Chapter 2
Three Tides: The Development and State of the Art of Urban Ecological Science

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Introduction

The goal of this chapter is to provide an overview and synthesis of the trajectory of urban ecology in the United States. This trajectory has benefited greatly from urban research in other parts of the world. We will recognize this cross fertilization but will not detail the history of discipline development in these other regions, nor discuss how the practice of urban ecology differs between the US and other regions. The perspective from which we write is that of ecological scientists reflecting on the development of our own field. We do, however, maintain extensive and long term collaborations with scholars and practitioners from other disciplines including the social sciences and design and these collaborations have influenced our thinking. We do not claim to be historians, but feel it is important to understand the nature of contemporary urban ecological science and how it differs from some clear precedents. Our historical contextualization begins with recognizing the different meanings of the phrase, urban ecology.

In the literature, urban ecology has two primary meanings (Sukopp 1998). One emphasizes designing environmental amenities for urban residents and is prevalent in the urban planning field. This perspective, which is especially strong in Europe (Sukopp 1998), provides ecological justification for planning goals and approaches (Deelstra 1998). The second definition, and the one we focus on here, comes from

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the science of ecology. This definition refers to studies of the distribution and abundance of organisms in and around cities, and on the biogeochemical inputs and outputs of urban areas (Pickett et al. 2011). The interaction of humans with the urban environment has been primarily the disciplinary home of geographers, planners, landscape architects, and social scientists of all types, among others. It wasn't until the 1990s that ecological research focusing on urban areas gained traction in United States (McDonnell 2011), despite the fact that the first volume of the journal Ecology contained a scientific paper devoted to the effect of weather on the spread of pneumonia in the human populations of New York and Boston (Huntington 1920).

The development of the science of urban ecology in the United States has not been continuous, but rather punctuated by periods of activity and advancement. We identify three specific periods during the twentieth century when the application of ecological science to understanding the structure and dynamics of urban areas gained momentum. We use the metaphor of tides to frame our discussion of the developments that allowed the tide to come in and that perhaps also caused that tide to ebb. Each tide however, contributed approaches and understandings that were ready to be used upon the arrival of the next tide. The tides have grown steadily in magnitude and effect. We will conclude the chapter by suggesting why we believe the third tide, which we are currently experiencing, is here to stay.

First Tide: The Chicago School and Understanding Spatial Differentiation

Ecological concepts were first applied to the urban area by Robert Park and Ernest Burgess of the University of Chicago's Department of Sociology in the 1920s (Park et al. 1925). This was the first university department of sociology in the United States, and sociologists were concerned primarily with developing a science firmly rooted in empirical research. In addition, they viewed the city of Chicago as a natural laboratory for asking important sociological questions. Their research, therefore, was motivated by trying to understand and solve urban problems that had never been investigated before (Cortese 1995). The approach of the Chicago School was to focus on space and social differentiation in the city, in other words, to focus on how different parts of the city were being used and the mechanisms by which human population was distributed across the metropolis (Burgess 1925; McKenzie 1925). This approach resonates with biological ecology that was dominant at the time because it considers humans simply as organisms.

During this time, Chicago was rapidly expanding due to migrations from the American South, as well as, from overseas. This was the heyday of the urban downtown for industry, business and commerce. Home mortgages and private vehicles were becoming more available and individuals with financial resources could live farther away from their work, which was typically located in the central business district and surrounding industrial belts. Sociology up to this time had primarily focused on rural communities. When sociologists turned their attention to rapidly changing and urbanizing Chicago they did so with a comparative lens that held rural living as the ideal (Bulmer 1984).

To understand the dynamics of this rapidly changing city, Park and Burgess investigated processes that led to spatial differentiation of people and activities in the urban landscape. Park, in particular, was especially aware of the biological sciences and was focused on understanding the adjustment of human groups to the environment (Park et al. 1925). He made extensive use of ideas developed within the science of ecology to inform his theoretical work on the structure and change of urban human communities (Cortese 1995; Light 2009). Though he recognized the importance of social and cultural influences on urban life, he argued that community organization was also based on non-social processes. He brought three ecological theories to bear: (1) competition, (2) niche partitioning, and (3) succession. These three theories are related to each other. Succession, which was being developed at the same time within the field of ecology (Clements 1916), describes the change in vegetation structure and composition over time in a particular place. This change in plant community composition and structure is in turn driven by competition among species for space and resources. The results of that competition are made visible by the spatial and temporal distribution of species. Therefore, competition is the mechanism that leads to community change, or succession, and that change is expressed by the spatial division or partitioning of niches. Applying these three ecological concepts to understanding the drivers of the spatial differentiation of people in cities, Park and Burgess suggested that competition for limiting resources in the urban environment, such as land, led to the partitioning of that resource into different niches used by either distinct social groups or activities, such as industry or housing. Therefore, people and businesses moved outward from the city center as they became more prosperous, and Park and Burgess called this directional movement succession (McKenzie 1925; Park et al. 1925).

Burgess focused on mapping city growth and subsequent spatial differentiation of land use and people. He proposed an application of the three general ecological theories in his concentric zone model of urban growth (Fig. 2.1; Burgess 1925). In this model, urban growth and expansion were conceptualized as a series of five concentric zones around an industrial downtown, or central business district. The five zones were based on typical patterns of land use. Zone I, the central business district (CBD) is restricted to commercial uses. Zones III-V are residential areas; Zone III contained workingmen's homes described as single family or multifamily tenement housing, Zone IV was labeled as residential and homes were single family frequently with garages and yards, and finally, the suburban zone, Zone V, required residents to commute to work. Zone II, located between the central business district and the beginning of the residential zones was called the Zone in Transition. This zone was characterized as mixed, where low-rent, slum residences were being replaced by businesses and factories. Burgess used the city of Chicago as a concrete illustration of this spatially explicit model of city structure and distribution of residents.

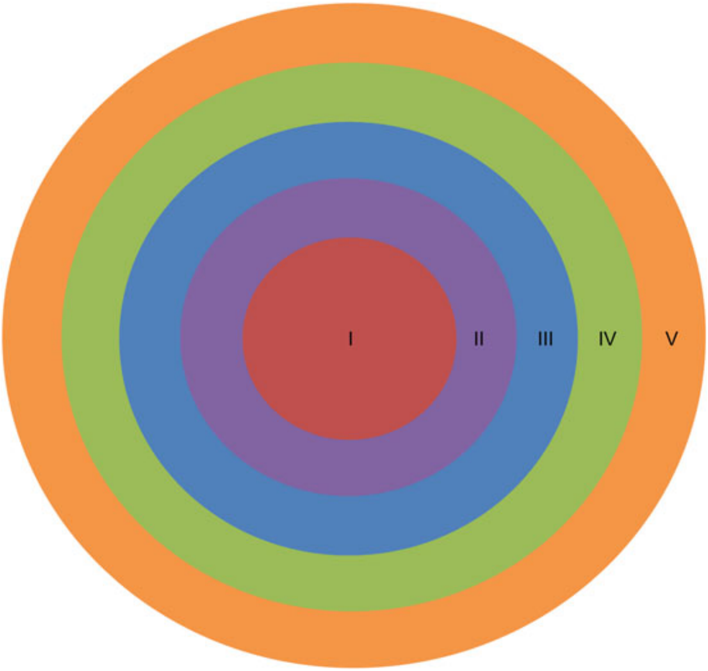

Fig. 2.1 Burgess' concentric zone model of urban form (See text for description of each zone Adapted from Burgess 1925)

Burgess conceptualized the process of urbanization as one of outward expansion and conversion of land uses such that each inner zone expanded out to the next zone. Competition for space, as the mechanism of growth and change, originated in Zone I and resulted in pressure through all of the zones in the model to steadily expand outward over time. As the central business district (Zone I) expanded, commercial uses increasingly invaded the residential areas in the Zone in Transition (Zone II). Because residential properties in Zone II would eventually be sold for commercial purposes, these properties were allowed to deteriorate. This, in turn, led to an expansion of the transitional, slum area into Zone III and so on (Burgess 1925). The concentric zone model assumes a relationship between the socio-economic status of households and distance from the CBD. Households farther away from the CBD have higher quality housing and longer commute times. Both of these characteristics require greater economic resources.

This early conceptualization of city structure was ultimately replaced due to its exclusive focus on spatial differentiation and on competition as the mechanism influencing that differentiation (Alihan 1938; Hollingshead 1947). It was criticized for ignoring other factors that may influence where people and businesses locate in urban areas (Firey 1945, 1947; Burch 1971; Masters 1989). The model was developed for American cities when these cities were growing very fast in population, and personal transportation was not yet widely available. As a consequence, the model has limited applicability to cities that have different growth dynamics such as those cities characteristic of the second half of the twentieth century in industrial countries. In this context, highways have enabled urban development to escape the conversion of land use and instead to take place directly on the fringe of development expanding that development outward. Second, the separation of place of work and place of residence across the different zones in the model was not generally the case until later in the twentieth century. Therefore, the exclusive focus on spatial differentiation and competition as the driver of differentiation while ignoring the role of individual decisions based on economics, or on cultural desires (Alihan 1938; Gettys 1940; Firey 1947; Hollingshead 1947; Hawley 1986) may have contributed to the ebbing of this tide in the development of urban ecology. In addition, the Chicago School held the rural landscape up as ideal and focused on the ills of the urban landscape such as crime and unemployment (Cortese 1995). Finally, Burgess' model was greatly simplified and was quickly recognized as not reflective of reality or experience; it was too abstract to be useful (Firey 1947).

Despite the limitations that influenced the ebbing of this tide, the Chicago School left several positive legacies that influenced future tides of urban ecology. The Chicago School introduced social science as a discipline and the use of the case study as an empirical approach (Bulmer 1984). Though no ecological scientists directly collaborated with Park and Burgess, it is no coincidence that ecological science influenced their thinking (McKenzie 1925). The University of Chicago was also an important nexus in the early developments in American ecology – particularly the concept of vegetation succession which was first conceptualized in the nearby dune system of Lake Michigan (Cowles 1899). Though the Burgess model was simplified, it did demonstrate the use of maps as research tools and recognized that urban settlements experience transitions in form and demographics (Bulmer 1984). In addition, the Chicago School approach was a multivariate one that incorporated physical, political, economic, and social understanding. These nuggets would resonate with future attempts to understand the city as an ecological system.

Second Tide: City as System

Oddly, during the early twentieth century, while major ideas in ecological science were informing the birth of sociology and were thus widely but indirectly applied in urban systems, most ecologists ignored cities and urban systems, preferring to study "pristine" locations so as to avoid the "impact" of humans. In the field of ecology, humans were considered as agents of disturbance and generally regarded to exist outside of the system of interest (Turner and Meyer 1993). In general, ecologists were slow to recognize the city as a system worthy of study until the middle of the twentieth century. Fortunately, there were a few intrepid pioneers among ecological scientists who ventured into the urban realm, armed with the intellectual tools of their discipline as they existed in mid-century (Numata 1977; Stearns 1970; Sukopp et al. 1979).

Following WWII, two approaches to urban ecology were taken. The first approach, mainly from Europe and Japan, focused on plant and animal populations in open urban spaces such as cemeteries, parks, and vacant sites destroyed by bombing during the war (Salisbury 1943; Numata 1977; Bornkamm et al. 1982; Sukopp 1990). These ecologists were interested in the same fundamental ecological questions as were their colleagues working in wilderness or the countryside, questions such as the patterns and mechanisms of plant establishment and how those newly established biological communities would change through time. But they were asking these questions in urban spaces which was novel for ecology at the time. The "natural" study sites of mid-century urban ecology were considered to be ecologically integrated parts of larger urban systems. However, the larger system itself was not the primary focus of the study, except as a way to understand coarse scale environmental factors, such as air pollution (Sukopp 2002).

The second approach focused on the city as a system and characterized the city as a metabolic machine. This approach was influenced by the International Biological Program (IBP), which existed from 1964 to 1974. The IBP was motivated by the need to address pressing environmental issues and attempted to institutionalize "big science" in ecology by encouraging large groups of scientists to work with the concepts of energetics, material budgets, and the metabolism of whole systems (Golley 1993; Coleman 2010). The program aimed to be explanatory and predictive of system structure and dynamics, but predictions could only be made at the macroscopic level. Nothing could be predicted in detail because ecosystems were too complex and influenced by historical contingencies. In other words, focusing down to the level of green patches in the city, which characterized the first approach to post-war urban ecology described immediately above, could not be scaled with this macroscopic research on metabolism. Hence, urban whole-systems research, and research focused on communities and populations of plants and animals were relatively separate. This thwarted the establishment of an integrated ecology of cities. Furthermore, the IBP only formally lasted a decade as the program lacked a clear, socially and scientifically pressing goal.

A crucial legacy of the IBP, however, was to increase the funding for ecosystem research which was a growing area of the science of ecology (Hagen 1992). Though the term "ecosystem" had been coined by Tansley in 1935, two brothers, H.T. and E.P. Odum, developed this systems approach into an area of research, and made it a paradigm in ecology by the 1960s and 1970s (Odum 1971; Odum and Odum 1976). Ecosystem ecology sought to understand the reciprocal metabolic connections between biological and physical components of systems. Models of an ecosystem employed a rigorous budgetary approach, such that systems consisted of physical and biological components and the fluxes of material, energy and information among them. Physical components included substrates such as soil or water, and organisms were the biological components of the system.

In order to use this approach, components and fluxes are identified and measured in a particular place. The boundaries of the system are specified by the researcher and informed by the particular research question being addressed. Determining the boundaries of the system is a crucial step because it determines which components

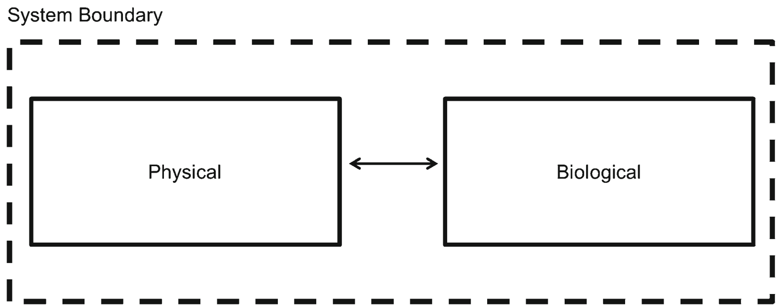

Fig. 2.2 An ecosystem contains physical and biological components that interact with each other within a specified boundary. Published with kind permission of © Mary L. Cadenasso, 2013. All Rights Reserved

and fluxes are considered by the research to be included and which, therefore, are beyond the scope of the specific question (Fig. 2.2). Ecologists working in non-urban areas may establish system boundaries to coincide with physical attributes of the landscape such as a lake or a watershed, management units such as an agricultural field or woodlot, or structural heterogeneity that can be used for comparisons, such as forested patches of different species or forest and meadow patches. A powerful attribute of the ecosystem approach is the flexibility to determine the boundaries of the system to be studied, which allows the concept to be applied across systems and spatial scales (Likens 1992; Pickett and Cadenasso 2002). Once the boundaries of a system are determined, the budgetary approach quantifies the fluxes of materials, organisms, or energy into and out of the system using a common currency. If the inputs are equivalent to the outputs then the system is considered to have a balanced budget; any difference between inputs and outputs determines whether the system is retaining or releasing the chemical element, or currency, being quantified (Fig. 2.3; Likens 1992).

The budgetary approach that is so fundamental to ecosystem science, has been applied to cities to investigate the stores and flows of energy and material. Whole-city budgets allow for the detailing of resource demand and use, and pollution storage and release among cities or in a specific city over time (Bernhardt et al. 2008; Ngo and Pataki 2008). This approach is epitomized by work in Hong Kong (Boyden et al. 1981). The City of Hong Kong is an island, making the determination of system boundaries and the quantification of inputs and outputs relatively straightforward. Using various data sources, the research documented inputs and outputs of water, resources, food, etc., from and to land, water and the atmosphere (Fig. 2.4).

Though the initial application of this approach was at the scale of the entire city, the concept can be applied at any scale, just as described above for non-urban ecosystems. The scale of application is related to the boundaries selected for the system. For example, a watershed can be a system and the inputs and outputs of material – water, nutrients, pollutants, etc. – can be quantified using the watershed boundary (e.g. Groffman et al. 2004). At a finer scale, the individual household may be of primary interest and the systems boundary can be set to isolate individual

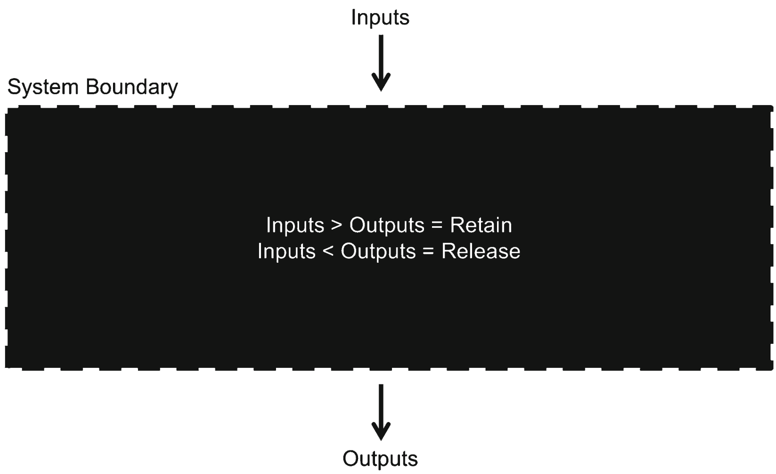

Fig. 2.3 An ecosystem boundary is permeable to fluxes of material, organisms, and energy. These fluxes can be inputs to, or outputs from, the focal system. If the inputs are greater than the outputs then the focal system is retaining materials or organisms. In contrast, if the inputs are less than the outputs then the focal system is releasing materials or organisms to surrounding systems. Published with kind permission of © Mary L. Cadenasso, 2013. All Rights Reserved

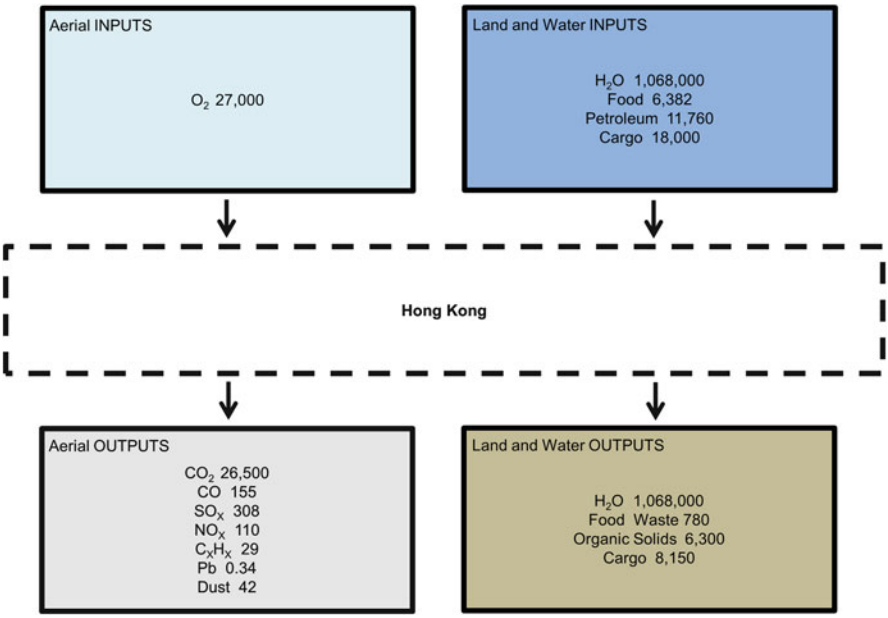

Fig. 2.4 Whole-city budget of Hong Kong. This is a specification of the abstraction shown in Figure 2. The system boundary of the island of Hong Kong is represented by the *dashed box*. Inputs to the system from air and land and water are shown in the *boxes above* the system. Outputs from the system to air and land and water are shown in the *boxes below* the system (Adapted from Boyden et al. 1981). Published with kind permission of © Mary L. Cadenasso, 2013. All Rights Reserved

Fig. 2.5 Defining system boundaries. The budgetary approach can be applied to any system but the boundary of the system must be delineated so that what is in and what is out can be determined. Three different system boundaries are shown – the municipal boundary of Sacramento, California (panel **a**), the watershed boundary for the Gwynns Falls in Baltimore, Maryland (panel **b**), and a household (panel **c**). A specific research question determines which boundary is appropriate. Published with kind permission of © Mary L. Cadenasso, 2013. All Rights Reserved

households allowing the inputs to and outputs from each household to be quantified (Baker et al. 2007). Therefore, the boundary of the system must be appropriate for the research question being addressed (Fig. 2.5).

The budgetary approach gave rise to industrial ecology (Frosch and Gallopoulos 1989) and urban metabolism (Wolman 1965). Both of these schools of thought analyze the material and energetic inputs, efficiencies, and outputs of urban systems and their components. The overarching goal of maximizing efficiency resonated with the interest in cybernetics that was occurring at the same time. Cybernetics focuses on how a system processes and reacts to information and how changes to the system influence its ability to do so (Wiener 1961). The motivation of efficiency fueled the perspective of systems, and cities in particular, as machines. From this perspective, cities are seen as made up of "units" that are interchangeable, can be easily fixed or altered, and have a very specific function (Shane 2005). This perspective is reflected in the large swaths of redundant "units" such as suburban housing (Fig. 2.6).

Though we have focused on the IBP program and the development of ecosystem ecology to demonstrate this tide, we recognize that there were several other factors at work during the same time (see McDonnell 2011). For example, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) began the Man and the Biosphere (MAB) program with the goal of studying human settlements from the perspective of multiple disciplines. The Hong Kong example referred to above was part of this program. In addition, large scale and pervasive environmental problems, such as air and water pollution, were increasingly causing concern in society and in 1970 the US government founded the Environmental Protection Agency and the first Earth Day was celebrated. Rising levels of

Fig. 2.6 Redundant residential developments typical of suburban areas. *Left image* illustrates the regularized nature of development on the landscape to form large swaths of consistent urban form as seen in the *right panel*. Published with kind permission of © Mary L. Cadenasso, 2013. All Rights Reserved

atmospheric CO_2 were just beginning to be documented at the Mauna Loa Observatory in Hawaii, reinforcing the impact of human activity on the globe's regulatory systems (Keeling 1998).

This era of urban ecology did not persist in the US as a comprehensive field for several reasons. Spatial heterogeneity within the system (Cadenasso et al., Chap. 6; Shane Chap. 7, this volume) was virtually ignored, which created a dissonance between urban ecology and the fine scale reality of many urban systems (Jacobs 1961; Clay 1987). The conceptualization of the system was as a "black box," obscuring internal detail while emphasizing inputs and outputs. This approach is valuable for tracking changes over time for a particular city or for comparing cities, but due to its focus on the coarse spatial scale, it is limited in its ability to inform specific management, restoration, or design interventions that may be needed to address excess use or output of nutrients or pollutants, for example. The social sciences of the mid-twentieth century also de-emphasized spatial heterogeneity, perhaps as a backlash against the Chicago School during the first tide which had emphasized spatial drivers of the distribution of land use and people (Gottdiener and Hutchison 2000).

Jane Jacobs (1961) provided a critical counterpoint to the approach of urban planning at the time which emphasized grand visions at the scale of the entire city. Realizing these visions of grandeur came at the cost of the richness and dynamics of neighborhoods. Jacobs (1961) emphasized the role of spatial and temporal heterogeneity of the neighborhood, which she described as an intricate ballet, as opposed to a precision dance with everyone in unison, and argued that these fine scale uses of the urban space by residents is how cities function.

In addition to the de-emphasis of spatial heterogeneity, considering humans as biological organisms may have also contributed to the receding of this tide. Humans were recognized as interacting with the system and influencing its function, and, in turn, also being influenced by the city. But the influence was the same sort that any biological organism would participate in, and did not include a differentiation in behaviors or a cultural lens through which behaviors and choices may be viewed and influenced (e.g. Ostrom 1990). Finally, this approach to understanding systems, while useful for some research questions, was not particularly relevant to the key concepts and questions driving the research of most ecologists in the field at the time.

This second tide of urban ecology ebbed, but left several positive legacies that contributed substantially to the third, contemporary tide. Conceptualizing the city as an ecosystem is central to the current approach to urban ecology (Pickett et al. 1997b; Grimm et al. 2000). This conceptualization opens the door to using material and energy budgets as ways to understand the ecological functioning of the city and to investigate how changes to city structure may influence its ecological functioning (McGrath, Chap. 11, this volume). The use of multiple boundaries such as nested watersheds, households, property parcels, and natural areas embedded within the urban matrix enhance the capacity of ecology to link system structure, human management choices, design and policy interventions, and their consequences for ecological functioning (Grove 2009). An additional positive legacy of the second tide is the integrative, collaborative approach of research fostered by the motivation to do big science. Urban systems are complex and require expertise and practice from many different disciplines. Developing critical questions, and researching their answers from a multidisciplinary perspective is critical for building understanding of how cities work and for working towards ecologically and socially resilient cities (Pickett et al. 2004; Redman et al. 2004; Alberti 2008).

Third Tide: Ecology of the City as an Inclusive Approach

Contemporary urban ecology has built on these earlier approaches and now includes several forms. In some cases, urban ecologists consider the impact of urbanization on remnant "natural" systems such as fragments of forest, desert, or wetland embedded in the urban matrix. Analog systems, such as vegetation in vacant lots, gardens, or intentional plantings can also be studied in this way. In this approach, focused as it is on green isolates, human decisions and activities are not studied directly but are instead considered as a single aggregated factor of urbanization that influences the ecological system of interest. This approach typically focuses on the non-built portions of the landscape and may be motivated by conservation of habitat or species. It has been termed ecology *in* the city (see also Pickett et al., Chap. 1, this volume).

The ecology in the city approach resonates with the motivations of European and Japanese ecologists, discussed above, to study plant and animal colonization of sites remaining open after WWII. This approach was also taken by a pioneering program in the United States that focused on the structure and function of forests arrayed along an urban to rural gradient. This program, referred to as Urban Rural Gradient Ecology, was initiated by Mark McDonnell, Steward Pickett, and Richard Pouyat. A 120 km transect extending from Manhattan to northwestern Connecticut, was used because it exhibited a linear decrease in urbanization moving from Manhattan out and was along the same soil type (McDonnell et al. 1997). Forests of similar age and species composition were located along the transect and characteristics of the landscape surrounding the forests were quantified to demonstrate the degrees of urbanization (Medley et al. 1995). Within the forests, research was conducted to address questions about soil nutrient dynamics (Pouyat et al. 1995; Pouyat and Turechek 2001), understory diversity and regeneration (Cadenasso et al. 2007a), and nutrient and pollutant inputs (Pouyat and McDonnell 1991; Lovett et al. 2000). Differences in these variables among forests along the transect were hypothesized to be due to the degree of urbanization surrounding the forests and additional mechanistic hypotheses developed and tested in experimental contexts (e.g. Carreiro et al. 1999).

Though this research program was based on a direct urban to rural gradient, it is important to remember that gradients can be indirect (Whittaker 1956). This crucial distinction is often overlooked by critics of the urban-rural gradient approach (e.g. Ramalho and Hobbs 2012). In the specific situation examined by the Urban Rural Gradient Ecology program, the degree of urbanization surrounding the forest patches decreased from most highly urbanized Manhattan to rural northwestern Connecticut. Because of this directional change in urbanization intensity across space, this gradient of urbanization is a direct gradient. Transects are a line along which samples are taken and they are a methodological approach to sampling that is appropriate if the change being quantified and described, or the influence of that change, is also directional. In other words, sampling along transects is appropriate if the gradient of change is directional along the transect. In many cases, however, urbanization does not decrease directionally outward from an urban downtown. Instead, patches of greater or lesser urbanization form a mosaic that cannot be described using a transect method of sampling. This does not negate the value of the urban-rural gradient approach. It simply means that the gradient of urbanization is indirect and a sampling method appropriate for patch mosaics should be employed (Pickett et al. 1997a; McDonnell and Hahs 2009; McDonnell et al. 2012).

A second approach, which is complimentary to the ecology in the city approach, focuses on the entire system, not just the vegetated areas, and takes a multidisciplinary stance to understand the integrated social-ecological system by synthesizing the ecological understanding of specific organisms and processes, social behaviors, and the feedbacks among them. This approach has been termed ecology *of* the city (Pickett et al. 1997a; Grimm et al. 2000) and it resonates with aspects of the city as system approach characteristic of the second tide. The difference, however, is that the "black box" of the city system is opened and the physical, biological, and social heterogeneities that occur throughout the city are recognized as important features that link to the processes and changes that occur within the city (Cadenasso et al. 2007b; Cadenasso et al. Chap. 6; Shane, Chap. 7, this volume). Both approaches, ecology *of* and ecology *in* the city, are needed in order to account for the heterogeneity and contexts in urban areas (e.g. Boone, Chap. 3; Sect. IV, this volume), and the best approach to use should be determined by a specific research question.

The more comprehensive approach of ecology of the city is characteristic of several relatively young programs around the world. Two long-term research programs focused on understanding urban systems in the United States exemplify the approach. In 1997, the National Science Foundation recognized that urban systems were important system types that were being overlooked by their Long Term Ecological Research (LTER) program. The LTER program was motivated by the need to study a particular place for periods of time longer than typical for scientific research in order to capture subtle changes or slow but directional changes over time (Likens 1989). A network of sites had been established in 1980 representing different natural biomes in the United States. Each site was mandated to study five core areas – primary production, organic matter accumulation, input and movement of inorganic matter, feeding structure and disturbances – to allow for cross system comparison in addition to conducting research on dynamics particularly relevant to the specific site (www.lternet.edu). In 1997, NSF broke with the traditional ecological focus on presumably natural systems and added two urban sites to the network, one in Baltimore, Maryland (www.beslter.org) and the other in Phoenix, Arizona (http://caplter.asu.edu/). Both of these sites address the five core areas of the LTER program but also, notably, include many other disciplines in an effort to understand urban systems as integrated social-ecological systems. In addition, interaction across the network has resulted in many of the non-urban sites recognizing the influence of humans on the ecological structures and processes they are studying. Other nations have made similar investments in the intellectual and institutional infrastructure required for urban socio-ecological research. These include the Australian Research Centre for Urban Ecology (http://arcue.botany.unimelb.edu.au/), the Zones Ateliers in France (http://www.za-inee.org/), many of which are embedded in urban areas, and several research units of the Chinese Academy of Sciences, such as the State Key Laboratory for Urban and Regional Ecology in Beijing (http://english.rcees.cas.cn/rh/rd/200906/t20090609_5367.html), the Institute of Urban Environment of the Chinese Academy of Sciences in Xiamen (http://english.iue.cas.cn/), and the Shanghai Key Lab for Urban Ecological Processes and Eco-Restoration (http://www.kluer.ecnu.edu.cn/EDefault.aspx). International comparisons and syntheses have begun to follow on these investments (Breuste et al. 1998; McDonnell et al. 2009; Pickett et al. 2011).

This third tide of urban ecology is still coming in. It is characterized by several features that differentiate it from the first two tides, and make it more comprehensive than these earlier approaches. First, it attempts to unify social and biological knowledge, concerns, and approaches (Redman et al. 2004). All areas in the city are now subject to ecological analysis, not just the conspicuous green areas. Second, it acknowledges and exploits spatial heterogeneity and fine-scale dynamics as a feature and cause of urban change (Grove and Burch 1997; Pickett et al. 2001; Cadenasso et al. 2007b). Even in the budgetary approach, the internal spatial configuration of different components of the urban area is recognized as potentially influencing the fluxes and transformations within the larger metropolis (Cadenasso et al. 2007b; 2008; Cadenasso et al., Chap. 6, this volume). Third, it seeks to understand the controls of biogeochemical processes throughout urban systems, including retention, fluxes, and

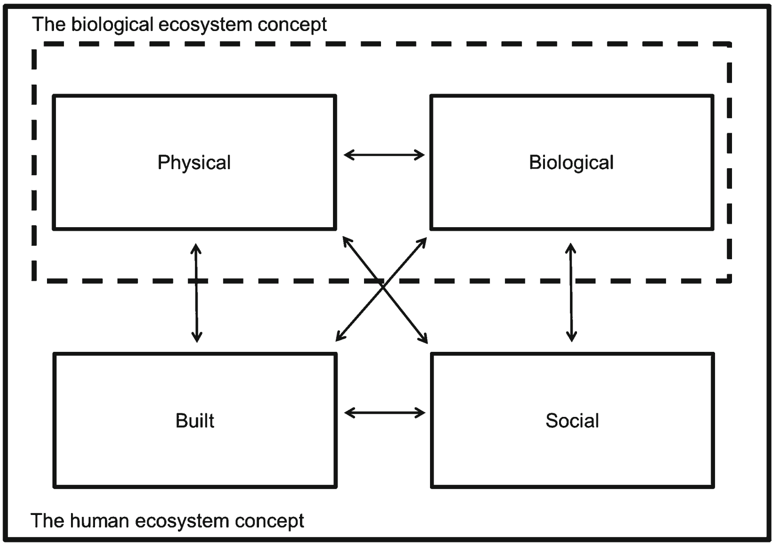

Fig. 2.7 Expanding the abstraction of the ecosystem to incorporate the built and social components that are part of cities and any social-ecological system. Though built and social components can be considered specific types of physical and biological components, we call them out specifically here and depict the inclusiveness of the human ecosystem. Published with kind permission of

leakage of limiting nutrients and pollutants (Kaye et al. 2006). Finally, the hybrid nature of the systems is acknowledged, so that cities are seen as neither fully human nor fully natural entities. Rather, they are inextricably both human constructions and biophysical features (e.g., Spirn 2012). Urban ecology was once a study of green spaces in the city. Now it is the study of the ecology of the entire urban area, including biological, built, social, and physical components (Fig. 2.7).

Will this current tide in urban ecology ebb, as did the previous ones in the United States? One difference between the current manifestation of urban ecology and the previous ones is institutional support. The pioneers of urban ecology in Europe, Japan, and the United States, did not have long-lasting research support. As a result, their efforts were sometimes short-lived. Now there are two urban Long-Term Ecological Research (LTER) sites in the United States and such longevity promotes interdisciplinary collaboration, continued use of research areas, developing on-going relationships with communities and decision-makers, and accumulation of lengthy data runs which can expose causal links and the role of pulse events (Grove et al. 2012; Pickett et al. 2012). More recently, a new program called Urban Long Term Research Areas was initiated with exploratory grants (ULTRA-Ex) to research programs starting up in over 20 cities. This symbolizes not only the growing commitment by funders but also the explosion of interest in the urban system as a system worthy of study from the community of ecological researchers. The news section of the July 16, 2010 issue of the journal Nature reported that only 1 in 6 papers published in the top 10 ecological science journals over the previous 5 years were from research intended to study land used by people (Corbyn 2010; see Martin et al. 2012). This result was cast as ecologists "shunning the urban jungle". What is missed in this characterization is the rapid increase in acceptance of urban ecological research within mainstream ecology which was noted in a response letter published 2 months later that discussed the urban LTER and ULTRA-Ex programs. There are additional signs of the relatively rapid increase in this field including an urban ecology section with the Ecological Society of America, several new journals focused on ecological research on urban areas (e.g. Urban Ecosystems, Cities and the Environment), and an dramatic increase in papers published over the course of the last 5 years.

Urban ecology has grown in importance as the world rapidly urbanizes. Now, for the first time, more than 50% of the global population lives in cities. This has been true for North America and Europe since the 1950s and populations on both those continents and Australia are now more than 80% urban. The global increase in urbanization is primarily due to large population shifts in developing countries from rural communities to more urban situations. Although cities occupy only an estimated 2–7% of the Earth's land surface, their influence extends far beyond their boundaries. It is critical for ecologists to study urban systems both to contribute towards making cities more livable and to gain insights into urban influences on non-urban systems.

By the middle of the last century, ecologists had begun to apply the ecosystem perspective to cities to estimate urban material budgets (e.g., Boyden et al. 1981). Stearns (1970) made a notable effort to bring urban ecology within the fold of mainstream ecology, as well as, integrate it with social sciences (Stearns and Montag 1974). However, it has taken the intervening period for the supporting conceptual frameworks to develop (Cadenasso et al. 2006a, b), the interdisciplinary dialogs to mature, and the empirical base to broaden sufficiently for urban research to take shape as an inclusive and rigorous field of ecological study, and to exhibit its potential for integrating with other disciplines in the physical and social sciences (Pickett et al. 2001, 2011). Perhaps this time, the tide gates can be closed behind the high tide, and the promise of urban socio-ecological research and application continue into the Earth's urban future. This urban ecology of the third tide is poised to engage better with urban design and this book is a product of a nascent effort to explore the form such an engagement could take.

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