Chapter 16
Building an Urban LTSER: The Case of the Baltimore Ecosystem Study and the D.C./B.C. ULTRA-Ex Project

J. Morgan Grove, Steward T.A. Pickett, Ali Whitmer, and Mary L. Cadenasso

Abstract There is growing scientific interest, practical need, and substantial support for understanding urban and urbanising areas in terms of their long-term social and ecological trajectories: past, present, and future. Long-term social-ecological research (LTSER) platforms and programmes in urban areas are needed to meet these interests and needs. We describe our experiences as a point of reference for other ecologists and social scientists embarking on or consolidating LTSER research in hopes of sharing what we have learned and stimulating comparisons and collaborations in urban, agricultural, and forested systems. Our experiences emerge from work with two urban LTSERs: the Baltimore Ecosystem Study (BES) and the District of Columbia-Baltimore City Urban Long-Term Ecological Research Area-Exploratory DC-BC ULTRA-Ex project. We use the architectural metaphor of constructing and maintaining a building to frame the description of our experience with these two urban LTSERs. Considering each project to be represented as a building gives the following structure to the chapter: (1) building site context; (2) building structure; and (3) building process and maintenance.

J.M. Grove, Ph.D. (✉)
Northern Research Station, US Department of Agriculture Forest Service, Baltimore, MD, USA
e-mail: mgrove@fs.fed.us

S.T.A. Pickett, Ph.D.
Cary Institute of Ecosystem Studies, Millbrook, NY, USA
e-mail: picketts@caryinstitute.org

A. Whitmer, Ph.D.
Georgetown University, Washington, DC, USA
e-mail: whitmer@georgetown.edu

M.L. Cadenasso, Ph.D.
Department of Plant Sciences, University of California, Davis, CA, USA
e-mail: mlcadenasso@ucdavis.edu

S.J. Singh et al. (eds.), *Long Term Socio-Ecological Research*, Human-Environment Interactions 2, DOI 10.1007/978-94-007-1177-8_16,

Keywords Urban Ecology • LTSER • Social Ecology • Baltimore • Sustainability

16.1 Introduction: A Building Tour

In this chapter, we address the challenge of building long-term social-ecological research (LTSER) platforms and programmes in urban areas. The motivation for addressing this challenge is that there is growing scientific interest, practical need, and substantial support for understanding urban and urbanising areas in terms of their long-term social and ecological trajectories: past, present, and future.

We present this overview of our experiences as a point of reference for other ecologists and social scientists embarking on or consolidating LTSER research in hopes of sharing what we have learned and stimulating comparisons and collaborations in urban, agricultural, and forested systems. Our experience emerges from work with two urban LTSERs: the Baltimore Ecosystem Study (BES) and the District of Columbia-Baltimore City Urban Long-Term Ecological Research Area-Exploratory – DC-BC ULTRA-Ex – project. The two projects partially overlap in their geography, but are motivated and structured differently. Hence, this chapter benefits from both similar and contrasting experiences.

We use the architectural metaphor of constructing and maintaining a building to frame the description of our experience with two these urban LTSERs. Considering each project to be represented as a building gives the following structure to the chapter (1) building site context, (2) building structure, and (3) building process and maintenance.

16.2 Building Site Context: Historical Origins of the Baltimore Ecosystem Study

The history of BES is an important thread in the emergence of urban ecological science in the United States. Although ecological thinking had been applied to American cities by specialists in social sciences, geography, planners, and urban designers, these important strands did not have very much empirical input from scientists trained in ecology. Urban wildlife ecology had been well developed, and there were also empirical studies to assess effects of urban contaminants (Vandruff et al. 1994), yard management (Loucks 1994), or urban metabolism (Boyden 1979). Calls for concerted action in the 1970s were cogent and forward looking, but ultimately they did not fundamentally expand the focus of ecological science to cities (Stearns 1970; Stearns and Montag 1974). In this relative empirical desert BES was established.

The roots of BES are in comparative ecological science conducted in the New York metropolitan region. Dr. Mark McDonnell, then of the Cary Institute of Ecosystem Studies in his role as forest ecologist for the New York Botanical Garden (NYBG) in the Bronx, New York, planted a seed which prepared the way for BES and which we believe was crucial in establishing contemporary urban ecological science in the US. When he and Dr. Carl White attempted to compare the nitrogen metabolism in the old growth forest on the grounds of the NYBG in 1985, they discovered the soils to be hydrophobic. Although this phenomenon was known from other cities, the finding stimulated McDonnell to broaden his comparison between the urban forest and other oak forests on similar substrates but located at greater distances from the New York City urban core. Ultimately, this comparison became known as the Urban-rural Gradient Ecology (URGE) project, and was advanced by interactions with Dr. Richard Pouyat, and an increasingly broad group of ecological researchers such as Dr. Margaret Carreiro.

With support from the Cary Institute of Ecosystem Studies under the leadership of Dr. Gene Likens, a postdoctoral researcher in geography, Dr. Kimberly Medley was hired as the first expert in social structures and processes to join the collaboration. The URGE project could soon claim a plethora of findings concerning soil contamination, nitrogen loading, denitrification, the role of exotic earthworms and different fungi, and forest structure along the gradient, for example (McDonnell et al. 1997; Pouyat et al. 2009). Attempts to increase the scope of the study by adding social science and economic collaborators beyond the expertise provided by Medley met with little success, due perhaps to limited interactions at the time between the social sciences and ecological sciences in general, and to the high level of prior commitment that characterised the social scientists McDonnell and colleagues approached.

In 1993, McDonnell became director of the Bartlett Arboretum, the Connecticut State Arboretum. Research on the New York metropolitan URGE project began to be carried out in diverse institutional homes of the established collaborators and as graduate students and post-doctoral associates moved on to other positions. Continued efforts to establish working relationships with social scientists bore fruit when Pouyat introduced McDonnell and Steward Pickett to his colleague in the USDA Forest Service, Dr. J. Morgan Grove, and through him to the social ecologist Dr. William R. Burch, Jr., from Yale University's School of Forestry and Environmental Studies and to their decade long research project in Baltimore, Maryland (Grove and Hohmann 1992). The desire of Grove and Burch to familiarise the ecologists with their social science research and community engagement resulted in a field trip to Baltimore. It became clear that these social scientists had established extensive social capital, including "street cred" in Baltimore. Their social networks with communities, action-oriented Non-Governmental Organisations (NGOs), and key environmentally relevant Baltimore city agencies were a precious and site-specific resource. If the desire to increase integration between biophysical science and social science were to be fulfilled, Baltimore seemed to be an ideal place to realise that goal. Pickett's position permitted him the freedom to pursue funding opportunities using Baltimore as a research arena. Over the next few years, colleagues interested in Baltimore, some from Baltimore area institutions like the University of Maryland, Baltimore County, and Johns Hopkins University were courted and became contributors to an emerging intellectual framework to support integrated biophysical and social research and outreach in Baltimore.

These efforts positioned the informal network of researchers to respond forcefully to the National Science Foundation's (NSF) call for proposals for up to two urban Long-Term Ecological Research sites in the United States. These urban sites would complement some two dozen other LTER sites that had been established across the United States to understand the structure and functioning of forested, grassland, agricultural, coastal, lake, river, and tundra ecosystems. The programme officers at NSF, especially the late Dr. Thomas Callahan, were convinced that ignoring urban systems left a gap in the understanding of America's diversity of ecological systems.

The initial team that produced the proposal included soil scientists, vegetation ecologists, ecological economists, social scientists, educators, landscape ecologists, spatial analysts, paleoecologists, hydrologists, microbial ecologists, climatologists, geomorphologists, and wildlife ecologists. The team included graduate and postdoctoral students, leaders in the NGO Parks & People Foundation, senior researchers from academic institutions and federal agencies including the USDA Forest Service and the US Geological Survey. Indeed, as budget planning proceeded, it became clear that the in-kind support for research and staff time from the USDA Forest Service under the leadership of Dr. Robert Lewis of the (then) Northeastern Research Station would exceed the funds available from NSF. Partnerships were sought with managers and policy makers from Baltimore City, Baltimore County and the State of Maryland, including environmental officers and school officials.

Various options for a Baltimore home, given that the proposed grantee institution would be the Cary Institute of Ecosystem Studies in Millbrook, NY, were sought. Ultimately the enthusiastic support of Dr. Freeman Hrabowski, III, President of the University of Maryland, Baltimore County to host the Baltimore offices and labs of the new urban LTER led to the establishment of a convenient and intellectually engaging home for the project. The Baltimore Ecosystem Study, named analogously to the Hubbard Brook Ecosystem Study LTER from which we drew inspiration for the experimental watershed approach, was established in November of 1997. As a result of the same competition, the NSF also funded the Central Arizona-Phoenix LTER, headquartered at Arizona State University and led by stream ecosystem ecologist Dr. Nancy Grimm, and archaeologist Dr. Charles Redman.

16.3 Building Structure

16.3.1 Why We Seek to Know

16.3.1.1 Practical Motivations

There are several motivations for developing LTSER research focused on urban and urbanising areas. From a practical perspective, it is essential to recognise that *the Earth is an urban planet*. In 1800, about 3% of the world's human population lived in urban areas. By 1900, this proportion rose to approximately 14% and exceeded 50% by 2008. Every week nearly 1.3 million additional people arrive in the world's cities, amounting to a total of about 70 million a year (Brand 2006; Chan 2007). The urban population of the globe is projected by the UN to climb to 61% by 2030 and eventually reach a dynamic equilibrium of approximately 80%

urban to 20% rural dwellers that will persist for the foreseeable future (Brand 2006; Johnson 2006). This transition from 3% urban population to the projected 80% urban is a massive change in the social-ecological dynamics of the planet (Brand 2009; Seto et al. 2010).

The spatial extent of urban areas is growing as well. In industrialised nations the conversion of land from wild and agricultural uses to urban and suburban settlement is growing at a faster rate than the growth in urban population. Cities are no longer compact (Pickett et al. 2001); they sprawl in fractal or spider-like configurations (Makse et al. 1995) and increasingly intermingle with wild lands. Even for many rapidly growing metropolitan areas, suburban zones are growing faster than other zones (Katz and Bradley 1999). The resulting new forms of urban development include edge cities (Garreau 1991) and a wildland-urban interface in which housing is interspersed in forests, shrublands, and desert habitats.

An important consequence of these trends in urban growth is that cities have become *the dominant global human habitat* of this century in terms of geography, experience, constituency and influence. Accompanying the spatial changes are changes in perspectives and constituencies. Although these urbanising habitats were formerly dominated by agriculturists, foresters and conservationists, they are now increasingly dominated by people possessing resources from urban systems, drawing upon urban experiences and expressing urban habits. This reality has important consequences for social and ecological systems at global, regional and local scales, as well as for natural resource organisations attempting to integrate ecological function with human desires, behaviours and quality of life.

From Local to Global, Cities Play a Critical Role in Climate Change Vulnerabilities, Mitigation, and Adaptation

Urbanisation creates both ecological vulnerabilities and efficiencies. For instance, coastal areas, where many of the world's largest cities occur, are home to a wealth of natural resources that are rich with diverse species, habitat types and productive potential. They are also vulnerable to land conversion, changes in hydrologic flows, outflows of sediment and waste and sea level rise (Grimm et al. 2008). In the US, 10 of the 15 most populous cities are located in coastal counties (NOAA 2004) and 23 of the 25 most densely populated US counties are in coastal areas. These areas have already experienced ecological disruptions (Couzin 2008).

While ecological vulnerabilities are significantly associated with urban areas, urbanisation also fosters ecological efficiencies. The ecological footprint of a city, i.e., the land area required to support it, is quite large (Folke et al. 1997; Johnson 2006; Grimm et al. 2008). Cities consume enormous amounts of natural resources, while the assimilation of their wastes – from sewage to the gases that cause global warming – are also distributed over large areas. London, for example, occupies 1,70,000 ha and has an ecological footprint of 21 million hectares – 125 times its size (Toepfer 2005). In Baltic cities, the area needed from forest, agriculture, and marine ecosystems corresponds to approximately 200 times the area of the cities themselves (Folke et al. 1997).

Ecological footprint analysis can be misleading, however, for numerous reasons (Deutsch et al. 2000). It ignores the more important question of efficiency, defined here as persons-to-area: how much land area (occupied area and footprint area) is needed to support a certain number of persons? From this perspective, it becomes clear that urbanisation is critical to delivering a more ecologically sustainable and resource-efficient world because the per-person environmental impact of city dwellers is generally lower than people in the countryside (Brand 2006; Johnson 2006; Grimm et al. 2008). For instance, the average New York City resident generates about 29 % of the carbon dioxide emissions of the average American. By attracting 9,00,000 more residents to New York City by 2030, New York City can actually save 15.6 million metric tons of carbon dioxide per year relative to the emissions of a more dispersed population (Chan 2007). The effects of urbanisation on ecological efficiency may mean that social-ecological pressures on natural systems can be dramatically reduced in terms of resources used, wastes produced, and land occupied. This may mean that cities can provide essential solutions of mitigation and adaptation to the long-term social-ecological viability of the planet, given current population trends for this century.

Current global demographic trends are paralleled by changing conceptions of cities and urbanisation. In very broad historical terms we have begun a new paradigm for cities. Since the 1880s, a great deal of focus has centred on the "Sanitary City," with concern for policies, plans and practices that promoted public health (Melosi 2000). While retaining the fundamental concern for the Sanitary City, we have begun to envelop the Sanitary City paradigm with a concern for the "Sustainable City," which places urbanisation in a social-ecological context at local, regional and global scales (Pincetl 2010).

Urban ecology and long-term studies have a significant role to play in this context. Already, urban ecology has an important applied dimension as an approach used in urban planning, especially in Europe. Carried out in city and regional agencies, the approach combines ecological information with planning methodologies (Hough 1984; Spirn 1984; Schaaf et al. 1995; Thompson and Steiner 1997; Pickett et al. 2004; Pickett and Cadenasso 2008).

Major investments in urban ecology theory, data, and practices are required to meet the needs of cities and urbanising areas. Cities face challenges that are increasingly complex and uncertain. Many of these complexities are associated with changes in climate, demography, economy, and energy at multiple scales. Because of these complex, interrelated changes, concepts such as resilience (Gunderson 2000), vulnerability (Turner et al. 2003), and ecosystem services (Bolund and Hunhammar 1999) may be particularly useful for addressing both current issues and preparing for future scenarios requiring long-term, and frequently capital-intensive, change.

Cities have already begun to address these challenges and opportunities in terms of policies, plans, and management. For example, on June 5th, 2005, mayors from around the globe took the historic step of signing the Urban Environmental Accords – Green City Declaration with the intent of building ecologically sustainable, economically dynamic and socially equitable futures for their urban citizens. The Accords covered seven environmental categories to enable sustainable urban living

Applied and Basic Research

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

Fig. 16.1 In *Pasteur's Quadrant*, Stokes categorises four different types of research. Most research associated with BES would be located in Pasteur's quadrant: Use-inspired basic research (Adapted from Stokes 1997)

and improve the quality of life for urban dwellers: (1) energy, (2) waste reduction, (3) urban design, (4) urban nature, (5) transportation, (6) environmental health, and (7) water (http://www.citymayors.com/environment/environment_day.html). International associations such as *ICLEI-Local Governments for Sustainability* (http://www.iclei.org/) are developing and sharing resources to address these issues. The ability to address these seven categories will require numerous, interrelated strategies and scientific domains.

16.3.1.2 Scientific Motivations

There are diverse scientific motivations for examining urban areas as LTSERs. Stokes (1997) offers a useful heuristic, *Pasteur's Quadrant* (Fig. 16.1), for different motivations or categories of scientific research. Three of these quadrants are of particular interest for urban LTSERs. The two most familiar quadrants may be the first and third quadrants. Stokes defines the first quadrant, Pure Basic Research, as science performed without concern for practical ends. This quadrant is labelled Bohr's Quadrant since physicist Nils Bohr had no immediate concern for use as he worked to develop a structural understanding of the atom. In this quadrant LTSERs work to understand physical, biological, and social laws that advance our fundamental understanding of the world. For instance, urban systems can be useful end members for understanding the effects of altered climates, organismal components, substrates and land forms (Zipperer et al. 1997; Carreiro et al. 2009), or changes in livelihoods and lifestyles on consumption, social institutions, identity and status. The third quadrant, Pure Applied Research, is defined as science performed to solve a social problem without regard for advancing fundamental theory or scientific method. Stokes labelled this Edison's Quadrant, since inventor Thomas Edison never considered the underlying implications of his discoveries in his pursuit of commercial illumination. In this quadrant LTSERs work to develop solutions to specific problems, such as bio-retention systems for removing pollutants from stormwater or social marketing to increase household participation in tree planting programmes.

Stokes defines the second quadrant, Use-inspired Basic, as science that is designed to both enhance fundamental understanding and address a practical issue. This quadrant is labelled Pasteur's Quadrant, because biologist Louis Pasteur's work on immunology and vaccination both advanced our fundamental understanding of biology and saved countless lives. In this quadrant LTSERs work to advance scientific theories and methods while addressing practical problems; for example, how do households' locational choices affect ecosystem services and vulnerabilty to climate change or how do ecological structures and social institutions interact over the long term to affect urban resilience and sustainability? While BES research can be located in each of these quadrants, most BES research is Use-inspired Basic located in Pasteur's Quadrant and addresses many of the practical motivations identified earlier (Pickett et al. 2011).

16.3.2 What We Seek to Know: From an Ecology in Cities to an Ecology of Cities

A driving idea for the design of the BES has been to promote the transition from an "Ecology *in* Cities" to an "Ecology *of* Cities." The study of social-ecological systems in general, and urban systems in particular has been an emerging area of significant attention over the past 15 years. During this time, a body of research and applications emerged that may be labelled "The Ecology *of* Cities". This corpus of work may be best described as the transition in the study of urban systems from an "Ecology *in* Cities" to an "Ecology *of* Cities," (Pickett et al. 1997a; Grimm et al. 2000) where the study of the "Ecology *in* Cities" focused historically on ecologically familiar places and compared urban and non-urban areas: parks as analogues of rural forests (e.g. Attorre et al. 1997; Kent et al. 1999) and vacant lots as analogues of fields or prairies (Vincent and Bergeron 1985; Cilliers and Bredenkamp 1999). Urban streams and remnant wetlands were the object of ecological studies similar in scope and method to those conducted in non-urban landscapes.

An "Ecology *of* Cities" in its current form incorporates new approaches from ecology in general and ecosystem ecology in particular. An "Ecology *of* Cities" builds upon but is very different from an "Ecology *in* Cities." First, the "Ecology *of* Cities" addresses the complete mosaic of land uses and management in metropolitan systems, not just the green spaces as rural analogues that were the focus of "Ecology *in* Cities". Second, spatial heterogeneity, expressed as gradients or mosaics, is critical for explaining interactions and changes in the city. Third, humans and their institutions are a part of the ecosystem, not simply external, allegedly negative influences. Finally, the role of humans at multiple scales of social organisation, from individuals through to households and neighbourhoods, and to complex and persistent agencies, is linked to the biophysical scales of urban systems. Thus, an Ecology of Cities opens the way towards understanding feedbacks among the biophysical and human components of the system, towards placing them in their dynamic spatial and temporal contexts, and towards examining their effects on ecosystem inputs and outputs at various social scales, including individuals, households, neighbourhoods, municipalities, and regions (Grove and Burch 1997).

The shift to addressing the complete mosaic of land uses and management in metropolitan systems is also important to the practical needs of enhancing urban sustainability. Most of the land in urban areas is not in "urban-rural" analogues. For example, the division between public and private ownership in the City of Philadelphia is 33% public and 67% private. Of those private lands, 85% are residential lands, with 459,524 individual parcels. Thus, in many cases, the new "forest owner" in urban areas is most often a residential homeowner. The shift to an "Ecology *of* Cities" provides a much better scientific understanding of the social and ecological characteristics of diverse ownerships and the dominant ownership type, which is required in order to enhance urban sustainability.

16.3.3 How We Seek to Know: Integrative Tools

To facilitate the transition from an Ecology *in* Cities to an Ecology *of* Cities, we employ a suite of integrative tools in our LTSER toolbox: (1) An Ecosystem Approach and LTSER Frameworks, (2) Patch Dynamics, (3) Complexity in Social-Ecological Systems, (4) Scalable Data Platforms, and (5) Watersheds. Many research projects have attempted to bring mainstream ecology and crucial social sciences more closely together (Pickett et al. 1997b; Grimm et al. 2000; Alberti et al. 2003; Redman et al. 2004).[1]

16.3.3.1 An Ecosystem Approach and LTSER Frameworks

We employ the ecosystem concept because of its utility for integrating the physical, biological, and social sciences (Pickett and Grove 2009) and addressing (1) differences among land uses and variations in management within and among land uses in terms of fluxes of individuals, energy, nutrients, materials, information and capital, and (2) ecological structures and social institutions that may regulate those fluxes.

The ecosystem concept owes its origin to Tansley (1935), who noted that ecosystems can be of any size, as long as the concern was with the interaction of organisms and their environment in a specified area. Further, the boundaries of an ecosystem

[1] When we began to contribute to this research agenda through the Baltimore Ecosystem Study in 1997, it was important to employ familiar concepts that each discipline could embrace. Hence, we began with ecosystems, watersheds, and patch dynamics as tools to organize research and conceptualize an urban area as an interdisciplinary research topic (Cadenasso et al. 2006). The sequence of integrative tools we present in this chapter is different from their historical development in BES. However, we chose the sequence presented here because watersheds are a particular application of the preceding four tools.

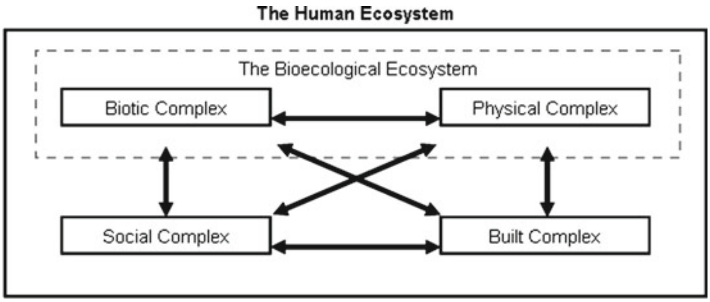

Fig. 16.2 The human ecosystem concept, bounded by the *bold line*, showing its expansion from the bioecological concept of the ecosystem as proposed originally by Tansley (1935) in the *dashed line*. The expansion incorporates a social complex, which consists of the social components and a built complex, which includes land modifications, buildings, infrastructure, and other artefacts. Both the biotic and the physical environmental complexes of urban systems are expected to differ from those in non-urban ecosystems (Figure copyright BES LTER and used by permission (Pickett and Grove 2009))

are drawn to answer a particular question. Thus, there is no set scale or way to bound an ecosystem. Rather, the choice of scale and boundary for defining any ecosystem depends upon the question asked and is the choice of the investigators. In addition, each investigator or team may place more or less emphasis on the chemical transformations and pools of materials drawn on or created by organisms; or on the flow, assimilation, and dissipation of biologically metabolisable energy; or on the role of individual species or groups of species on flows and stocks of energy and matter. The fact that there is so much choice in the scales and boundaries of ecosystems, and how to study and relate the processes within them, indicates the profound degree to which the ecosystem represents a research approach rather than a fixed scale or type of analysis (Allen and Hoekstra 1992; Pickett and Cadenasso 2002).

The Human Ecosystem Framework

When Tansley (1935) originated the term 'ecosystem', he noted carefully that "*… ecology must be applied to conditions brought about by human activity. The "natural" entities and the anthropogenic derivatives alike must be analyzed in terms of the most appropriate concepts we can find*." An explicit conception of the human ecosystem brings all the resilient ideas in Tansley's original, core ecosystem concept together. Tansley's core definition of ecosystem was focused on the main ecological topics of his day: organisms and the physical environment. That way of conceiving of the ecosystem is outlined in the inner, dashed box in Fig. 16.2. However, if ecologists are to account for all the kinds of patterns, processes, and interactions that have been identified for social-ecological research (Machlis et al. 1997; Redman et al. 2004; Collins et al. 2011), then it is useful to include two additional "complexes" within the idea of the ecosystem appropriate for the twenty-first century (Fig. 16.2).

It is important to note that each complex shown in Fig. 16.2 can be disaggregated. In the case of the social complex, social scientists have focused on interactions between humans and their environments since the origin of their disciplines. Further, social scientists have focused specifically on an expanded view of the ecosystem approach that includes humans along a continuum from urban areas to wilderness since the 1950s (Hawley 1950; Schnore 1958; Duncan 1961, 1964; Burch and DeLuca 1984; Machlis et al. 1997). Recently, the social and medical sciences have focused increasingly on the ecosystem concept because of its usefulness for natural resource policy and management (Rebele 1994) and public health (Northridge et al. 2003).

Frameworks for urban ecosystems need to recognise the reciprocal relationships of biological structures and processes, socioeconomic structures and processes, slowly changing historical or evolutionary templates, and global or regional external drivers. Furthermore, they need to acknowledge the role of social differentiation and the perception by individuals or institutions as mediators of the interactions between biophysical and socioeconomic patterns and processes. Feedbacks, often with time lags and indirect effects, are a part of the conceptual frameworks of urban ecosystems.

BES has used the Human Ecosystem Framework (Fig. 16.3) as the "disaggregated" version of Fig. 16.2 (Burch and DeLuca 1984; Machlis et al. 1997; Pickett et al. 1997b). Originally proposed by social ecologists Bill Burch, Gary Machlis and colleagues (Burch and DeLuca 1984; Machlis et al. 1997), this analytical framework identifies and describes the various structures and kinds of interactions that are important for including humans as components of ecosystems. The framework identifies the resource base of the ecosystem, which includes biophysical and social resources and the kinds of ways in which people organise themselves to exploit and manage those resources in order to accomplish the various functions of life (Fig. 16.3). The framework also recognises that individuals and institutions change over time, based on inherent human physiological rhythms and institutional 'timing cycles' (Fig. 16.3).

This analytical framework is not a theory or model in and of itself. Rather we have used it in BES to identify the specific kinds of variables and interactions to be included in our urban ecological research and applications. Machlis et al. (1997) note that some features of the framework are "orthodox to specific disciplines and not new". They also indicate, however, that the framework contains some less commonplace features such as myths as cultural resources, or justice as a critical institution. We adopt their view that the human ecosystem framework is a coherent entity that is useful in structuring the study of human ecosystems.

The Human Ecosystem Framework is crucially important for reminding all participants in BES that they are studying, explaining, or contributing to the management of a complex, human inhabited ecosystem (Machlis et al. 1997). This has been especially important in linking our biophysical and social scientists, engineers, urban designers, and decision makers (Grove and Burch 1997; Pickett et al. 2001; Grove et al. 2005). There are several elements that are critical to the successful application of this framework. First, it is important to recognise that the primary drivers of human ecosystem dynamics are both biophysical and social. Second, there is no single,

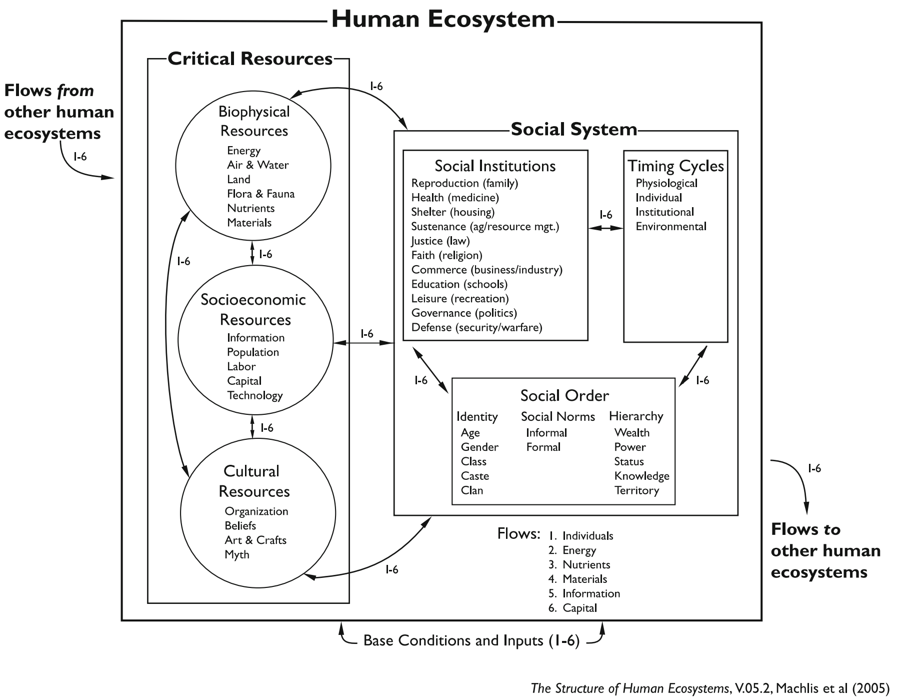

Fig. 16.3 The human ecosystem framework. This conceptual framework identifies the components of the resource and human social systems required by inhabited ecosystems. The resource system is comprised of both biophysical and social resources. The human social system includes social institutions, cycles, and the factors that generate social order. This is a framework from which models and testable hypotheses suitable for a particular situation can be developed. It is used to organise thinking and research and is a valuable integrating tool for the BES (Re-drawn from Machlis et al. 1997)

determining driver of anthropogenic ecosystems. Third, the relative significance of drivers may vary over time. Fourth, components and their interactions with each other need to be examined simultaneously (Machlis et al. 1997). Finally, researchers need to examine how dynamic biological and social allocation mechanisms such as ecological constraints, economic exchange, authority, tradition and knowledge, affect the distribution of critical resources including energy, materials, nutrients, population, genetic and non-genetic information, labour, capital, organisations, beliefs and myths, within any human ecosystem (Parker and Burch 1992).

Press-Pulse Dynamics Framework

We include the Press-Pulse Dynamics Framework (PPD) as a complimentary, interactive framework to the Human Ecosystem Framework (HEF). The PPD was developed over a 3-year period by members from ecological and social science

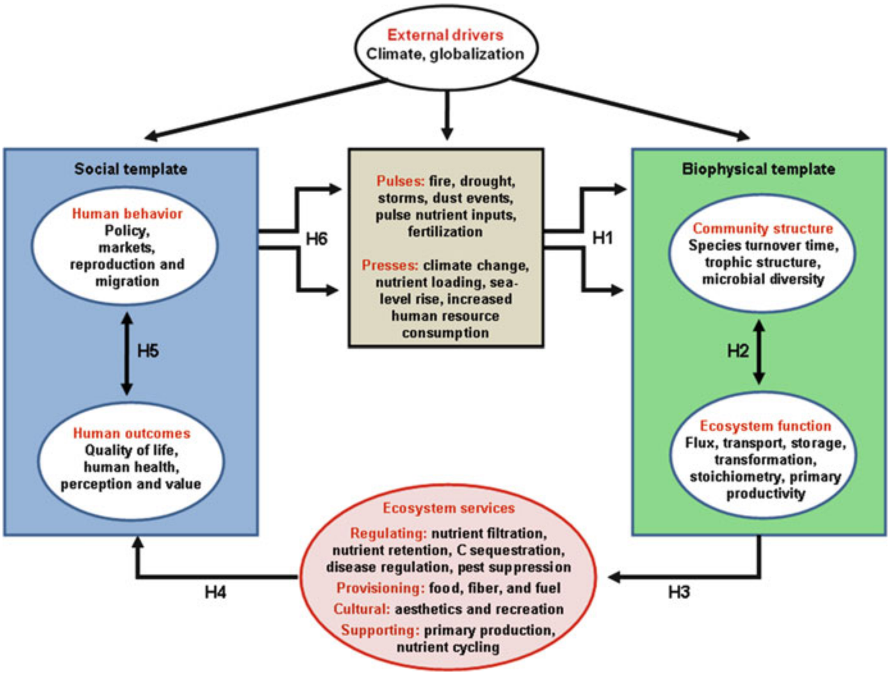

Fig. 16.4 Press–pulse dynamics framework (*PPD*). The PPD framework provides a basis for long-term, integrated, socio–ecological research. The *right-hand side* represents the domain of traditional ecological research; the *left-hand side* represents traditional social research associated with environmental change; the two are linked by pulse and press events influenced or caused by human behaviour and by ecosystem services, top and bottom, respectively (Collins et al. 2011). Individual items shown in the diagram are illustrative and not exhaustive

communities in the United States to promote long-term social ecological research (Collins et al. 2007, 2011). Like the Human Ecosystem Framework, the PPD (Fig. 16.4) is not a theory nor a model in and of itself. And like the Human Ecosystem Framework, the PPD incorporates methods and data from the geophysical, biological, social, and engineering sciences. The PPD differs from the Human Ecosystem Framework because of its focus on (1) "press and pulse events" that may drive socio-ecological systems and (2) the linkages between social and ecological templates in terms of changes in the quantity and quality of ecosystem services. The PPD adds to the traditional topics of existing long-term ecological research – i.e. the biophysical template (structure and function) and regulating and provisioning ecosystem services shown in Fig. 16.4 – by including topics such as cultural and supporting ecosystem services; the social template; social pulse and press drivers; and the relationships between these topics. The PPD and the HEF are complementary because the PPD provides a template for flows, interactions and connections of the entities and processes identified by the Human Ecosystem Framework.

The intention of the PPD is to provide a generalisable, scalar, mechanistic, and hypothesis-driven framework to promote socio-ecological research within existing long-term ecological research projects, the development of new long-term socio-ecological research, and comparisons among existing and new projects. The PPD can be used to focus a long-term socio-ecological research agenda through the identification of and connections among six strategic research questions (Collins et al. 2011):

1. How do long-term press disturbances and short-term pulse disturbances interact to alter ecosystem structure and function (H1)?
2. How can biotic structure, including built structure, be both a cause and consequence of ecological fluxes of energy and matter (H2)?
3. How do altered ecosystem dynamics affect ecosystem services (H3)?
4. How do changes in vital ecosystem services alter human outcomes (H4)?
5. How do changes in human perceptions and outcomes affect human behaviours and institutions (H5)?
6. Which human actions influence the frequency, magnitude or form of press and pulse disturbance regimes across ecosystems and what determines these actions (H6)?

Because the PPD framework focuses on press and pulse types of disturbance, we feel it is important to define the term. Disturbance is a technical term when used in socio-ecological research. It was originally used to refer to events with sharp onset and short duration, and with the ability to affect the physical structure of any ecological system. The term was provocative when first introduced because such events, although they disrupted some aspects of ecological systems, generated results that were positive for some other features of ecological systems. For example, disturbance often created opportunities for disadvantaged species to persist or enter an ecosystem, or provided locations in which resource conversion rates increased, facilitating access by suppressed or newly establishing organisms. Disturbance as originally introduced was distinct from ecological stress, which was often a longer lasting event that directly affected the function or metabolism of a system. Both disturbance and stress can be unified as perturbations, and this term reminds researchers that the effects on any specific system component or entire system may be positive, negative, or neutral. Since its introduction in the mid-1980s, the concept of disturbance has been refined, and has led to a new consideration of ecological events in general. Events are now considered to be complex occurrences characterised by an onset, a duration in time, and potentially a later decline. Ecologists recognise that the complexities of onset, duration, and demise of events will result in different effects. A short flood may not kill many plant species on a floodplain, while an unusually long flood may cause mortality and may even remove sensitive species from the system.

The complexity of ecological events can be abstracted in the contrast of pulses and presses. While this contrast does not consider all possible combinations of sharpness of onset, length of duration, or existence or rate of decline (Pickett and Cadenasso 2009), it focuses attention on two end members of that rich array of events: those that are transient and those that are persistent, at least for a relatively long time. Pulse events have sharp attack and quick demise, though they may have substantial effects on ecological systems. An earthquake is a good example of a pulse event. Press events alter the conditions in a system over a long time period, and may in fact be more akin to stresses. A shift in a climate regime from wet to dry, or the injection of a new level of resource supply through pollution are examples of biological pulses. Social pulses and presses are also important. New investment in a neighbourhood may be a pulse. A shift in demographic composition in a district of a city would illustrate a press. Presses and pulses are raw material for advancing integration between bioecological and social structures and processes in human ecosystems. The human ecosystem (Fig. 16.2) is a general concept that can be made operational by using a framework of potential components in the form of the Human Ecosystem Framework (Fig. 16.3), and a hypothetical model of connections and interactions in the form of the PPD (Fig. 16.4). How such models can be applied to spatially heterogeneous ecosystems such as urban areas is the concern of the next major framework used by BES.

16.3.3.2 Patch Dynamics

Patch dynamics is the second integrative tool employed by BES. It is important to the transition from an Ecology *in* to an Ecology *of* Cities because it can be used to account for the spatial heterogeneity of different lands uses and variations in management within land uses in terms of fluxes of (1) individuals, (2) energy, (3) nutrients, (4) materials, (5) information, and (6) capital and the ecological mechanisms and social institutions that control the flux of those resources across space.

Patch dynamics recognises that spatial heterogeneity is a key attribute of ecological systems. Emerging in the late 1970s, and originating from much the same impetus as the spatially focused discipline of landscape ecology, patch dynamics was used to describe the spatial structure of areas, the flows of materials, energy, and information across spatial mosaics, and the changes in individual spatial components of the mosaic as well as in the mosaic as a whole (Pickett et al. 2001). In other words, patch dynamics is concerned with the spatial structure, function and change of mosaic systems. At a particular scale, the heterogeneity can be resolved into patches that differ from each other. Although the patches may be heterogeneous at finer scales, at the scale of interest they are internally homogeneous relative to one another (Cadenasso et al. 2003). Examples include forest and field patches discriminated at the scale of km, or, at the scale of metres, tree fall pits and mounds in old growth forests (Pickett and White 1985). It is important to note that the mosaics can comprise discrete, bounded patches, or can be conceived of as gradients or fields defining continuous surfaces of differentiation. Patch dynamics can also be applied within a hierarchical structure, with different types of patches identified with processes at nested scales (Wu and Loucks 1995; Grove and Burch 1997).

Patch dynamics is important in urban systems as well because urban social-ecological systems are notoriously heterogeneous or patchy (Jacobs 1961; Clay 1973). Biophysical patches are a conspicuous layer of heterogeneity in cities. The basic topography, although sometimes highly modified, continues to govern important processes in the city (Spirn 1984). The watershed approach to urban areas has highlighted the importance of slopes, and of patchiness along slopes, in water flow and quality (Band et al. 2006). Steep areas are often the sites of remnant or successional forest and grassland in and around cities. Soil and drainage differ with the underlying topography. Vegetation, both volunteer and planted, is an important aspect of biophysical patchiness. The contrast in microclimate between leafy, green neighbourhoods versus those lacking a tree canopy is a striking example of biotic heterogeneity (Nowak 1994). Additional functions that may be influenced by such patchiness include carbon storage (Jenkins and Riemann 2001) and animal biodiversity (Adams 1994; Hostetler 1999; Niemela 1999).

Social differentiation and its spatial manifestation in terms of patches is also pronounced in and around cities and is not limited to categories such as land use (Grove and Burch 1997). Social patchiness can exist in such phenomena as economic activity and livelihoods, family structure and size, age distribution of the human population, wealth, educational level, social status, and lifestyle preferences (Burch and DeLuca 1984; Field et al. 2003). Social differentiation is important for human ecological systems because it affects both locational choices and the allocation of critical resources, including natural, socioeconomic, and cultural resources. In essence, social differentiation determines "who gets what, when, how and why" (Lenski 1966; Parker and Burch 1992). This allocation of critical resources is rarely equitable, but instead results in rank hierarchies. Unequal access to and control over critical resources is a consistent fact within and between households, communities, regions, nations and societies (Machlis et al. 1997). Environmental justice scholarship is a particular application of social differentiation research. Environmental justice research has demonstrated that disadvantaged groups, especially racial and ethnic minorities, are disproportionately burdened with environmental disamenities and enjoy fewer amenities compared to the privileged majority (Mohai and Saha 2007). These inequitable outcomes are typically the result of unjust procedures that burden racial and ethnic minorities with the most polluted and hazardous environments close to where they live (Bolin et al. 2005; Lord and Norquist 2010; but see Boone et al 2009).

Temporal dynamics are just as important as spatial pattern, since socio-ecological patterns are not fixed in time. For example, a city patch possessing a tree canopy will change as the trees mature and senesce, reducing canopy extent. Patches can also exhibit social dynamics, as when a neighbourhood of predominantly older residents shifts to dominance by young families. In these contrasting states, the patch makes different demands on the infrastructure and government. For example, young families may want playgrounds and access to schools while elderly residents may demand access to health services and passive recreation. The social requirements of specific patches will thus shift through time.

It is also critical to include the built nature of cities as a component of patch dynamics as well. Most people, and indeed most architects and designers, assume that the built environment is a permanent fixture. However, buildings and infrastructure change, as do their built and biophysical context. This elasticity in the urban system suggests a powerful way to re-conceptualise urban design as an adaptive, contextualised pursuit (Pickett et al. 2004; Shane 2005; Colding 2007; McGrath 2007). Such dynamism combines with the growing recognition of the role of urban design in improving the ecological efficiencies and processes in cities, particularly as existing structures may offer challenges to realising these efficiencies. Although this application of patch dynamics is quite new, it has great promise to promote the interdisciplinary melding of ecology and design and to generate novel designs with enhanced environmental benefit (McGrath et al. 2007). Thus, patches in urban systems can be characterised by physical structures, biological structures, social structures, built structures, or a combination of the four over time (Cadenasso et al. 2006) (Fig. 16.2).

16.3.3.3 Complexity in Socio-ecological Systems: Types and Levels

A third integrative tool in BES is a framework for examining complexity in terms of three types of complexity and levels of complexity within each type (Cadenasso et al. 2006). This complexity framework is useful in making the transition from an Ecology *in* Cities to an Ecology *of* Cities because it builds upon our patch dynamics approach by further developing its spatial and temporal dimensions and by adding a multi-scalar dimension to the types and levels of understanding social-ecological systems. In essence, this structural approach to socio-ecological systems can be used to ask what pieces are there and how are they arranged, how do the pieces interact, and how do they change through time (Fig. 16.5)? The complexity framework thus permits researchers to examine three realms: (1) the spatial heterogeneity of the urban system, (2) the organisation and connectivity of the spatially arrayed components, and (3) the role of history, contingency, and path dependency on the dynamics of urban ecosystems (Cadenasso et al. 2006).

The first type of complexity is spatial heterogeneity. Complexity of spatial heterogeneity increases as the perspective moves from patch type and the number of each type, to spatial configuration, and to the change in the mosaic through time (Wiens 1995; Li and Reynolds 1995) (Fig. 16.5). At the simplest structural end of the spatial axis, systems can be described as consisting of a roster of patch types. Richness of patch types summarises the number of patch types making up the roster. Structural complexity is increased as the number of each patch type is quantified. This measurement is expressed as patch frequency. How those patches are arranged in space relative to each other increases the complexity of understanding the heterogeneity or structure of the system (Li and Reynolds 1993). Finally, each patch can change through time. Which patches change, and how they change and shift identity constitutes a higher level of spatial complexity. The most complex understanding of system heterogeneity is acquired when the system can be quantified as a shifting mosaic of patches, or when the patch dynamics of the system is spatially explicit and quantified (Fig. 16.5). Although the passage of time is an element at the highest level of spatial complexity, this is distinct from historical complexity, where the function of such phenomena as lags and legacies is the concern (Cadenasso et al. 2006).

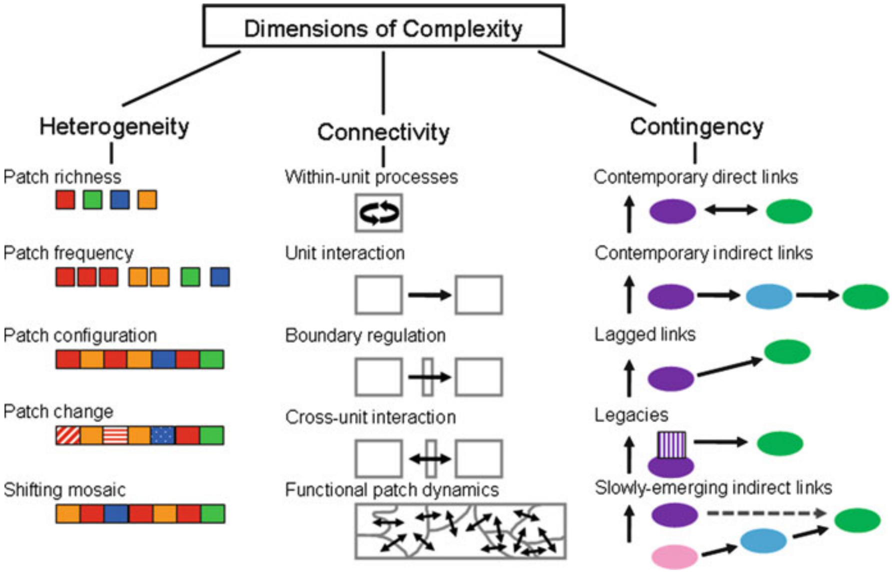

Fig. 16.5 Framework for complexity of socio-ecological systems. The three dimensions of complexity are spatial heterogeneity, organisational connectivity and temporal contingencies. Components of the framework are arrayed along each axis increasing in complexity. For example, a more complex understanding of spatial heterogeneity is achieved as quantification moves from patch richness, frequency and configuration to patch change and the shift in the patch mosaic. Complexity in organisational connectivity increases from within unit process to the interaction of units and the regulation of that interaction to functional patch dynamics. Finally, historical contingencies increase in complexity from contemporary direct effect through lags and legacies to slowly emerging indirect effects. The *arrows* on the *left* of each illustration of contingency represent time. While not shown in the figure, connectivity can be assessed within and between levels of organisation (Cadenasso et al. 2006)

The second type of complexity is organisational connectivity. The organisational axis reflects the increasing connectivity of the basic units that control system dynamics within and between levels of organisation. Within organisational hierarchies, causality can move upward or downward (Ahl and Allen 1996). Organisational complexity drives system resilience, or the capacity to adjust to shifting external conditions or internal feedbacks (Holling and Gunderson 2002). Following our structural approach, we can return to the patch as an example of the basic functional unit of a system to explain this axis more fully. In this case, the simplest end of the connectivity axis is within-patch processes. As the interaction between patches is incorporated, complexity increases. Understanding how that interaction may be regulated by the boundary between patches constitutes a higher level of complexity. The organisational complexity axis continues to increase with recognition that patch interaction may be controlled by features of the patches themselves in addition to the boundary. Finally, the highest level of structural complexity on the organisational axis is the functional significance of patch connectivity for patch dynamics, both of a single patch and of the entire patch mosaic (Fig. 16.5). Note that from the perspective of complex behaviour, each range of this axis would be considered a structure whose complex behaviour could be evaluated and compared to other ranges of the gradient (Cadenasso et al. 2006).

The third type of complexity is historical contingency. Historical contingency refers to relationships that extend beyond direct, contemporary ones. Therefore, the influence of indirect effects, legacies or apparent memory of past states of the system, the existence of lagged effects, and the presence of slowly appearing indirect effects constitute increasing historical complexity (Fig. 16.5). To explain the steps of this axis we start with the simple or contemporary ones. Contemporary interactions includes those interactions where element A influences element B directly. Indirect contemporary interactions involve a third component, C, to transmit the effect of A on B. An interaction is lagged if the influence of element A on element B is not immediate but manifested over some time period. A higher level of temporal complexity is invoked by legacies. Legacies are created when element A modifies the environment and that modification, whether it be structural or functional, eventually influences element B. At the high end of the temporal complexity axis are slowly emerging indirect effects. These types of interaction occur when the apparent interaction of elements A and B is illusory and element B is actually influenced by some earlier state of element A and that influence is mediated through an additional element, C (Fig. 16.5) (Cadenasso et al. 2006).

16.3.3.4 Scalable Data Platform

The spatial, temporal, and hierarchical dimensions of socio-ecological systems require a scalable data platform to integrate biophysical and social patterns and processes in urban regions. The BES and DC-BC ULTRA-Ex use a parcel-relevant sampling approach that combines both plot-based and pixel-based data in an extensive-intensive sampling framework, with pixels as a type of extensive data, plots as a type of intensive data, and parcels as a scale of analysis.

There are several motivations for using parcels as a crucial unit of sampling and analysis. First, parcels are a complete census of an entire urban area and all ownership types. Since most of the land in urban areas is not in "urban-rural" analogs, the use of parcels is critical for the shift to an "Ecology *of* Cities." Second, parcels are a basic unit of decision-making associated with household and firm locational choices and behaviours. Third, parcels and their owners have social and ecological histories, and their geographies and attributes can be documented and described over time through a variety of sources (Boone et al. 2009; Lord and Norquist 2010; Buckley and Boone 2011). Fourth, parcels can be aggregated into other units of analysis, such as patches, neighbourhoods, watersheds, and municipalities (Grove et al. 2006a). Disaggregation is also possible, for example, to investigate differences between biophysical and social features of front and back residential yards (Loucks 1994).

An extensive – intensive sampling framework provides the capacity for linking pattern and process (Figs. 16.6 and 16.7). In general, extensive sampling may be

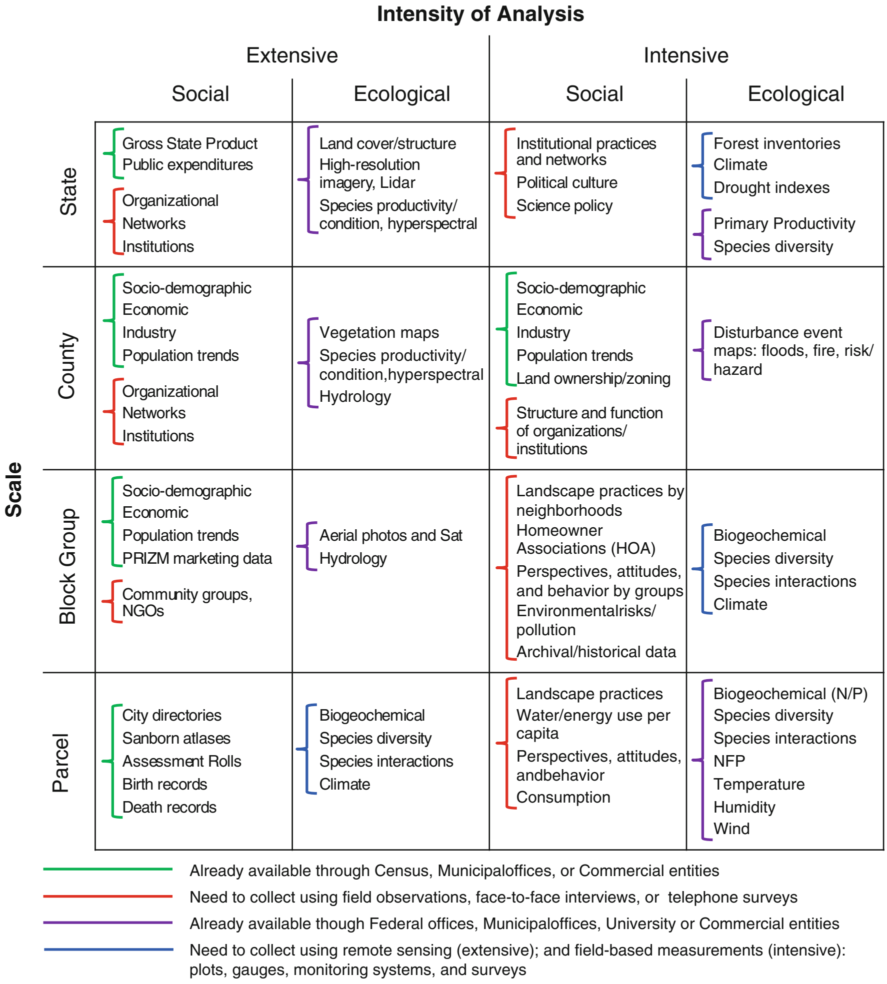

Fig. 16.6 Examples of socio-ecological data types organized by scale and intensity of analysis. Data types marked in *green* are data that LTSER sites must typically acquire, document, and archive. Data types marked in *red* are typically collected by LTSER sites (Zimmerman et al. 2009)

more useful for measuring pattern and inferring process, while intensive sampling may be more appropriate over time for the direct measurement and quantification of process and mechanism, particularly the motivations of social actors. An extensive – intensive data framework provides complementary sampling opportunities. Extensive sampling provides a basis for developing strategies for more intensive sampling, including the formulation of stratified sampling plans across space and time. Intensive sampling can be used to validate extensive data because the same phenomenon can be measured both extensively and intensively. For instance, vegetation productivity can be measured using both remote sensing and field-based measurements. Intensive

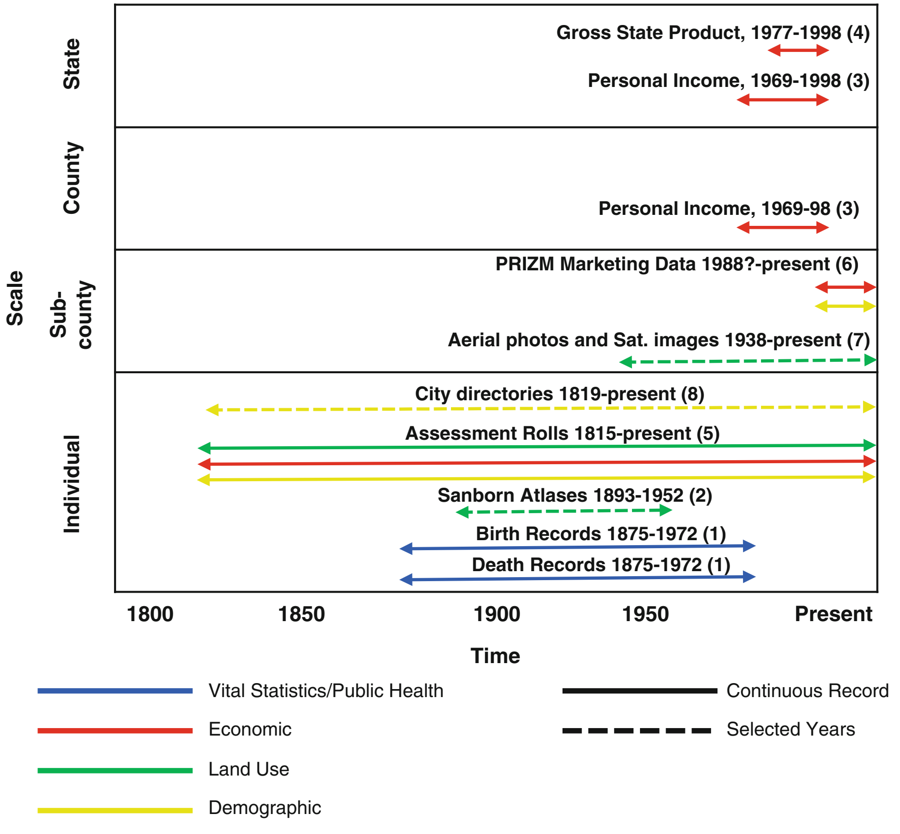

Fig. 16.7 Example of non-census data sets with spatial reference to Baltimore City, 1800–2000 (Figure developed for Baltimore LTER Figure copyright BES LTER and used by permission from Boone)

sampling can be used to generate more detailed, process-based and mechanistic models. Subsequently, extensive sampling provides the basis for generalising these process-based models across space and time.

The empirical ability to examine and integrate social and ecological characteristics in an extensive-intensive framework is relatively new in the United States. The widespread adoption of Geographic Information Systems (GIS) by federal, state, and local governments and recent advances in remote sensing have greatly increased the availability of high-resolution geospatial data (<1 m). In particular, cadastral information maintained by local governments in hardcopy format is increasingly available digitally (Troy et al. 2007). These cadastral maps include a variety of information such as the boundaries and ownership of land parcels and infrastructure such as streets, storm drains, and retention ponds. High resolution imagery can be used to derive vegetation cover and combined with cadastral data and digital surface water data to distinguish vegetation extent, structure, and productivity between private property and public rights-of-way, including along streets. These parcel data also include attributes such as building type, building age, and building characteristics such as the number of bedrooms and bathrooms, building condition, transacted value, owner, land use and zoning (Zhou et al. 2009a, b).

These empirical advances provide a foundation for combining traditional social and ecological data. For instance, different types of social and ecological surveys can be linked to these data by both a unique address and by latitude and longitude. In the case of telephone surveys, telephone lists can include address and spatial location, while field observations and interviews can record both address and Global Positioning System (GPS) location as surveys are conducted. All of these data can be linked to Census geographies, which provide the basis for including demographic and socioeconomic data from the Census and commercial marketing data that are available at the Block Group level. Some of these marketing data include residential land management behaviours such as household expenditures on lawncare supplies and services (Zhou et al. 2009b). These data can be further combined with a variety of present and archival data that are address based, including real estate transactions, business directories, legal and health records, biographies and diaries, photographs and neighbourhood association minutes, for example (Merse et al. 2009).

16.3.3.5 Watersheds

We use the watershed approach in Baltimore because of its proven success and general application in ecology (e.g. Bormann and Likens 1979), its integrative role as a particular application of an ecosystem and patch dynamics approach (Band and Moore 1995; Law et al. 2004), and its practical relevance to decision making.

Hydrologists examine how the abiotic attributes of different patches within a watershed, such as temperature and physical characteristics including topography, soil properties, water table depth and antecedent soil moisture, contribute variable amounts of water and nutrients to streamflow, depending upon their spatial location in the watershed (Black 1991). Hydrologists have summarised mosaics of the characteristics listed above using the Variable Source Area (VSA) approach. The VSA approach can be integrated with a delineation of patches based upon the biotic attributes of the watershed such as vegetation structure and species composition (Bormann and Likens 1979), and the social attributes of the watershed such as indirect effects from land-use change, forest/vegetation management and direct effects from inputs of fertilisers, pesticides, and toxins to examine how the abiotic, biotic, and social attributes of different patches within a watershed contribute variable amounts of water and nutrients to streamflow (Grove 1996). This integrated approach builds on the VSA approach introduced by hydrologists to combine nested hierarchies of land use and land cover, socio-political structures and hydrological heterogeneity. By dividing watersheds into areas that differ in their ability to absorb or yield water, a more mechanistic understanding of the water yield from a watershed can be achieved.

One of the powers of the watershed approach is that large catchments can be divided into smaller catchments, or aggregated into still larger drainages. In other words, the source areas can be subdivided or grouped together. Therefore, the watershed approach can be scaled to match the extent or grain of the research question, or of the model or theory used to link with another discipline. This approach resonates with the hierarchical patch dynamics approach (Wu and Loucks 1995; Grove and Burch 1997).

A focus on watersheds also facilities interactions between scientists and decision makers, which we discuss later in this chapter. In Baltimore, watersheds are increasingly a management focus. The Chesapeake Bay, on which Baltimore is located, is the largest estuary in the United States, drawing on a watershed that intersects seven states. Although it is vast, the Bay is shallow, and pollution has reduced its water and habitat quality (Kennedy and Mountford 2001). Policy and management decisions are promulgated by public agencies and NGOs such as watershed associations and neighbourhood groups in order to reduce nitrogen pollution and sedimentation to the Bay.

In BES, we focus on a diverse set of watersheds draining the City of Baltimore and much of adjacent Baltimore County. These watersheds present a range in size, condition, use and history: from industrial and commercial lands along the Inner Harbor; to established residential patches of varying densities, structures, and ages; to commercial strips and zones; to stable agriculture; rural forests preserves; and agricultural land actively being converted into suburban housing and business uses. Small catchments have been selected in each of these areas, and the cumulative effect of urbanisation on water quality and the pattern of water flow has been sampled and monitored to assess the ecological structure and function throughout the metropolis (Fig. 16.8).

The Gwynns Falls is the largest of our intensively sampled watersheds, covering 17,150 ha. Gwynns Falls is sampled by three stations on the main stem of the stream, focusing on headwaters, middle and upper reaches, and the downstream reach. The sampling stations represent a gradient of urbanisation, and the downstream reach represents the net output of the watershed. The contribution of the upper reaches can be assessed by subtraction. In addition, four tributary subwatersheds of Gwynns Falls, representing contrasting land covers, are sampled. The tributary watersheds represent (i) dense urban, with industrial and commercial as well as residential land; (ii) early twentieth century rowhouse suburbs; (iii) agricultural land in a suburban matrix; and (iv) recent low density suburban development. All Gwynns Falls stations are sampled weekly for water flow and quality.

Pond Branch, a tributary of the Baisman Run, serves as the forested reference watershed for comparison to the more built-up watersheds. This gauged catchment has been sampled weekly for flow and water chemistry. Smaller watersheds were added to the sampling network to address specific situations of land cover and management. The remainder of Baisman Run represents recent large-lot, suburban development. Moore's Run is the location of the atmospheric eddy flux tower, and drains heavily wooded older suburbs. Mine Bank Run is the site of a restoration

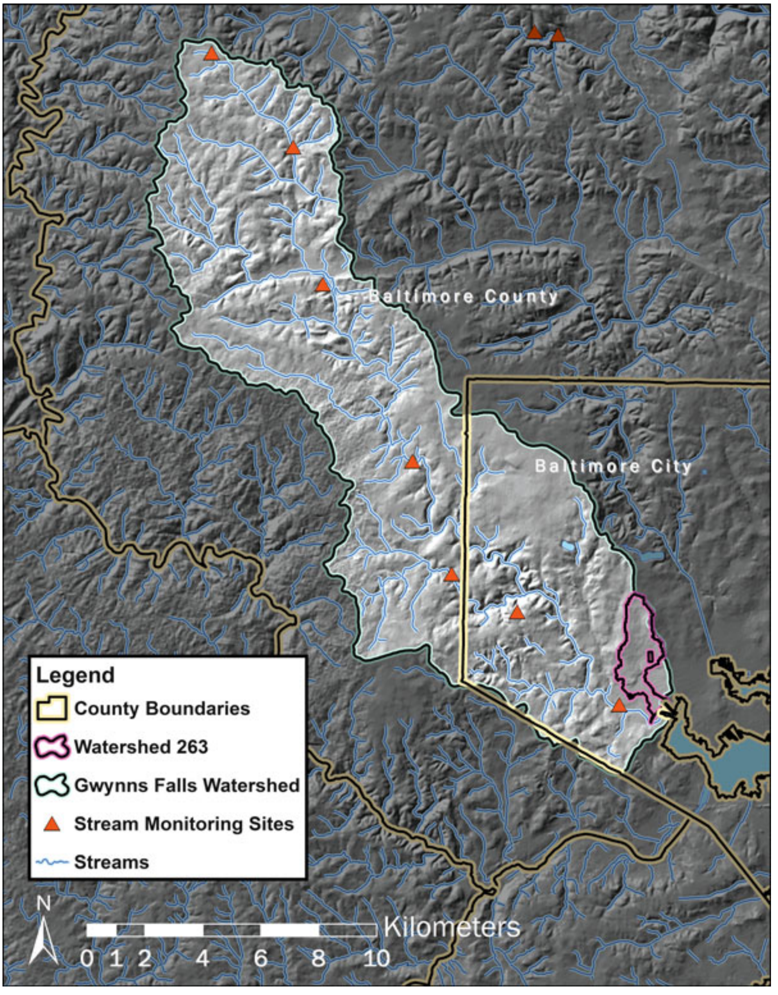

Fig. 16.8 BES has instrumented a set of nested and reference watersheds that vary in current, historical, and future land use and condition (Figure copyright BES LTER and used by permission from O'Neil-Dunne)

project conducted by Baltimore County, in which BES scientists measure variables that can assess the success of the restoration. The Minebank Run project seeks to restore stream channel geomorphology, riparian function, and in-stream nutrient and organic matter retention. Finally, a 367-ha storm drain catchment, Watershed 263, in Baltimore City has recently been added to the network. Sampling is conducted in the storm drain pipes in two subwatersheds on the same schedule as the major surface drainages. Watershed 263 is an urban restoration and greening project to test the impact of extensive tree planting and removal of impervious surfaces on storm water quality.

16.4 Ways of Knowing: Analytical Strategies

We employ three analytical strategies, or "ways of knowing" in combination with our integrative tools. These three analytical strategies are: (1) Carpenter's Table, (2) Environmental History, and (3) Linkages between Scientists and Decision makers.

16.4.1 Carpenter's Table: Long-Term Monitoring, Experimentation, Comparative Analyses, and Modelling

Research in BES is organised around the idea that long-term social-ecological research can be viewed as a table with four legs: long-term monitoring, experiments, comparative analyses, and modelling. This strategy is modified from an analysis by Carpenter (1998). The table metaphor suggests that the largest goal of the scientific enterprise is understanding or theory, represented by the table top. For complete understanding of a topic, such as socio-ecological systems in the long term, all four activities must be conducted. To the extent that one or more of the activities are absent or poorly developed, understanding will be incomplete (Fig. 16.9).

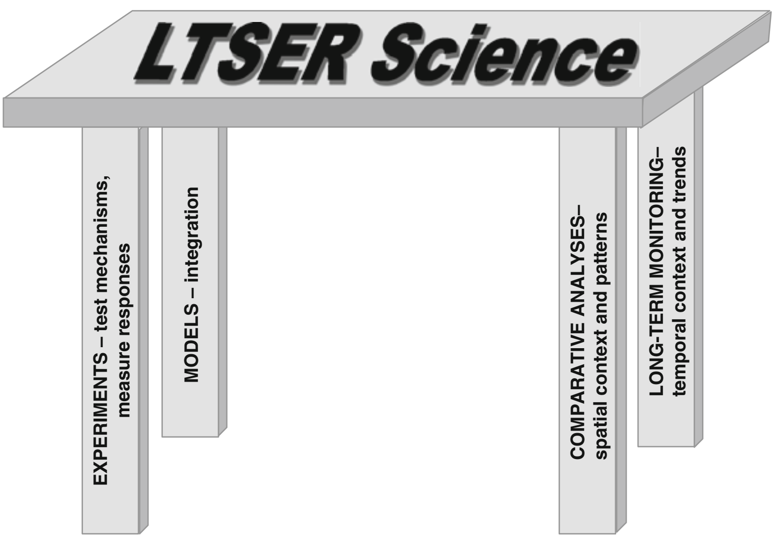

Fig. 16.9 LTSER Platforms are similar to a table with four legs essential to the integrity of the whole: long-term monitoring, experimentation, comparative analyses, and modelling (Figure adapted from Carpenter 1998)

Long-term monitoring. In BES, long-term monitoring includes a variety of social and biophysical data that are organised within our scalable data framework, including both extensive and intensive data. Long-term monitoring is intended to continue for long periods into the future. Consistency of method, overlapping of methods when it is necessary to change instruments or approaches, regularity of sampling, and continual quality assurance and quality control are features of successful long-term monitoring (Likens 1989). The collection of long-term data include those from historical sources, such as archives and published records. Paleoecological approaches also extend long-term data into the past.

Experiments. Traditional manipulative experiments are difficult to carry out in urban watersheds due to concerns about environmental justice and constraints on human subjects research (Grove and Burch 1997; Cook et al. 2004). However, spatial variation in the nature and extent of land cover, i.e. the urban-rural gradient, provides numerous opportunities for experimental variation of factors controlling biophysical and social parameters. In addition, management initiatives such as efforts to improve sanitary sewer infrastructure, watershed restoration projects such as W263 (Fig. 16.8), Baltimore City's Urban Tree Canopy Goal (Fig. 16.13), and conversion of abandoned lots to community-managed open space represent experimental opportunities, which are sometimes called "natural" experiments in the social sciences. These management efforts provide strong opportunities for integration of biophysical and social sciences and for education and outreach.

Comparative analyses. Comparative analyses occur between social and ecological geographies and periods of time within the BES research area. Comparative analyses can also be made with other LTSER projects.

Modelling. A long-term goal of social and biogeophysical modelling activities in BES is to establish an "end-to-end system" of models and observational instruments to gather and synthesise information on social and biogeophysical components of the human ecosystem represented in the PPD framework (Fig. 16.4). The objective of this synthesis is to understand how individual and institutional behaviours; the urban landscape and infrastructure; ecosystem services, other push/pull factors; and climate interact to affect water and biogeochemical storage and flux in the urban hydrologic cycle; terrestrial and aquatic carbon and nutrient cycling and storage; and the regulation of surface energy budgets. BES uses biogeophysical models to simulate water, carbon, and nitrogen cycle processes and econometric and structural models to simulate locational choices and patterns of land development and change at multiple scales across the region. Coupling of these models is intended to provide predictive understanding of the feedbacks between environmental quality, ecosystem services, locational choice, and land development and redevelopment. BES uses specific policy scenarios aimed at enhancing sustainability in the Baltimore region related to water quality and carbon sequestration to motivate its coupled modelling and synthesis activities. These modelling activities are crucial for formalising our existing knowledge of how the system functions over time as well as identifying gaps in our current theory and observational systems. These models can also be used with decision makers to test future scenarios comparing current conditions, future trends, and possible policy interventions.

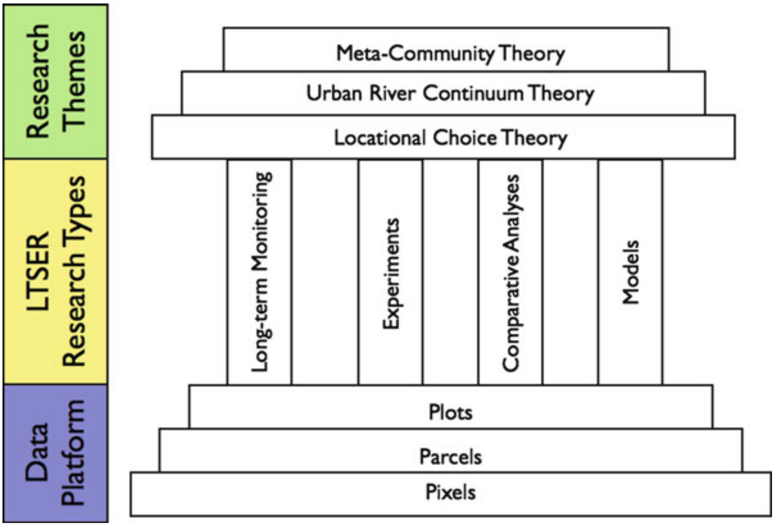

Fig. 16.10 The LTSER data temple, with specific BES research themes included (Figure copyright BES LTER and used by permission from Grove)

16.4.1.1 Putting It All Together: From Carpenter's Table to BES Temple

In BES we have taken the structural legs of Carpenter's table and converted them into columns (Fig. 16.10). We make this change in order to represent more fully the emerging and essential structure for BES research, which combines our integrative tools, ways of knowing, and research themes. The visual representation of this framework is a classic Greek temple composed of three primary elements. The first element is the foundation of the temple, or scalable data framework, which provides the base for all BES activities. This base is made up of pixels, parcels, and plots that are organised using our extensive-intensive approach (Figs. 16.6 and 16.7). The second element of our temple is the four columns to the temple, or research types (Fig. 16.9). These research types are supported by the data framework and, in turn, support the roof of the temple, or research themes from our current research foci. Each type of research uses our patch dynamics approach and pursues different types and levels of complexity (Fig. 16.5) appropriate to the research theme. The roof of the temple is made up of our BES research themes. Each theme can be located in one of Pasteur's Quadrants (Fig. 16.1) and detailed using the PPD (Fig. 16.4).

16.4.2 Environmental History

Environmental history is a second way of knowing used by BES. Employing historical methods has several benefits (see Winiwarter et al., Chap. 5 in this volume; Cunfer and Krausmann, Chap. 12 in this volume; Gingrich et al., Chap. 13 in this volume).

First, it is good practice for researchers focused on the present and future. We have found in our research that historical analyses provide a conducive environment for researchers who focus on contemporary systems to work together in understanding “why” and “how” socio-ecological processes have operated to produce present-day patterns (van der Leeuw 1998; Pickett et al. 1999; Foster et al. 2002). The time spent in collaborating on background issues helps to build trust among researchers – an intangible but crucial and constructive element of integrated research. Second, historical analyses help build skills for understanding key dimensions of socio-ecological systems because the past is already integrated (interdisciplinary) and phenomena can be located in space and time, and attributed to different social and ecological scales. Finally, current and future conditions are often influenced by lags, legacies, and path dependencies (cp. Figs. 16.5 and 16.7). Thus, it is critical to understand the past because it informs the present and the future.

16.4.3 Linking Decision Making and Science

A third way of knowing is based upon linking decision making and science. In this case, science located in Pasteur’s and Edison’s quadrants are most relevant to this discussion. We have found that there are two parts to linking decision making and science: a) a framework for identifying linkages between decision making, science, and monitoring and assessment, and b) understanding the dynamic feedbacks between decision making and science. We note that decision makers are potentially made up of a diverse set of actors, including government agencies, NGOs, community groups, or individual citizens of all ages.

16.4.3.1 Linkages Between Decision Making, Science, and Monitoring and Assessment

There are several types of linkages between decision making, science, and long-term monitoring (Fig. 16.11). We describe these linkages with illustrations from BES.

<u>Decision making and Science (A).</u> There are numerous opportunities for decision making and research to intersect, and these intersections will be either use-inspired basic research or pure applied research. Some examples of activities that are part of this intersection include research to understand the ability of riparian areas, forests and lawns to take up nitrogen (Groffman et al. 2003), examining the relationship between residential land management and crime (Troy et al. 2007), or studying the relationships among climate change, vector-borne diseases and public health (LaDeau et al. 2011).

<u>Decision making and Monitoring and Assessment (B).</u> Decision makers rely upon a variety of data to monitor and assess the effectiveness, efficiency, and equity of their activities. These data can be associated with each of the human ecosystem complexes

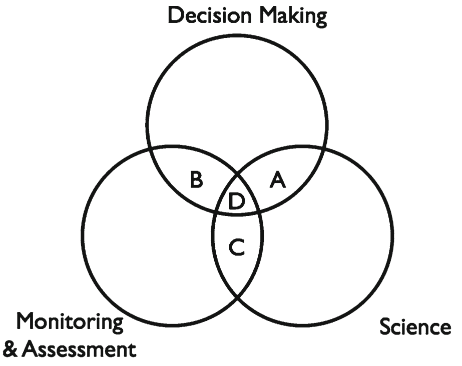

Fig. 16.11 Linkages between decision making, science, and monitoring & assessment (Figure copyright BES LTER and used by permission from Grove)

described earlier (Fig. 16.2), such as climate, flooding and air quality (physical), landcover, tree species and tree health (biological), public health, crime, employment and ownership (social), and the distribution and condition of buildings, roads, and sanitary and stormwater pipes (built).

Increasingly, local governments are making their data publicly available. In the case of Baltimore, OpenBaltimore has been developed to provide access to City data in order to support government transparency, openness and innovative uses that will help improve the lives of Baltimore residents, visitors and businesses. A goal of OpenBaltimore is to enable local software developer communities to develop applications that will help solve city problems (http://data.baltimorecity.gov/).

<u>Science and Monitoring and Assessment (C).</u> Scientists in BES contribute to long-term monitoring and assessments. Like (B) above, these data are associated with each of the human ecosystem complexes. Further, BES data are structured using the scalable data framework described previously. Data are documented with metadata and publicly available (http://www.beslter.org). Because BES collects data at parcel, neighbourhood, and county levels, and over the long term, comparisons can be made among these geographies for a specific point in time, or in terms of trends over time.

<u>Intersection of A + B + C (D).</u> The intersection of A, B, C occurs in D. Activities in D primarily involve coordinating activities among government agencies, NGOs, BES scientists and citizens. For instance, BES participates in and helps support a technical committee and workshops that include mid-level managers from government agencies and NGOs focused on urban sustainability issues such as land management, storm water, and urban agriculture.

An important opportunity for decision makers and scientists is that decision makers' policies, plans, and management represent important changes to the socio-ecological system. In Baltimore, scientists can help monitor and assess past, current and future activities. Important lessons can be learned about the effectiveness, efficiency and equity of decisions and the underlying social and ecological dynamics of the region. Thus, coordinating activities in D can be helpful to alert scientists of decision makers' plans and provide scientists and decision makers with time to initiate monitoring activities before decision makers begin to implement changes

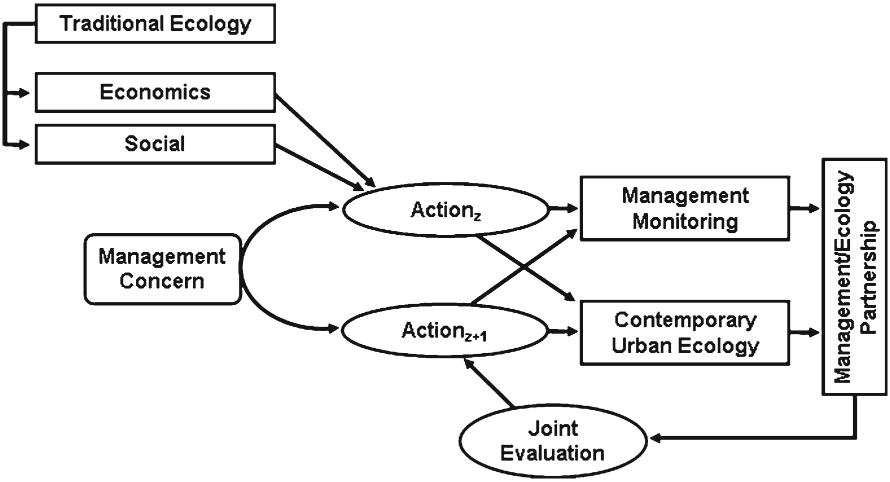

Fig. 16.12 An abstracted cycle of interaction between research and management. The cycle begins with the separate disciplines of ecology, economics and social sciences interacting with a management or policy concern. In the past, ecology has neglected the urban realm as a subject of study, leaving other disciplines to interpret how ecological understanding would apply to an urban setting. A management or policy action (Action$_z$) results. Management monitors the results of the action to determine whether the motivating concern was satisfied. Contemporary urban ecology, which integrates with economics and social sciences, is now available to conduct research that recognises the meshing of natural processes with management and policy actions. Combining this broad, human ecosystem and landscape perspective with the concerns of managers can generate a partnership to enhance the evaluation of management actions. New or alternative management actions can result (Actions$_{z+1}$) (Pickett et al. 2007)

in policies, plans, or management. Some examples of the intersection between decision making, science, and monitoring and assessment include research related to and technical assistance with the development of Baltimore City's Urban Tree Canopy (UTC) policies, plans and management (Grove et al. 2006a, b; Galvin et al. 2006; Troy et al. 2007; Locke et al. 2011) and with urban watershed reclamation projects, such as W263 (Fig. 16.8 and http://www.parksandpeople.org/greening/greening-for-water-quality/watershed-263/). In both cases, BES assists in the monitoring and assessment of the projects' social, economic and ecological costs and benefits.

16.4.3.2 Dynamic Feedbacks Between Decision Making and Science

LTSERs can lead to a dynamic coupling between scientists, interested parties and decision makers (Fig. 16.12). An example from BES illustrates this opportunity. The Baltimore region is characterised by ecologically functional watersheds and stream valleys that have contributed to Baltimore's economic and cultural history.

An early test of the BES LTER project was to apply and demonstrate the utility of forested, watershed studies from the Coweeta, H. J. Andrews, and Hubbard Brook Experimental Forests/LTERs in the United States (Bormann and Likens 1979) to an urban watershed system. One of the initial questions that BES asked, using a watershed approach, was "do riparian zones, thought to be an important sink for N in many non-urban watersheds, provide a similar function in urban and suburban watersheds?"

Somewhat surprisingly, BES analyses found that rather than sinks, riparian areas had the potential to be sources of nitrogen in urban and suburban watersheds. This finding could be explained by the observation that hydrologic changes in urban watersheds, particularly incision of stream channels and reductions in infiltration in uplands due to stormwater infrastructure, led to lower groundwater tables in riparian zones. This "hydrologic drought" created aerobic conditions in urban riparian soils which decreased denitrification, an anaerobic microbial process that converts reactive nitrogen into nitrogen gases and removes it from the terrestrial system (Groffman et al. 2002, 2003; Groffman and Crawford 2003).

Based upon these results, the Chesapeake Bay Program re-assessed their goals for riparian forest restoration in urban areas (Pickett et al. 2007). Given that riparian zones in deeply incised urban channels were not likely to be functionally important for nitrate attenuation in urban watersheds, the programme focused instead on establishing broader urban tree canopy goals for entire urban areas (Fig. 16.13), with the idea that increases in canopy cover across the city would have important hydrologic and nutrient cycling benefits to the Bay (Raciti et al. 2006).

This science-decision making cycle is dynamic and iterative. The Urban Tree Canopy (UTC) example has already progressed through four cycles. After the establishment of Baltimore's UTC goal, analyses of the relationship between property regimes and urban tree canopy found that an "All Lands, All People" approach would be critical for achieving the City of Baltimore's urban tree canopy goal (Action_{z+2}). Private lands under the control of households are a critical component to achieving any vegetation management goal in the City. Total existing canopy cover is 20%, with 90% of that cover located on private lands. Likewise, about 85% of the unplanted land area, where potential planting could occur in the future, is on private land as compared to under 15% on public rights of way (Galvin et al. 2006).

The importance of residential households to achieving Baltimore's UTC goal led to research addressing the relationships between households, their lifestyle behaviours, and their ecologies (Grove et al. 2006a, b; Troy et al. 2007; Boone et al. 2009; Zhou et al. 2009b). A critical finding from this body of research was that although lifestyle factors such as family size, life stage and ethnicity may be weakly correlated with socioeconomic status, these lifestyle factors play a critical role in determining how households manage the ecological structure and processes of their properties. These findings suggested the need for novel marketing campaigns that differentiated between and promoted UTC efforts to different types of neighbourhoods (Action_{z+3}). The need to "market" to different neighbourhoods led to the need to understand existing and potential gaps in stewardship networks (Dalton 2001; Svendsen and Campbell 2008; Romolini and Grove 2010) – both functional and

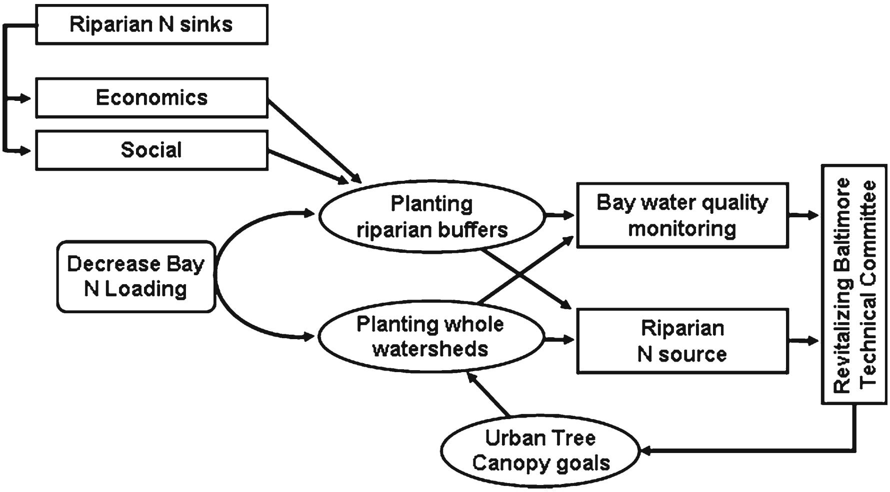

Fig. 16.13 An example of the management-research interaction in Baltimore City watersheds. Traditional ecological information indicated that riparian zones are nitrate sinks. The management concern was to decrease nitrate loading into the Chesapeake Bay. In an effort to achieve that goal, an action of planting trees in riparian zones was proposed. Management monitoring indicated that progress toward decreasing Bay nitrate loadings was slow. Results from BES research suggested that stream channel incision in urban areas has resulted in riparian zones functioning as nitrate sources rather than sinks. In partnership with managers and policy makers in Baltimore City and the Maryland Department of Natural Resources, a re-evaluation of strategies to mitigate nitrate loading was conducted. This led to a decision to increase tree canopy throughout the entire Chesapeake Bay watershed. Baltimore City adopted an Urban Tree Canopy goal, recognising both the storm water mitigation and other ecological services such canopy would provide (Pickett et al. 2007)

spatial dimensions of the network as a mechanism to communicate and organise local, private stewardship ($Action_{z+4}$).

Practical benefits from urban LTSER projects are not limited to a LTSER site. The findings and methods developed in Baltimore through these successive science-decision making cycles have had widespread utility in other urban areas. For instance, the tools developed in Baltimore to assess and evaluate existing and possible UTC have been disseminated through existing Forest Service networks and applied to more than 70 urban areas in the United States and Canada (http://nrs.fs.fed.us/urban/utc/).

16.5 Building Process and Maintenance: Platform and Programme

Platform and programme are like building structure and function. They emphasise two related parts of a research "design". We do not talk much about platforms for relatively simple or focused research efforts, because the platform is such a familiar part of the culture that it hardly seems remarkable. For a single or small group of disciplinary investigators, the platform is the two or three bay university laboratory, or the experimental field plot or the glasshouse. Each of these familiar facilities has a standard set of fittings and supporting infrastructure. Labs may have benches, gas, 220 V electric service, fume hoods and the like. The simple field plot might consist of several hectares a few miles from the university campus on the edge of town, and equipped with a chain link fence, a padlocked gate and a small storage shed for some field gear.

In contrast, for large teams or multidisciplinary groups, or work requiring special technology, the platform becomes something quite complex and sometimes massive. Examples include the particle accelerators of physics, the telescopes of astronomy and the research vessels of oceanography. Even a university field station or an experimental forest is relatively complex. The largest of these are separate properties, often with administrative offices, laboratories, motor pools, class and meeting rooms and dormitories. Field stations sometimes house sophisticated laboratory and analytic equipment that facilitate the work of research on site. The fittings and support infrastructure for each of these platforms are an order of magnitude greater than those of a university lab, greenhouse, or field plot. A platform serves one or more complex questions, or a question that requires extraordinary technology. Platforms often, indeed most likely must, serve questions and researchers well beyond the identity of the founding investigators or questions.

A programme is the suite of research questions, experiments, comparisons, and models. Such activities are decided upon by the deliberations of a community of researchers, often in collaboration with a funding entity. Complex programmes have a number of characteristics. They may bind different disciplines together, reach across scales, or take the lead in employing radically different approaches to a research question or mission-oriented research problem. As the empirical base of the field(s) expands, and as data are generated through the use of the platform itself, the research questions will very likely evolve. New questions will be posed, and old ones will be answered or deemed uninteresting in light of advancing understanding.

Socio-ecological programmes have many characteristics that suggest the need for complex research and engagement platforms. Note that engagement with the communities, decision leaders, institutions of governance, government agencies in abutting or overlapping jurisdictions, and property holders and managers are requirements of successful socio-ecological research. Therefore, research platforms for socio-ecological projects must have the capacity and mandate for engagement with constituents and stakeholders.

Platforms consist of many elements. There are field sites and laboratories, offices and meeting space, dedicated vehicles, instruments for measurement, facilities for data management, storage and dissemination, web-based communication and collaboration technologies, and analytic software. It is important to recognise that many aspects of these platforms are intangible and are more likely to be grounded in collaboration science than in engineering. The specific form these components take reflects the specific research needs, the funding availability, and the intellectual network assembled to address the research questions.

This last point about platforms introduces the idea that a programme is inhabited by or emerges from a community of collaborators. While it may not be appropriate to speak about people as a part of the programme, the latter hardly exists separate from them. Hence, a community and its culture are essential to a programme. The culture and maintenance of the programme includes such features as the social network of communication, a shared vocabulary, the habits of credit and collaboration, the recruitment and assimilation of new scientists and students, and the schedule and scope of formal and informal meetings within the project and between the programme and interested parties beyond. Crucial to success in socio-ecological research is the willingness, training or ability of participants to listen and communicate effectively across disciplinary boundaries, and to understand and respect the different expertises and approaches members represent (Pickett et al. 1999).

In conclusion, programmes and platforms are inextricably linked as a research and engagement system. The platforms employed by vigorous research programmes become generators of new questions, new transdisciplinary knowledge, and new generations of researchers and scholars equipped for work at a farther frontier. Part of the challenge in developing an urban ecology research platform is the need to combine physical instruments (e.g., Hubble telescope or a NOAA ship) with people. The scientific community is used to researchers making the case for building something physical. The fact that building an urban ecology research platform sounds too much like "community development" to many represents a challenge for this work.

16.6 Conclusion

We have offered a working blueprint for the design of urban LTSERs based upon our experiences since 1997 in Baltimore and more recently in Washington, D.C.. We note, however, that the approach to urban long-term socio-ecological research described here can apply to any such system. Our architectural metaphor of siting, constructing, and maintaining a "building" highlights processes that can support research in any socio-ecological system. Using common approaches to LTSER platforms and programmes can help us develop overarching theories for understanding differences among urban areas, and among urban, agricultural, and forested systems. The need for and challenge to LTSERs for all types of systems will only grow as societies and ecologies become increasingly intertwined.

Acknowledgments This material is based on work supported by the USDA Forest Service Northern Research Station and the National Science Foundation under DEB 1027188 (Baltimore Ecosystem Study) and DEB 0948947 (Washington D.C./Baltimore ULTRA-Ex). We gratefully acknowledge additional support from the Center for Urban Environmental Research and Education (CUERE) at the University of Maryland, Baltimore County and Georgetown University. Partnerships with the US Geological Survey, the City of Baltimore Department of Public Works and Department of Recreation and Parks, the Baltimore County Department of Environmental Protection and Resource Management and Department of Recreation and Parks, the Maryland Department of Natural Resources, Forest Service, The Parks & People Foundation, and the Casey

Trees Foundation have been instrumental in the lessons reported here. We are grateful to our colleagues at these institutions for their intellectual contributions and insights into the environment and environmental management in the Baltimore region.

We would like to thank Cherie L. Fisher, Jarlath O'Neil-Dunne, Chris Boone and Gary Machlis for their assistance with figures for this chapter and helpful suggestions from Chris Boone, Dan Childers and two anonymous reviewers.

References

Adams, L. W. (1994). *Urban wildlife habitats: A landscape perspective*. Minneapolis: University of Minnesota Press.

Ahl, V., & Allen, T. F. H. (1996). *Hierarchy theory: A vision, vocabulary, and epistemology* (p. 206). New York: Columbia University Press.

Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C., & Zumbrunnen, C. (2003). Integrating humans into ecology: Opportunities and challenges for studying urban ecosystems. *BioScience, 53*, 1169e–1179e.

Allen, T. F. H., & Hoekstra, T. W. (1992). *Toward a unified ecology*. New York: Columbia University Press.

Attorre, F., Stanisci, A., & Bruno, F. (1997). The urban woods of Rome. *Plant Biosystems, 131*, 113–135.

Band, L. E., & Moore, I. D. (1995). Scale: Landscape attributes and geographical information systems. *Hydrological Processes, 9*, 401–422.

Band, L. E., Cadenasso, M. L., Grimmond, S., & Grove, J. M. (2006). Heterogeneity in urban ecosystems: Pattern and process. In G. Lovett, C. G. Jones, M. G. Turner, & K. C. Weathers (Eds.), *Ecosystem function in heterogeneous landscapes* (pp. 257–278). New York: Springer.

Black, P. E. (1991). *Watershed hydrology*. Prentice Hall: Englewood Cliffs.

Bolin, B., Grineski, S., & Collins, T. (2005). The geography of despair: Environmental racism and the making of south Phoenix, Arizona, USA. *Human Ecology Review, 12*, 156–168.

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics, 29*, 293–301.

Boone, C., Cadenasso, M., Grove, J., Schwarz, K., & Buckley, G. (2009). Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: Why the 60s matter. *Urban Ecosystems, 13*, 255–271.

Bormann, F. H., & Likens, G. (1979). *Patterns and processes in a forested ecosystem*. New York: Springer.

Boyden, S. (1979). *An integrative ecological approach to the study of human settlements*. Paris: UNESCO.

Brand, S. (2006). City planet. S*trategy + Business, 42*. Retrieved from: http://www.strategy-business.com/press/16635507/16606109

Brand, S. (2009). *Whole earth discipline: An ecopragmatist manifesto*. London: Viking/Penguin.

Buckley, G. L., & Boone, C. G. (2011). "To promote the material and moral welfare of the community": Neighborhood improvement associations in Baltimore, Maryland, 1900–1945. In R. Rodger & G. Massard-Guilbaud (Eds.), *Environmental and social justice in the city: Historical perspectives* (pp. 43–65). Cambridge: White Horse Press.

Burch, W. R., Jr., & DeLuca, D. R. (1984). *Measuring the social impact of natural resource policies*. Albuquerque: New Mexico University Press.

Cadenasso, M. L., Pickett, S. T. A., Weathers, K. C., Bell, S. S., Benning, T. L., Carreiro, M. M., & Dawson, T. E. (2003). An interdisciplinary and synthetic approach to ecological boundaries. *BioScience, 53*, 717–722.

Cadenasso, M. L., Pickett, S. T. A., & Grove, J. M. (2006). Dimensions of ecosystem complexity: Heterogeneity, connectivity, and history. *Ecological Complexity, 3*, 1–12.

Carpenter, S. R. (1998). The need for large-scale experiments to assess and predict the response of ecosystems to perturbation. In M. L. Pace & P. M. Groffman (Eds.), *Successes, limitations, and frontiers in ecosystem science* (pp. 287–312). New York: Springer.

Carreiro, M. M., Pouyat, R. V., Tripler, C. E., & Zhu, W. (2009). Carbon and nitrogen cycling in soils of remnant forests along urbanerural gradients: case studies in New York City and Louisville, Kentucky. In M. J. McDonnell, A. Hahs, & J. Breuste (Eds.), *Comparative ecology of cities and towns* (pp. 308–328). New York: Cambridge University Press.

Chan, S. (2007, December 4). Considering the urban planet 2050. *New York Times*, New York.

Cilliers, S. S., & Bredenkamp, G. J. (1999). Analysis of the spontaneous vegetation of intensively managed open spaces in the Potchefstroom Municipal Area, North West Province, South Africa. *South African Journal of Botany, 65*, 59–68.

Clay, G. (1973). *Close up: How to read the American City*. New York: Praeger Publishers.

Colding, J. (2007). Ecological land-use complementation' for building resilience in urban ecosystems. *Landscape and Urban Planning, 81*, 46–55.

Collins, S., Swinton, M, Anderson, C. W., Benson, B. J., Brunt J., Gragson, T. L., Grimm, N., Grove, J. M., Henshaw, D., Knapp, A. K., Kofinas, G., Magnuson, J. J., McDowell, W., Melack, J., Moore, J. C., Ogden, L., Porter, L., Reichman, J., Robertson, G. P., Smith, M. D., vande Castle, J., & Whitmer, A. C. (2007). *Integrated science for society and the environment: A strategic research initiative* (LTER Network Office Publication No 23). Albuquerque: LTER Network Office.

Collins, S., Carpenter, S. R., Swinton, S. M., Orenstein, D. E., Childers, D. L., Gragson, T. L., Grimm, N. B., Grove, J. M., Harlan, S. L., Kaye, J. P., Knapp, A. K., Kofinas, G. P., Magnuson, J. J., McDowell, W. H., Melack, J. M., Ogden, L. A., Robertson, G. P., Smith, M. D., & Whitmer, A. C. (2011). An integrated conceptual framework for long-term social–ecological research. *Frontiers in Ecology and the Environment, 9*, 351–357.

Cook, W. M., Casagrande, D. G., Hope, D., Groffman, P. M., & Collins, S. L. (2004). Learning to roll with the punches: Adaptive experimentation in human-dominated systems. *Frontiers in Ecology and the Environment, 2*, 467–474.

Couzin, J. (2008). Living in the danger zone. *Science, 19*, 748–749.

Dalton, S. E. (2001). *The Gwynns Falls watershed: A case 3 study of public and non-profit sector behavior in natural resource management*. Published doctoral dissertation, Johns Hopkins University, Baltimore.

Deutsch, L., Jansson, A., Troell, M., Ronnback, P., Folke, C., & Kautsky, N. (2000). The "ecological footprint": communicating human dependence on nature's work. *Ecological Economics, 32*, 351–355.

Duncan, O. D. (1961). From social system to ecosystem. *Sociological Inquiry, 31*, 140–149.

Duncan, O. D. (1964). Social organization and the ecosystem. In R. E. L. Faris (Ed.), *Handbook of modern sociology* (pp. 37–82). Chicago: Rand McNally & Co., Il printing.

Field, D. R., Voss, P. R., Kuczenski, T. K., Hammer, R. B., & Radeloff, V. C. (2003). Reaffirming social landscape analysis in landscape ecology: A conceptual framework. *Society and Natural Resources, 16*, 349–361.

Folke, C., Jansson, A., Larsson, J., & Costanza, R. (1997). Ecosystem appropriation by cities. *Ambio, 26*, 167–172.

Foster, D. R., Swanson, F., Aber, J., Tilman, D., Bropakw, N., Burke, I., & Knapp, A. (2002). The importance of land-use legacies to ecology and conservation. *BioScience, 53*(1), 77–88.

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

Garreau, J. (1991). *Edge city: Life on the new frontier*. New York: Doubleday.

Grimm, N., Grove, J. M., Pickett, S. T. A., & Redman, C. L. (2000). Integrated approaches to long-term studies of urban ecological systems. *BioScience, 50*, 571–584.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science, 319*, 756–760.

Groffman, P. M., & Crawford, M. K. (2003). Denitrification potential in urban riparian zones. *Journal of Environmental Quality, 32*, 1144–1149.

Groffman, P. M., Boulware, N. J., Zipperer, W. C., Pouyat, R. V., Band, L. E., & Colosimo, M. F. (2002). Soil nitrogen cycling processes in urban riparian zones. *Environmental Science and Technology, 36*, 4547–4552.

Groffman, P. M., Bain, D. J., Band, L. E., Belt, K. T., Brush, G. S., Grove, J. M., Pouyat, R. V., Yesilonis, I. C., & Zipperer, W. C. (2003). Down by the riverside: Urban riparian ecology. *Frontiers in Ecology and the Environment, 1*, 315–321.

Grove, J. M. (1996). *The relationship between patterns and processes of social stratification and vegetation of an urban-rural watershed.* Published doctoral dissertation, Yale University, New Haven.

Grove, J. M., & Burch, W. R., Jr. (1997). A social ecology approach and applications of urban ecosystem and landscape analyses: A case study of Baltimore, Maryland. *Journal of Urban Ecosystems, 1*, 259–275.

Grove, J. M., & Hohmann, M. (1992). GIS and social forestry. *Journal of Forestry, 90*, 10–15.

Grove, J. M., Burch, W. R., & Pickett, S. T. A. (2005). Social mosaics and urban forestry in Baltimore, Maryland. In R. G. Lee & D. R. Field (Eds.), *Communities and forests: Where people meet the land* (pp. 248–273). Corvalis: Oregon State University Press.

Grove, J. M., Cadenasso, M. L., Burch, W. R., Jr., Pickett, S. T. A., O'Neil-Dunne, J. P. M., Schwarz, K., Wilson, M., Troy, A. R., & Boone, C. (2006a). Data and methods comparing social structure and vegetation structure of urban neighborhoods in Baltimore, Maryland. *Society and Natural Resources, 19*, 117–136.

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

Gunderson, L. H. (2000). Ecological resilience – In theory and application. *Annual Review of Ecology and Systematics, 31*, 425–439.

Hawley, A. H. (1950). *Human ecology: A theory of community structure*. New York: Ronald Press.

Holling, C. S., & Gunderson, L. H. (2002). Resilience and adaptive cycles. In L. H. Gunderson & C. S. Holling (Eds.), *Panarchy: Understanding transformations in human and natural systems* (pp. 25–62). Washington, DC: Island Press.

Hostetler, M. (1999). Scale, birds, and human decisions: A potential for integrative research in urban ecosystems. *Landscape and Urban Planning, 45*, 15–19.

Hough, M. (1984). *City form and natural process: Towards a new urban vernacular*. New York: Van Norstrand Reinhod Company.

Jacobs, J. (1961). *The death and life of great American cities*. New York: Vintage Books.

Jenkins, J. C., & Riemann, R. (2001). What does nonforest land contribute to the global C balance? In R. E. McRoberts, G. A. Reams, P. C. Van Deusen, & J. W. Moser (Eds.), *Proceedings of the third annual forest inventory and analysis symposium, general technical report* (pp. 173–179). St Paul: Department of Agriculture, Forest Service, North Central Research Station.

Johnson, S. (2006). *The ghost map: The story of London's most terrifying epidemic – and How It changed science, cities, and the modern world*. New York: Riverhead Books.

Katz, B., & Bradley, J. (1999, December). Divided we sprawl. *Atlantic Monthly*, pp. 26–42.

Kennedy, V. S., & Mountford, K. (2001). Human influences on aquatic resources in the Chesapeake Bay watershed. In P. D. Curtin, G. S. Brush, & G. W. Fisher (Eds.), *Discovering the Chesapeake: The history of an ecosystem* (pp. 191–219). Baltimore: The Johns Hopkins University Press.

Kent, M., Stevens, R. A., & Zhang, L. (1999). Urban plant ecology patterns and processes: A case study of the flora of the city of Plymouth, Devon, UK. *Journal of Biogeography, 26*, 1281–1298.

LaDeau, S. L., Calder, C. A., Doran, P. J., & Marra, P. P. (2011). West Nile virus impacts in American crow populations are associated with human land use and climate. *Ecological Research, 26*, 909–916.

Law, N. L., Band, L. E., & Grove, J. M. (2004). Nutrient input from residential lawn care practices. *Journal of Environmental Planning and Management, 47*, 737–755.

Lenski, G. E. (1966). *Power and privilege: A theory of social stratification*. New York: McGraw-Hill.

Li, H., & Reynolds, J. F. (1993). A new contagion index to quantify spatial patterns of landscapes. *Landscape Ecology, 8*, 155–162.

Li, H., & Reynolds, J. F. (1995). On definition and quantification of heterogeneity. *Oikos, 73*, 280–284.

Likens, G. E. (Ed.). (1989). *Long-term studies in ecology: Approaches and alternatives*. New York: Springer.

Locke, D. H, Grove, J. M., Lu, J. W. T., Troy, A., O'Neil-Dunne, J. P. M., & Beck, B. (2011). The 3Ps March on: Prioritizing potential and preferable locations for increasing urban tree canopy in New York City. *Cities and the Environment, 3, article 14*. Retrieved from http://escholarship.bc.edu/cate/vol3/iss1/4

Lord, C., & Norquist, K. (2010). Cities as emergent systems: Race as a rule in organized complexity. *Environmental Law, 40*, 551–597.

Loucks, O. L. (1994). Sustainability in urban ecosystems: Beyond an object of study. In R. H. Platt, R. A. Rowntree, & P. C. Muick (Eds.), *The ecological city: Preserving and restoring urban biodiversity* (pp. 48–65). Amherst: University of Massachusetts Press.

Machlis, G. E., Force, J. E., & Burch, W. R., Jr. (1997). The human ecosystem part I: The human ecosystem as an organizing concept in ecosystem management. *Society and Natural Resources, 10*, 347–367.

Makse, H. A., Havlin, S., & Stanley, H. E. (1995). Modeling urban growth patterns. *Nature, 377*, 608–612.

McDonnell, M. J., Pickett, S. T. A., Pouyat, R. V., Parmelee, R. W., & Carreiro, M. M. (1997). Ecosystem processes along an urban-to-rural gradient. *Urban Ecosystems, 1*, 21–36.

McGrath, B., Marshall, V., Cadenasso, M. L., Grove, J. M., Pickett, S. T. A., Plunz, R., & Towers, J. (Eds.). (2007). *Designing urban patch dynamics*. New York: Columbia University Graduate School of Architecture, Planning and Preservation, Columbia University.

Melosi, M. V. (2000). *The sanitary city: Urban infrastructure in America from colonial times to the present*. Baltimore: Johns Hopkins University Press.

Merse, C. L., Buckley, G. L., & Boone, C. G. (2009). Street trees and urban renewal: A Baltimore case study. *The Geographical Bulletin, 50*, 65–81.

Mohai, P., & Saha, R. (2007). Racial inequality in the distribution of hazardous waste: A national-level reassessment. *Social Problems, 54*, 343–370.

Niemela, J. (1999). Ecology and urban planning. *Biodiversity and Conservation, 8*, 118–131.

NOAA. (2004). *Population trends along the coastal United States: 1980–2008*. Washington, DC: U.S. Department of Commerce.

Northridge, M. E., Sclar, E. D., & Biswas, P. (2003). Sorting out the connection between the built environment and health: A conceptual framework for navigating pathways and planning healthy cities. *Journal of Urban Health: Bulletin of the New York Academy of Medicine, 80*, 556–568.

Nowak, D. J. (1994). Atmospheric carbon dioxide reduction by Chicago's urban forest. In E. G. McPherson (Ed.), *Chicago's urban forest ecosystem: Results of the Chicago Urban Climate Project* (pp. 83–94). Radnor: Northeastern Research Station, USDA Forest Service.

Parker, J. K., & Burch, W. R., Jr. (1992). Toward a social ecology for agroforestry in Asia. In W. R. Burch Jr. & J. K. Parker (Eds.), *Social science applications in Asian agroforestry* (pp. 60–84). New Delhi: IBH Publishing.

Pickett, S. T. A., & Cadenasso, M. L. (2002). The ecosystem as a multidimensional concept: Meaning, model, and metaphor. *Ecosystems, 5*, 1–10.

Pickett, S. T. A., & Cadenasso, M. L. (2008). Linking ecological and built components of urban mosaics: An open cycle of ecological design. *Journal of Ecology, 96*, 8–12.

Pickett, S. T. A., & Cadenasso, M. L. (2009). Altered resources, disturbance, and heterogeneity: A framework for comparing urban and non-urban soils. *Urban Ecosystems, 12*, 23–44.

Pickett, S. T. A., & Grove, J. M. (2009). Urban ecosystems: What would Tansley do? *Urban Ecosystems, 12*, 1–8.

Pickett, S. T. A., & White, P. S. (Eds.). (1985). *The ecology of natural disturbance and patch dynamics*. Orlando: Academic.

Pickett, S. T. A., Burch, W. R., Jr., & Dalton, S. (1997a). Integrated urban ecosystem research. *Urban Ecosystems, 1*, 183–184.

Pickett, S. T. A., Burch, W. R., Jr., Dalton, S., Foresman, T., Grove, J. M., & Rowntree, R. (1997b). A conceptual framework for the study of human ecosystems in urban areas. *Journal of Urban Ecosystems, 1*, 185–199.

Pickett, S. T. A., Burch, W. R., Jr., & Grove, J. M. (1999). Interdisciplinary research: Maintaining the constructive impulse in a culture of criticism. *Ecosystems, 22*, 302–307.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., & Costanza, R. (2001). Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecology and Systematics, 32*, 127–157.

Pickett, S. T. A., Cadenasso, M. L., & Grove, J. M. (2004). Resilient cities: Meaning, models and metaphor for integrating the ecological, socio-economic, and planning realms. *Landscape and Urban Planning, 69*, 369–384.

Pickett, S. T. A., Kolasa, J., & Jones, X. (2007). *Ecological understanding: The nature of theory and the theory of nature* (2nd ed.). New York: Springer.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Boone, C. G., Groffman, P. E., Irwin, E., Kaushal, S. S., Marshall, V., McGrath, B. P., Nilon, C. H., Pouyat, R. V., Szlavecz, K., Troy, A. R., & Warne, P. (2011). Urban ecological systems: Scientific foundations and a decade of progress. *Journal of Environmental Management, 92*, 331–362.

Pincetl, S. (2010). From the sanitary to the sustainable city: Challenges to institutionalizing biogenic (nature's services) infrastructure. *Local Environment, 15*, 43–58.

Pouyat, R. V., Carreiro, M. M., Groffman, P. M., & Pavao-Zuckerman, M. A. (2009). Investigative approaches to urban biogeochemical cycles: New York metropolitan area and Baltimore as case studies. In M. J. McDonnell, A. Hahs, & J. Breuste (Eds.), *Ecology of cities and towns: A comparative approach* (pp. 329–351). New York: Cambridge University Press.

Raciti, S., Galvin, M. F., Grove, J. M., O'Neil-Dunne, J., & Todd, A. (2006). *Urban tree canopy goal setting: A guide for communities*. Annapolis: USDA Forest Service, Chesapeake Bay Program Office, Northeastern Area, State and Private Forestry.

Rebele, F. (1994). Urban ecology and special features of urban ecosystems. *Global Ecology and Biogeographical Letters, 4*, 173–187.

Redman, C. L., Grove, J. M., & Kuby, L. H. (2004). Integrating social science into the long-term ecological research (LTER) network: Social dimensions of ecological change and ecological dimensions of social change. *Ecosystems, 7*, 161–171.

Romolini, M., & Grove, J. M. (2010, August 3). *Polycentric networks and resilience in urban systems: A comparison of Baltimore & Seattle.* Ecological Society of America annual meeting, Pittsburgh, PA.

Schaaf, T., Zhao, X., & Keil, G. (1995). *Towards a sustainable city: Methods of urban ecological planning and its application in Tianjin, China*. Berlin: Urban System Consult GmbH.

Schnore, L. F. (1958). Social morphology and human ecology. *The American Journal of Sociology, 63*, 620–634.

Seto, K., Sanchez-Rodriguez, R., & Fragkias, M. (2010). The new geography of contemporary urbanization and the environment. *Annual Review of Environmental Resources, 35*, 167–194.

Shane, G. D. (2005). *Recombinant urbanism: Conceptual modeling in architecture, urban design, and city theory*. Chichester: Wiley.

Spirn, A. W. (1984). *The granite garden: Urban nature and human design*. New York: Basic Books, Inc.

Stearns, F. (1970). Urban ecology today. *Science, 170*, 1006–1007.

Stearns, F., & Montag, T. (Eds.). (1974). *The urban ecosystem: A holistic approach*. Stroudsburg: Dowden, Hutchinson and Ross, Inc.

Stokes, D. E. (1997). *Pasteur's Quadrant – Basic science and technological innovation*. Washington, DC: Brookings Institution Press.

Svendsen, E. S., & Campbell, L. K. (2008). Urban ecological stewardship: Understanding the structure, function and network of community-based urban land management. *Cities and the Environment, 1*, 1–32.

Tansley, A. G. (1935). The use and abuse of vegetational concepts and terms. *Ecology, 16*, 284–307.

Thompson, G. E., & Steiner, F. R. (Eds.). (1997). *Ecological design and planning*. New York: Wiley.

Toepfer, K. (2005). *From the desk of Klaus Toepfer, United Nations Under-Secretary-General and Executive Director*, UNEP. Our Planet.

Troy, A. R., Grove, J. M., O'Neil-Dunne, J. P. M., Pickett, S. T. A., & Cadenasso, M. L. (2007). Predicting opportunities for greening and patterns of vegetation on private urban lands. *Environmental Management, 40*, 394–412.

Turner, B. L., II, Kasperson, R. E., Matosn, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., Kasperson, J. X., Luers, A., Martello, M. L., Polsky, C., Pulsipher, A., & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences USA, 100*, 8074–8079.

van der Leeuw, S. E. (1998). *The ARCHAEOMEDES Project B understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean Basin*. Luxemburg: Office of Publications of the European Union.

Vandruff, L. W., Bolen, E. G., & San Julian, G. J. (1994). Management of urban wildlife. In T. A. Bookhout (Ed.), *Research and management techniques for wildlife and habitats* (pp. 507–530). Bethesda: The Wildlife Society.

Vincent, G., & Bergeron, Y. (1985). Weed synecology and dynamics in urban environment. *Urban Ecology, 9*, 161–175.

Wiens, J. A. (1995). Landscape mosaics and ecological theory. In L. Hansson, L. Fahrig, & G. Merriam (Eds.), *Mosaic landscapes and ecological processes* (pp. 1–26). New York: Chapman & Hall.

Wu, J., & Loucks, O. L. (1995). From balance of nature to hierarchical patch dynamics: A paradigm shift in ecology. *The Quarterly Review of Biology, 70*, 439–466.

Zhou, W., Troy, A. R., & Grove, J. M. (2009a). Modeling residential lawn fertilization practices: Integrating high resolution remote sensing with socioeconomic data. *Environmental Management, 41*, 742–752.

Zhou, W., Grove, J. M., Troy, A., & Jenkins, J. C. (2009b). Can money buy green? Demographic and socioeconomic predictors of lawncare expenditures and lawn greenness in urban residential areas. *Society and Natural Resources, 22*, 744–760.

Zimmerman, J. K., Scatena, F. N., Schneider, L. C., Gragson, T., Boone, C., & Grove, J. M. (2009). *Challenges for the implementation of the decadal plan for long-term ecological research: Land and water use change: Report of a workshop* (LTER Network Office Report).

Zipperer, W. C., Foresman, T. W., Sisinni, S. M., & Pouyat, R. V. (1997). Urban tree cover: An ecological perspective. *Urban Ecosystems, 1*, 229–247.