of behaviour, and the social status of individuals in different rank hierarchies. The inclusion of social cycles emphasises that none of these structures or arrangements is static and that they often have predictable patterns.

Together these three components make up the human ecosystem, and their interactions govern the success, resilience, adaptability, and wellbeing of individuals and communities. The framework provides raw material for specific research models.

FIG. 2. The four watersheds shared by Baltimore City and Baltimore County.

The watershed

Urban studies often neglect the watershed concept because the infrastructure for water management may seem more obvious. However, the watershed concept (Fig. 2) has been important in BES because it emphasises that the flow of water sculpts surfaces, links systems belowground, transports and transforms nutrients and contaminants, and concentrates materials from extensive landscapes. Of course, the watersheds of urban systems are complicated by the transport of clean water from great distances. Likewise, stormwater is often channeled rapidly away from structures and streets, and sewage flushed to treatment facilities or, in areas where such plants are lacking, simply transported as far away as practicable. The networks of pipes intended for these different purposes interact, however. Leaks from drinking water pipes, from storm drains, and from sanitary sewers all contribute to urban groundwater, and often contaminate or add water to the other networks. Groundwater that would otherwise contribute to the flow in urban streams can be lost to sewers and drains. Further complications of urban watersheds arise from the ubiquity of impervious surface, the resultant depletion of groundwater, and the alterations of transpiration by irrigation and changes in vegetation cover. Nevertheless, the watershed is useful because it promotes a bookkeeping approach to the water in cities, exposes how that water interacts with other materials, and how the arrangement of surfaces and human institutions affects water flow and contamination (Cadenasso et al. 2008). The watershed concept also helps connect with the larger, regional context, in this case, the Chesapeake Bay estuary.

At broad scales in Baltimore, to have more than a 50-percent chance of observing at least one cavity-nesting bird requires more than 35 percent of tree canopy cover within a one-kilometre radius.

FIG. 3. A patch array in the Glyndon area of Baltimore County, showing bare ground prepared for suburban construction near an older commuter village and light industrial area. The map represents HERCULES, novel urban land cover classification (Cadenasso et al. 2007) (Image: BES LTER).

FIG. 5. A stormwater detention pond in a residential suburb of Baltimore (Photo: Chris Swan).

FIG. 4. Lifestyle groups based on market segmentation and their association with the amount of urban tree canopy, shown by the relative height of the bars.

Patch dynamics

The first two frameworks each contain dynamic elements. The human ecosystem includes cycles that emphasise that individuals, organisations, and social networks change through time (Fig. 1). Likewise, the watershed refers to volumes and surfaces that have been manifestly shaped by the flow of water over time. However, lest these two frameworks be taken to present fixed templates, patch dynamics provides an antidote.

Patch dynamics sees all spatial arrays or landscapes as dynamic (McGrath et al. 2007). Patches are discrete areas that differ from their neighbours in one or more of three features: structure, composition, and function (Fig. 3). In urban systems, patches can be discriminated by key features. Structural discrimination can be based on: the presence and kind of surface, whether bare or paved; the presence and kind of vegetation, whether tree canopy or herbaceous cover; and the kind and coverage of buildings (Cadenasso et al. 2007). Functionally, patches can be discriminated based on demographic parameters, such as ethnicity, national origin, education attained, and income. Social differentiation among patches can exist as lifestyle groupings (Fig. 4). Such groups reveal the "ecology of prestige" in which social identity affects the environmental decisions that households make (Grove et al. 2006). Biodiversity can be directly affected by lifestyle through the desire for different kinds of landscaping, the level of lawn maintenance, the contrast between front- and backyards, or the preference for flower or vegetable gardens. The structure of families is important as well, determining whether there are young children for whom a play lawn is maintained. Of course, availability of exotic species, regulations about yard maintenance, the nursery and lawn care industries, and housing age can be factors in urban biodiversity as well.

Sampling Biodiversity: Scale and Partnerships

Biodiversity in Baltimore is impacted by decisions made at the lot, block, and neighbourhood scales. Sampling of vegetation included 400 randomly located vegetation and structural sampling points throughout the Baltimore region. Sampling for nutrient dynamics is conducted in both forest and lawn plots located in small watersheds that differ in land use and land cover. Sampling for soil organisms has been conducted in remnant forests, parks, and residential lots. Riparian or streamside and upland plant communities are sampled in pairs. Finally, aquatic sampling is conducted across stream and storm drain networks or stormwater detention ponds that contrast in social and physical features. These sampling strategies permit BES to address various spatial and organisational scales.

Partnerships are crucial for sampling urban areas. The collaborations supporting research on biodiversity in Baltimore, like our sampling strategy above, span from the individual parcel, to the neighbourhood, to the jurisdictional scale of counties. This range of scales requires interaction with individual owners or renters, communities that have an interest in open space regardless of its ownership, formal neighbourhood associations, municipal arborists, parks managers, municipal decision makers, and state environmental and natural resource managers. The individual residents in Baltimore, who are the most difficult to reach in our research and the most difficult to engage in biodiversity management and conservation, are the least known component.

Partnership with a community is exemplified by that in the suburban neighbourhood around Cub Hill. The hill itself supports a sophisticated atmospheric sampling tower. In order to correlate biological diversity with the atmospheric and environmental data from around the tower, BES investigators attended many community association meetings to explain the goals, sampling methods, and benefits of the study. Most residents were extremely helpful and welcoming of sampling in their yards. Once the sampling had been done, a one-page report was mailed to residents, including colour reproductions of the large research posters that the participating students had prepared. Other communities have also been engaged in sampling. For example, a partnership with the leaders of an after-school programme in the Rognel Heights neighbourhood was one with unexpected outcomes. While we had expected to share the process of scientific inquiry and results about forest composition in the nearby park with the students participating in the programme, we had not anticipated the fact that the survival of our plots and the security of our samplers would also benefit from the influence of the community leaders who ran the programme.

Partnerships for sampling and sharing information have also centred on teachers and pre-college students. Teacher workshops have been focused on soil biodiversity as an urban resource for education. BES scientists have participated in teacher workshops, and have visited classrooms and after-school

MAJOR HABITAT CATEGORY	GROWTH FORM	ORIGIN	NO. OF SPECIES
Total Species, Upland & Wetland			147
	Trees	Native & Exotic	59
	Herbs	Native & Exotic	88
	Trees	Exotic	10
	Herbs	Exotic	45
Total Upland Species			56
	Trees		23
		Native	17
		Exotic	6
	Shrubs and Herbs		33
		Native	13
		Exotic	20
Total Wetland Species			20
	Trees		10
		Native	8
		Exotic	2
	Shrubs and Herbs		10
		Native	5
		Exotic	5

TABLE 1. Plant species found in the Gwynns Falls Watershed, metropolitan Baltimore, Maryland. All species, species specialised on upland habitats, and species found in wetland habitats are enumerated. For each of these groups, trees, herbs, and shrubs have been separated, as are the number of species that are native to the Baltimore region compared to those that originated from elsewhere in the world or were introduced from elsewhere in North America.

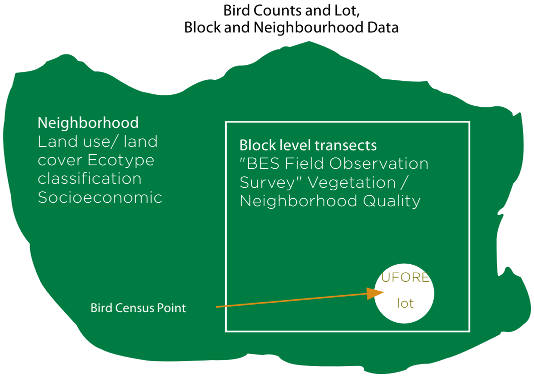

FIG. 6. A schematic showing the different scales of data collection used to document bird biodiversity in Baltimore, and its relationships to other processes.

FIG. 8. An analysis of tree canopy (dark green) and lawn (light green) in privately held property parcels in Baltimore City. Public rights of way are excluded.

FIG. 7. Riparian forest along the Gwynns Falls, Baltimore (Photo: BES LTER).

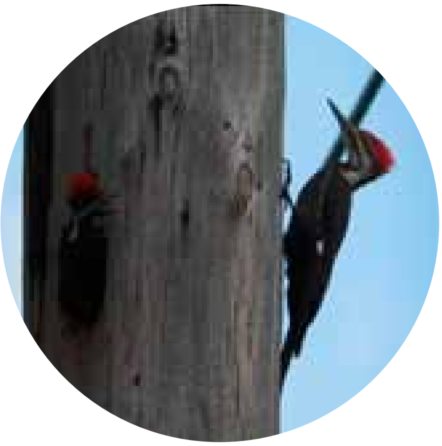

FIG. 9. Pileated woodpeckers exploiting a wooden utility pole (Photo: James P. Smith).

programmes to explain and sample soil biodiversity. These efforts produced teaching modules shared with schools and teachers in the Baltimore area. High school students and disadvantaged youth in a green careers programme visited Szlavecz's laboratory and conducted soil animal sampling on the Johns Hopkins University campus.

Biodiversity Patterns in Baltimore

BES researchers have studied a variety of aspects of biodiversity (Swan et al. 2011; Szlavecz et al. 2011).

Aquatic biodiversity

Aquatic plants and animals have long served as sensitive indicators of human interactions with urban waters. Stormwater detention ponds (Fig. 5) are designed to capture precipitation in order to reduce flooding and the delivery of contaminants from paved surfaces to streams and rivers. These ponds, however, now harbour highly structured ecological communities. Ponds in residential areas support the biodiversity of small crustaceans, which amount to nearly twice of that in commercial ponds. This suggests an opportunity to improve urban aquatic biodiversity through the management of the landscape around these built habitats.

Birds and urban environment

Bird diversity was related to environmental characteristics at different scales (Fig. 6). The lot-level research reveals that bird species composition is positively related to the percentages of tree cover, maintained lawn, and unmaintained grass. Negative predictors are the percentages of building cover and paved surface. At the city block scale, variables are selected to describe blocks as patches. Positive predictors were the number of trees, number of housing units with trees, and number of shrubs. A negative predictor was the number of housing units. At the neighbourhood scale, positive predictors were the percentages of tree canopy cover, buildings, and non-tree vegetation. Several of the US census block groups examined were unimportant, including the percentage of residents older than 25 years of age holding a bachelor's degree, percentage of African-Americans, and percentage of single-parent households receiving public assistance.

Distributions of exotic riparian species along an urban-to-rural gradient

A gradient of habitat types ranging from rural or agricultural to suburban, and ultimately to urban, provides a useful window into urban biodiversity. In riparian habitats along such an urban-rural gradient in Baltimore, 147 plant species were identified. Of these, 54 were introduced from Eurasia or elsewhere in North American. Although only 25 percent of the tree species and 27 percent of the shrub species were exotic, 47 percent of the herbs were exotic (Table 1).

Exotic trees occurred primarily in the urbanised areas, where they have been widely planted. The most important species was the tree of heaven, followed by the white mulberry. The most abundant exotic shrubs were multiflora rose and Japanese honeysuckle. Native herbs were primarily wetland species, while exotics are predominantly upland species. Except for ground ivy, exotic herbs occurred in discrete locations, albeit abundantly. The restricted distributions of exotic herbs indicate that only a few of these plants are generalists, and suggest that the highly disturbed riparian area in Baltimore (Fig. 7) has provided many opportunities for exotic species to become established.

Geologic controls on tree distributions in the Gwynns Falls watershed

In spite of the importance of human intervention in the biodiversity, significant natural relationships remain in the urban region. Geologically, the upstream areas of the watershed are underlain by schist with some serpentinite. Amphibolite, gneiss, and schist dominate the middle section, while downstream, as far as the Fall Zone, is characterised by amphibolite and mafic rocks. Downstream from the Fall Zone are Coastal Plain sands, clays, and human-generated fill.

Different geologies generate different soils, with those weathered from schist providing the most desirable habitat for trees, followed by gneiss, amphibolite, with mafic being the poorest habitat. Only four of the 45 species found in an extensive sample occurred on all substrates: red maple, green ash, black gum, and black cherry. Box elder, most common in riparian zones, was restricted to amphibolite and clay-sand soils. American beech occurred abundantly but only on amphibolite. Red oak was the most widespread of the oaks, while white oak, blackjack oak, and post oak were restricted to amphibolite and mafic soils. Despite a heterogeneous history of land use along the gradient, geology plays a fundamental role in the distribution of upland trees, and thus remains a driver of urban biodiversity.

Urban tree canopy

Baltimore City intends to double its tree canopy cover by 2030, and Baltimore County has long worked to reduce forest fragmentation and promote sustainable management. There are several reasons to value forest cover, including the: mitigation of urban heat stress; reduction and filtration of stormwater; promotion of healthy, outdoor-oriented lifestyles; sequestration of carbon; calming of traffic and social interactions; and provision of a focus for neighbourhood action.

The interaction of BES with policy makers helped identify the need for increasing urban tree canopy and strategise where increased tree canopy would be most beneficial. Furthermore, this research demonstrated that if the goals are to be met, the residents on private property, which occupies 85 percent of Baltimore City's plantable area (Fig. 8), must be engaged (Galvin et al. 2006). An array of social groups differentially express the ecology of prestige, as mentioned earlier. Acknowledging the variety of social motivations, capacities, and constraints that affect neighbourhood or parcel-by-parcel support of tree planting is an important step in the effort to double Baltimore's urban tree canopy. This effort has great potential to enhance biodiversity in Baltimore.

Precipitous losses of urban trees in forested regions of the United States have raised concerns over effects on local climate, water quality, and neighbourhood vitality. Less attention has been paid to implications for biodiversity, however. At both broad and local scales, the decline of urban forests has clear impacts on wildlife. For species dependent on dead wood, such as cavity-nesting birds (Fig. 9), those effects may be complex. At broad scales in Baltimore, to have more than a 50-percent chance of observing at least one cavity-nesting bird requires more than

35 percent of tree canopy cover within a one-kilometre radius. At the scale of individual trees, however, cavity nesters may benefit from the acceleration of decay in urban trees caused by stresses of urban life.

Biodiversity in the soil

Important biodiversity in urban areas is hidden in the soil. Today, more and more studies recognise the crucial role of soil organisms in nutrient circulation, especially in the formation and retention of soil organic matter, which is key in global carbon cycling and climate (Szlavecz et al. 2011). Soil organisms are fundamental to the food webs that birds and other larger animals depend on in cities and suburbs. Because soils, even in cities, can harbour a diverse biological community, they can contribute to ecosystem services in urban ecosystems. Yet, soil biodiversity is poorly known, both in urban and more pristine areas. Species new to science have been found in Baltimore, New York, and other urban soils.

Indeed, soil biodiversity responds to a complex range of habitats and combinations of natural and human disturbances. Habitats that remain after agricultural or native habitats are converted to urban uses can be important refugia for soil organisms. At the same time, the novel habitats created by construction and land modification in cities can harbour new soil faunas. Green roofs, greenhouses, basements and cellars, and soils sealed beneath pavements are habitats characteristic of urban systems. Ants, and very likely earthworms, can live beneath pavements as long as there are cracks for access. Isopods or "pillbugs" are also among the most successful soil organisms in cities (Fig. 10).

Whether urban soil biodiversity is lower or higher than the previous habitat depends on the nature of that historical habitat. The replacement of large-scale agricultural fields with suburbs, with their more diverse plantings and finer-scale spatial heterogeneity, can actually increase soil biodiversity. In contrast, the replacement of forest can reduce soil biodiversity. The composition of urban soil communities can be affected by a number of additional factors. Among the most important are: the accidental introduction of species associated with the transport of live plants in soil by horticultural trade, the impact of fertilisers, and the exclusion of some species by pesticides. Heavy metal pollution and alteration of soils by excavation and filling, or by the removal of leaf litter, are further limits on soil organisms. However, there is a component of urban soil fauna in temperate zones that are "people followers", and which tend to homogenise the composition of cities in similar climates. The net result of all these controls on soil biodiversity is often a surprisingly similar richness of species between city and countryside, even though the identities of species in the two extremes may be quite different.

The study of soil biodiversity in Baltimore and other cities reveals that urban soil is not just sterile, lifeless "dirt". Rather, there is a surprisingly rich soil community that conducts useful ecological work in the circulation of nutrients, the control of carbon, and the supply of food to larger organisms that people value in cities.

Biodiversity in neglected sites

Not all biodiversity resides in lovingly managed sites. There are many habitat types that are incidental, or not purposefully managed. Vacant lots and derelict spaces, such as abandoned industrial sites, lightly managed rights-of-way, or forgotten slivers of private property are examples. In the vacant lots of nine square blocks of west Baltimore City (Fig. 11), Erica Tauzer documented 117 plant species. Such areas may serve as a source of biological capacity, a location for unstructured play, and a bit of nearby nature. Of course there are negative perceptions and problems associated with vacant lots, not the least of which is the absence of culturally recognised "cues to care" (Nassauer and Corry 2004) in such sites. However, these neglected and undervalued lands have a role, along with forested parks and meadows, yards, and gardens, in maintaining the biophysical functions within urban areas. Research and education about their contribution to biodiversity and ecosystem services in urban areas are urgently needed.

Designing with Ecology in Mind

Practising urban design with ecology in mind has advantages for the functioning of urban ecosystems (Spirn 1984). First, it presents an opportunity to enhance biodiversity. Because biodiversity is a fundamental ingredient of the adaptability of ecological systems, designs that maintain space and programmatic roles

FIG. 10. Examples of four cosmopolitan or "people follower" soil invertebrates found in cities, all of which are common in Baltimore's forests and residential yards and in many other cities in the temperate region. The top two are species of isopod, originally from Europe: *Oniscus asellus* and *Porcellio scaber* (Photos: Katarina Juhaszova). Below are two species of earthworms: *Amynthas hilgendorfi* (fourth from top), originally from Asia, and *Lumbricus rubellus* (third from top), originally from Europe (Photos: Chih-Han Chang).

FIG. 11. Abandoned lots are a potential resource for biodiversity and for local communities (Photo: BES LTER).

FIG. 12. A design combining: rooftop- and soil-based water harvesting, filtering, and storage; greening and recreational space; and wind energy capture. Plots for biofuel and urban agriculture are also provided (Design: Sven Augusteyns, Parsons—KU Leuven design project, supervised by B. McGrath).

FIG. 13. Sequence of activities to implement the biodiversity study in New York, including site preparation, soil amendments, plant procurement, marking the plots, and planting (Photos: Alex Felson).

for biodiversity can contribute to the capacity of urban areas to respond to both anticipated and unexpected changes.

Second, design with ecology in mind provides an opportunity to enhance the contribution of biological processes to the health of the urban ecosystem and the wellbeing of its residents. Values include reducing the reliance on energy-intensive hard engineering, moderating the heat extremes of urban microclimates, reducing stormwater runoff and contamination, and psychological and physical health benefits to people. Enhancing biodiversity and ecosystem functioning can be important parts of the design of new urban neighbourhoods or systems and in revitalising older ones.

Designs that incorporate biodiversity and the role of ecological processes in green space are exemplified in Baltimore. A recent collaboration between Parsons The New School for Design and Katholieke Universiteit Leuven in Belgium has produced designs that combine water management, urban agriculture, energy harvesting, and neighbourhood greening in east Baltimore (Fig. 12). BES shares designs with the Baltimore City Office of Sustainability, which aims to meet the needs of citizens and environmental quality citywide.

Design As Experiment

An example of a large design as experiment (Felson and Pickett 2005) comes from the New York City Afforestation Project (NY-CAP). A component of the MillionTreesNYC initiative, it includes a large experiment to study the relationship between biodiversity and ecosystem function in the city (Fig. 13). The experimental design includes differences in compositional, structural, and functional plant diversity. Given that the effect of species diversity on the functioning of ecosystems has been debated over the last two decades (Naeem et al. 2009), and that most of the experiments supporting the hypothesis that species richness leads to greater ecosystem functioning have been performed on non-urban sites (Knops et al. 1999; Tilman 1999), there is a pressing need to discern the role of biodiversity in the performance of constructed aspects of urban ecosystems. With the promotion of green infrastructure projects in cities across the world, NY-CAP will help redress the lack of evidence connecting the performance of these urban ecosystem projects with their anticipated ecosystem services (Pataki et al. 2011).

A smaller-scale experiment is illustrated by a partnership between BES and the Baltimore City Department of Public Works. This project has examined best management practices (BMPs) for stormwater management, such as curb-cut rain gardens and regreened street verges, installed in a storm drain watershed in an old rowhouse neighbourhood in Baltimore. Comparison with small catchments in which BMPs have yet to be installed demonstrated improvements in water quality. However, the comparison also pointed to puzzling complications in the water budget of old, center city storm water catchments.

Conclusion

The BES is an example of an integrated approach to social-ecological research and education in spatially complex and extensive urban system. It has employed three linked conceptual frameworks to bring together researchers trained in different social and biophysical disciplines. Furthermore, a scaled sampling strategy has allowed relationships between drivers and response variables in both the social and biophysical realms to be examined across a similarly broad array of scales. This multi-scalar sampling approach has depended on partnerships that extend from individuals, through communities, to NGOs, and to government agencies. Biodiversity, with the ecosystem services and adaptive capacity it represents, has emerged as an additional focus that has engaged the various academic disciplines within the project. However, the concern with the biological richness and function of the entire urban system has also proven to be a productive focus for engaging urban design, urban managers, and policy makers. Altogether, BES has demonstrated a new approach to the ecology of the city.

References:

Cadenasso, M.L., S.T.A. Pickett, P.M. Groffman, L.E. Band, G.S. Brush, M.F. Galvin, J.M. Grove, G. Hagar, V. Marshall, B.P. McGrath, J.P.M. O'Neil-Dunne, W.P. Stack, and A.R. Troy. 2008. "Exchanges across land-water-scape boundaries in urban systems: strategies for reducing nitrate pollution." *Annals of the New York Academy of Sciences* 1134: 213-232.

Cadenasso, Mary L., Steward T.A. Pickett, and Morgan J. Grove. 2006. "Integrative approaches to investigating human-natural systems: the Baltimore Ecosystem Study." *Natures, Sciences, Sociétés* 14: 1-14.

Cadenasso, Mary L., Steward T.A. Pickett, and Kirsten Schwarz. 2007. "Spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification." *Frontiers in Ecology and Environment* 5: 80-88.

Felson, Alexander J., and Steward T.A. Pickett. 2005. "Designed experiments: new approaches to studying urban ecosystems." *Frontiers in Ecology and Environment* 3: 549-556.

Galvin, Michael F., J. Morgan Grove, and Jarlath P.M. O'Neil-Dunne. 2006. *A report on Baltimore City's present and potential urban tree canopy*. Maryland Department of Natural Resources, Forest Service.

Grove, J. Morgan. 2009. "Cities: managing densely settled social-ecological systems." In *Principles of ecosystem stewardship: resilience-based natural resource management in a changing world*, edited by F. Stuart Chapin III, Gary P. Kofinas, and Carl Folke, 281-294. New York: Springer.

Grove, J.M., A.R. Troy, J.P.M. O'Neil-Dunne, William R. Burch, M.L. Cadenasso, and S.T.A. Pickett. 2006. "Characterization of households and its implications for the vegetation of urban ecosystems." *Ecosystems* 9: 578-597.

Knops, Johannes M.H., David Tilman, Nick M. Haddad, Shahid Naeem, Charles E. Mitchell, John Haarstad, Mark E. Ritchie, Katherine M. Howe, Peter B. Reich, Evan Siemann, and James Groth. 1999. "Effects of plant species richness on invasion dynamics, disease outbreaks, insect abundances and diversity." *Ecology Letters* 2: 286-293.

Machlis, Gary E., Jo Ellen Force, and William R. Burch Jr. 1997. "The Human Ecosystem Part 1: The Human Ecosystem as an Organizing Concept in Ecosystem Management." Soci*ety & Natural Resources* 10: 347-367.

McGrath, Brian P., Victoria Marshall, Joel Towers, and Richard Plunz, eds. 2007. *Designing patch dynamics*. New York: Columbia University Graduate School of Architecture, Preservation and Planning.

Naeem, Shahid, Daniel E. Bunker, Andy Hector, Michel Loreau, and Charles Perrings, eds. 2009. *Biodiversity, ecosystem functioning, and human wellbeing: an ecological and economic perspective*. New York: Oxford University Press.

Nassauer, Joan I., and Robert C. Corry. 2004. "Using normative scenarios in landscape ecology." *Landscape Ecology* 19: 343-356.

Pataki, Diane E., Margaret M. Carreiro, Jennifer Cherrier, Nancy E. Grulke, Viniece Jennings, Stephanie Pincetl, Richard V. Pouyat, Thomas H. Whitlow, and Wayne C. Zipperer. 2011. "Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions." *Frontiers in Ecology and the Environment* 9: 27-36.

Pickett, Steward T.A., Mary L. Cadenasso, J. Morgan Grove, Christopher G. Boone, Peter M. Groffman, Elena Irwin, Sujay S. Kaushal, Victorial Marshall, Brian P. McGrath, C.H. Nilon, R.V. Pouyat, Katalin Szlavecz, Austin Troy, and Paige Warren. 2011. "Urban ecological systems: scientific foundations and a decade of progress." *Journal of Environmental Management* 92: 331-362.

Spirn, Anne W. 1984. *The granite garden: urban nature and human design*. New York: Basic Books.

Swan, C.M., S.T.A. Pickett, K. Szlavecz, P. Warren, and K.T. Willey. 2011. "Biodiversity and community composition in urban ecosystems: coupled human, spatial, and metacommunity processes." In *Handbook of Urban Ecology*, edited by J. Niemela, 179-186. New York: Oxford University Press.

Szlavecz, Katalin, Paige Warren, and Steward Pickett. 2011. "Biodiversity on the urban landscape." In *Human population: its influences on biological diversity*, edited by Richard P. Cincotta, and Larry J. Gorenflo, 75-101. New York: Springer.

Tilman, David. 1999. "The ecological consequences of changes in biodiversity: A search for general principles." *Ecology* 80, no. 5: 1455-1474.