Urban Ecology

Patterns, Processes, and Applications

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The History of Urban Ecology

An Ecologist's Perspective

Mark J. McDonnell

Introduction

Urban ecology developed into a bona fide subdiscipline of ecology in the latter decades of the twentieth century from intellectual seeds sown in the late 1940s and early 1950s in Europe, North America, and Asia (McDonnell & Pickett 1993; Marzluff *et al*. 2008b; Alberti 2008; McDonnell *et al*. 2009). As with any attempt to write a history, it is especially difficult to write one in which many of the participants are still alive. Indeed, several of the pioneers of the ecological study of human-dominated landscapes have written chapters in this book. Due to the space limitations imposed by a single book chapter and the breadth of material presented in the following chapters, I will not attempt to provide a comprehensive assessment of the literature that delineates the field. Instead, this chapter will briefly discuss: 1) the early roots of urban ecology and 2) the emergence of the interdisciplinary science of urban ecology.

I have intentionally included 'an ecologist's perspective' in the title in order to explicitly expose the biases in my appraisal of this history. Over the last two decades, it has become increasingly evident that the developing discipline of urban ecology is an amalgamation of several disciplines (Alberti 2008) and it is closely aligned to the relatively new discipline of landscape ecology (Sukopp 1998, 2002; Wu 2008b; Breuste *et al*. 2008). Today, urban ecologists are trained in and utilize terminology, paradigms, and methodologies from a diversity of disciplines such as ecology, human ecology, planning, architecture, geography, economics, political science, engineering, sociology, social work, anthropology, psychology, and health sciences (McDonnell & Pickett 1993; Young & Wolf 2006; Dooling *et al*. 2007; Alberti 2008; McDonnell *et al*. 2009). Thus, urban ecology is evolving into a truly inter- and transdisciplinary science (Alberti 2008). In this chapter, I attempt to elucidate this evolution, but I am certain authors writing histories with a background in one of these other disciplines may highlight different punctuation points. However, I would hope we would all produce unique, but relatively similar depictions of the emergence of the discipline of urban ecology.

Emergence of the discipline of urban ecology

The science of ecology

The emergence of ecology as a distinct discipline occurred in Europe and North America at the end of the nineteenth century and the early twentieth century. Ecological concepts such as the 'balance of nature' have been around in different forms since Aristotle's day (Egerton 1983, 1985; McIntosh 1985). The ecological notion that nature is in a balanced state under the auspices of a creator was fundamental to the work of eighteenth century naturalists such as the father of modern taxonomy, Carl Linnaeus (Egerton 1983, 1985; McIntosh 1985). In the nineteenth century distinguished naturalists such as Malthus, De Candolle, Lyell, and Darwin articulated the role of competition for resources in controlling population growth and as a driver of

extinction. These concepts form the theoretical cornerstones of modern ecology and evolutionary biology (Egerton 1983, 1985; McIntosh 1985). It is generally agreed that the publication of the first books that describe the study of ecology in the late 1800s and the early 1900s mark the establishment of the new scientific discipline of ecology (McIntosh 1985). Ecology was initially considered a fad by other biologists, but developed rapidly in the twentieth century into a legitimate and important scientific discipline (McIntosh 1985).

Early ecologists simply defined ecology as 'the study of organisms and their environment' (McIntosh 1985). There have been many modifications of this definition over the years (McIntosh 1985; Likens 1992; Krebs 2001), but I believe the definition below proposed by Likens (1992) encompasses the current scope of the discipline:

> 'The scientific study of the processes influencing the distribution and abundance of organisms, the interactions among organisms, and the interactions between organisms and the transformation and flux of energy and matter.' (Likens 1992, pg 8.)

Today, ecological studies examine complex systems at a variety of spatial scales ranging from individual organisms to our entire planet (Likens 1992). A number of subdisciplines have been identified within the discipline of ecology that focus on different proportions of the physical (abiotic) and biotic environment (Fig. 1, Likens 1992). These range from the subdisciplines of bio-geochemistry and ecosystem ecology that include elements of meteorology, geology, and hydrology (i.e. more physical sciences) to the subdisciplines of behavioural and evolutionary ecology that involve more traditional biological sciences such as systematics, genetics, and physiology (Likens 1992). To obtain a detailed understanding of the breadth of the science of ecology, I encourage readers to examine the textbooks by Odum *et al*. (2004) and Begon *et al*. (2006).

The myth of the balance of nature

Egerton (1993) describes the fundamental role that the concept of the 'balance of nature' has played in the development of the discipline of ecology.

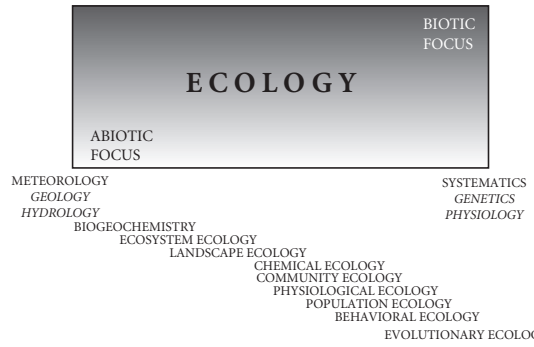

Figure 1. A diagrammatic representation of the subdisciplines of ecology arranged as a function of the different proportions of the physical (abiotic) and biotic environment they address (modified from Likens 1992)

Around the same time as proto-ecologists articulated key ecological principles, George Perkins Marsh published *Man and Nature* (Marsh 1864). In this book Marsh proposed that the world, (i.e. nature) maintained a state of stability (i.e. balance) unless disturbed by the actions of man (Lowenthal 1990; Turner & Meyer 1993). This view of the world advanced the belief that natural disturbances such as hurricanes or fires, and therefore human actions, had little or no long-term influence on the structure and function of natural ecosystems for nature was in 'balance'. This has been traditionally referred to by ecologists as the 'equilibrium paradigm' that is embodied in the cultural metaphor 'balance of nature' (Simberloff 1982; Pickett *et al*. 1992). This paradigm has had a profound effect on the development of the discipline of ecology as well as the development of conservation strategies, for it implies that to effectively study 'nature' or successfully conserve nature, ecologists and conservationists had to locate study sites far from human actions or explicitly exclude humans from conservation areas. An examination of ecology and conservation textbooks, journals, and guidelines of granting agencies that supported ecological work over the first 60 years of the twentieth century reveals a paucity of information on humans and human dominated ecosystems, especially in North America (Pickett & McDonnell 1993; Collins *et al*. 2000). In fact, Rees (1997) states that in Western industrial cultures humans are traditionally not viewed as biological beings that are part of the ecosystem. Thus, many students and practitioners of the discipline of ecol-

ogy, especially those involved in basic research, were compelled to treat humans as external to the systems they studied. Consequently, for much of the twentieth century the discipline of ecology contributed relatively little information to our understanding of the ecology of human settlements. Sukopp (1998) states that some biological researchers viewed cities as 'anti-life' (i.e. without nature) for they supported few plants and animals. Those organisms that did survive had distribution patterns that were merely coincidental and were thus considered undeserving of study (Sukopp 1998).

There were exceptions to this exclusion of human-built environments as subjects of ecology, especially in Asia (Numata 1982) and Europe (Gilbert 1989; Sukopp 2002). Sukopp (2002) provides an excellent overview of the early vegetation studies conducted in European cities, while also noting the numerous applied research efforts on air pollution ('Rauchschadenforschung'), soil contamination, bioclimatology, lake rehabilitation, and on human health and welfare. Much of this early biological, physical, and sociological research conducted in cities in Europe was problem oriented and focused on improving the human condition. Indeed, similar applied research on land and water degradation and pollution effects was also conducted in North America and other cities around world over the same period, but was generally not considered under the umbrella of the emerging field of urban ecology. Instead, they formed the foundations of the new discipline of environmental science (e.g. environmental chemistry and soil science, and toxicology, etc). An important point here is that the 'balance of nature' paradigm significantly affected basic and theoretical ecology research in human-dominated landscapes, but it had little or no effect on applied research focused on solving practical problems in cities and towns.

The advent of the non-equilibrium paradigm

Over the last 30 years, there has been a mounting body of scientific evidence indicating that this old 'equilibrium paradigm' is flawed (Botkin 1990; Pickett *et al*. 1992; Fiedler *et al*. 1997). There has been an emergence of a new 'non-equilibrium paradigm' that incorporates recent knowledge of how ecosystems are structured and function (Pickett *et al*. 1992; Fiedler *et al*. 1997). This new paradigm views ecological systems as driven by process rather than end-point and as open systems potentially regulated by external forces (Pickett *et al*. 1992; Fiedler *et al*. 1997). With regard to the emergence of the subdiscipline of urban ecology, this new 'non-equilibrium paradigm' explicitly allows for the inclusion of humans as components of ecosystems studied by ecologists (Egerton 1993; Pickett *et al*. 1992; Pickett & McDonnell 1993). To make this point perfectly clear, if ecologists now accept that the structure and function of ecosystems can be regulated by external forces such as fires and floods, then human activities have to be considered as important agents of ecosystem change (Pickett & McDonnell 1993). As discussed in detail in McDonnell & Pickett (1993) and Alberti (2008), humans are components of ecosystems and human dominated ecosystems provide a new and challenging arena for inter- and transdisciplinary studies involving the physical, ecological, and social sciences.

Urban ecosystems become legitimate subjects of ecological study

While ecology was emerging as a unique discipline in the 1900s, the world population was approximately 1.4 billion people (Demeny 1990). Today, the world population is over 6.5 billion and is continuing to increase, especially in undeveloped countries (Lee 2007; UNFPA 2007; Henderson & Wang 2007). By the late 1950s and early 1960s, it was becoming apparent to everyone on the planet that humans had significantly altered local and regional ecosystems (Thomas 1956; Turner *et al*. 1990; McDonnell & Pickett 1993; Berkes & Folke 1998). In addition, the emergence of the subdiscipline of historical ecology revealed that many ecologists had indeed been working for years in areas transformed by subtle and not so subtle human actions (Cronon 2003; Botkin 1990; Russell 1993, 1997).

A decisive event in the recognition by ecologists of the inclusion of humans as components of ecosystem was the publication of the rising atmospheric CO_2 data in the early 1960s (Keeling 1998) which was soon followed by the realization that human actions were changing our global climate

(Weart 2003). Gradually, there was the recognition that no ecosystem on Earth was free from the actions of humans (Berkes & Folke 1998; Vitousek *et al*. 1997). In the early 1970s, a relatively small number of scientists in Europe, North America, and Australasia recognized the important role the science of ecology could play in mitigating the impacts of human settlements, and organized regional and national meetings to recruit multidisciplinary teams of researchers in this endeavor (Nix 1972; Duvigneaud 1974; Stearns & Montag 1974; Boyden *et al*. 1981). Around this same time, The United Nations Educational, Scientific and Cultural Organization (UNESCO) took the bold step to initiate the Man and Biosphere (MAB) program to conserve and study both natural and cultural ecosystems (Boyden *et al*. 1981; Douglas 1983; Sukopp *et al*.1990; Deelstra 1998). This UNESCO effort was critical to the establishment of the first multidisciplinary ecological studies of human settlements and thus can be credited with consolidating the emerging discipline of urban ecology (Boyden *et al*. 1981; Douglas 1983; Sukopp *et al*.1990; Deelstra 1998). The MAB program stimulated the ecological study of human settlements around the world (Dyer & Holland 1988, Song & Gao 2008) and it produced such classic urban ecology studies as the ecology of Hong Kong and its people by Boyden *et al*. (1981). Unfortunately, these early urban ecology studies did not motivate a significant number of ecologists to continue to build the discipline in the 1970s and 1980s. This was most likely due to the enduring deep-seated prejudice in the field of ecology that human-dominated ecosystems were not legitimate subjects of ecological study. A renaissance in the development of the discipline of urban ecology occurred in the late 1990s that was stimulated, in part, by the enlightened initiative of the US National Science to fund two urban long-term ecological research (LTER) programs in Baltimore, Maryland and Phoenix, Arizona, USA (Grimm *et al*. 2000).

It is now widely accepted by ecologists and others that the growth and expansion of cities worldwide are major drivers in local, regional, and global environmental change and that human actions have altered the distribution of organisms as well as the transformation and flux of energy and matter at global scales (McDonnell *et al*. 2009). The recent emergence of urban ecology and global climate research bring the science of ecology into the forefront of understanding and mitigating human impacts on ecosystems and the planet as a whole.

The role of the social sciences in the development of the discipline of urban ecology

As ecologists were busy conducting research to understand the pattern and processes of ecological systems containing relatively few humans, researchers in the fields of human ecology, planning, architecture, geography, economics, political science, sociology, social work, and health sciences were busy studying human settlements (Berkes & Folke 1998; Alberti 2008). Of particular note is the 'Chicago School' of urban sociology that pioneered the use of ecological theory and terms to describe the structure and function of cities (Hawley 1944; Park & Burgess 1967). Today, social scientists, human ecologists, and urban geographers still debate the utility of the early applications of traditional ecological theory and terms to the study of humans in cities (Alihan 1964; Catton & Dunlap 1978; Cousins & Nagpaul 1979). In contrast, their documentation of the physical features of cities coupled with investigations of how structural patterns influenced social processes is still a useful concept and is employed today to study the interactions between humans and the urban environments in which they live (Dunlap & Catton 1994). The research questions and methods developed by the Chicago School were central to the development of the discipline of human ecology (Steiner & Nauser 1993; Rees 1997).

The vast amount of information and understanding obtained by the social sciences on the structure and function of human dominated ecosystems is vital to the development of the discipline of urban ecology (Alberti 2008). But it is important to recognize that most of this work was carried out within the conceptual frameworks and paradigms of these well-established autonomous disciplines and they were typically not explicitly presented or published by their practitioners under the banner of urban ecology. Unfortunately, the explicit recognition of the role of the social sciences in the development of

the discipline of urban ecology continues to be a contentious issue amongst urban ecologists (Young & Wolf 2006, 2007; Dooling *et al*. 2007).

The science of urban ecology

Defining urban ecology

It is generally accepted that the discipline of urban ecology arose in the early 1970s (Stearns & Montag 1974; Rebele 1994; Sukopp 1998, 2002; McDonnell *et al*. 2009). Historically, the term 'urban ecology' has evoked a diversity of meanings. As mentioned in the previous section, in the 1920s the Chicago School of sociologists used the term to describe their work. Deelstra (1998) reminds us that in the early 1970s the UNESCO Man and the Biosphere Program (MAB) funded the first integrated urban ecology research that brought together three sciences: 1) natural sciences, 2) engineering/planning, and 3) humanities (i.e. social sciences). Each of these sciences utilizes different terminology, paradigms, and methodologies and encompass different goals and objectives, thus resulting in an assortment of definitions and meanings for the term urban ecology. For example, natural scientists would define urban ecology in a similar manner to the definition of ecology presented earlier, but would limit their studies to urban and urbanizing landscapes (Grimm *et al*. 2000; Pickett *et al*. 2001; Alberti 2003; Niemelä *et al*. 2009). Thus, ecologists focus their work on the distribution and abundance of organisms (i.e. biodiversity) as well as the flow of nutrients and energy in urban ecosystems (i.e. ecosystem services). All of the subdisciplines of the science of ecology presented in Fig. 1 can be applied to the study of urban ecosystems. Engineers and planners, on the other hand, focus on designing facilities and services in urban environments with the goal of reducing environmental impacts and creating sustainable cities (Deelstra 1998; Pickett *et al*. 2001). Social scientists focus primarily on social structure and the social allotment of natural and institutional resources (Pickett *et al*. 2001; Alberti 2008). Today, social scientists working under the umbrella of urban ecology are exploring how to create greener more healthy and sustainable cities.

So how should we define the current discipline of urban ecology? A number of urban ecologists have endeavored to define the boundaries of the discipline (Collins *et al*. 2000; Sukopp 2002; Alberti 2008; Wu 2008b; Niemelä *et al*. 2009). I propose the following simple definition:

> Urban ecology integrates both basic (i.e. fundamental) and applied (i.e. problem oriented), natural and social science research to explore and elucidate the multiple dimensions of urban ecosystems.

Alberti proposes '…urban ecology is the study of the ways that human and ecological systems evolve together in urbanizing regions.' (Alberti 2008, page xiv). She suggests that the science of urban ecology is emerging from the integration of several disciplines as a result of a mutual interest in understanding the ecological structure and function of cities and towns. Indeed, today the borders between these different disciplines and urban ecology are blurred. Which of these disciplines become integrated, and what degree of integration occurs, will depend on the questions being addressed. As students of urban ecology are trained more broadly and more research is conducted by interdisciplinary teams of researchers, I propose that over time, as the discipline of urban ecology matures, we will experience a dissolving of the existing boundaries between the ecological and social science disciplines. As mentioned at the beginning of the chapter, urban ecology is evolving and emerging into a truly inter- and transdisciplinary science.

Urban ecology societies, books, and journals

In general, the state of the development of a scientific discipline is strongly associated with the existence of scientific societies as well as the nature, quality, and quantity of the books and journals available that address the subject matter. Although there are urban ecology sections in some societies, the first independent international society, The Society of Urban Ecology (SURE), was established in 2009 to foster and develop knowledge and implementation of urban ecology worldwide (SURE 2010).

Several books and journals devoted to the study of the ecological, physical, and sociological conditions of urban environments appeared in the early 1970s heralding the arrival of the new discipline of urban

ecology. The initial books to appear were edited compilations from multidisciplinary conferences and workshops held in the United States (Stearns & Montag 1974), Europe (Bornkamm *et al*. 1982), and Australasia (Nix 1972). Each of these volumes describe the growing ecological and social problems of cities around the world and the need for an integrated approach involving the ecological, social, and physical sciences to develop strategies to mitigate the negative impacts of human settlements. A common thread running through each of these volumes is the acknowledgment of the lack of ecological information that existed at the time for cities and the call to increase urban ecology research in order to develop appropriate solutions in the future.

The increase in knowledge and understanding of urban ecosystems, as well as the development of urban ecology as an inter- and transdisciplinary science in the 1990s and early 2000s, has been well documented in a collection of edited volumes that can be categorized into three perspectives: 1) bio-ecology, 2) planning and design, and 3) education. All of these compilations are multidisciplinary in nature and bring together the leaders in the ecological, physical, and social dimensions of the field of urban ecology, but the volumes have slightly different themes and are pitched to different audiences. It is also apparent from these books that the concept of creating sustainable cities has become a major focus of urban ecology research. The majority of these edited works have a strong bio-ecology theme with a modicum of research focused on the social dimensions of urban ecosystems. This category of books includes the works of Grodzinski *et al*. (1984), Sukopp *et al.* (1990), McDonnell and Pickett (1993), Brueste *et al*. (1998), Marzluff *et al*. (2001), Marzluff *et al*. (2008b), Carreiro *et al*. (2008) and McDonnell *et al*. (2009). Compilations of urban ecology research by Platt *et al*. (1994) and Sukopp *et al*. (1995) also include a multidisciplinary perspective, but they have a strong landscape design and planning focus. Berkowitz *et al*. (2003) provide a unique collection of chapters that explore how an understanding of urban ecosystems facilitates the development of strategies to solve future environmental problems.

Somewhat surprisingly, there are relatively few single or multi-authored books, as opposed to edited compilations, that address the subject of urban ecology. Gilbert (1989) and Wheater (1999) describe the ecology of urban habitats in the United Kingdom (UK). These volumes are very descriptive and, although comprehensive in their treatment of the subject matter, they focus primarily on the physical and bio-ecological conditions of urban habitats. They are excellent examples of what we would refer to today as the ecology 'in' cities component of the discipline of urban ecology.

As previously mentioned, Boyden *et al*. (1981) published *The Ecology of a City and its People: The Case Study of Hong Kong* which is considered by many to be the first classic book on the ecology of a city. This volume provides a comprehensive account of the Hong Kong Human Ecology Program which was composed of a multidisciplinary group of researchers from the Australia National University (ANU) in Canberra, Australia. The program started in 1972 and became the first pilot program of the UNESCO Man and the Biosphere Program (MAB) in 1974. The book is considered a classic because it 1) provided an intellectual framework on which the work was conducted, 2) utilized and integrated empirical data from many sources to describe the city and its people, 3) elucidated the ecological and societal problems facing human settlements, and 4) provided the first model for integrating the ecological and sociological dimensions of urban ecosystems. Most of the ideas, concepts, and methodologies used in this study are still very relevant to urban ecologists today.

Forman (2008), a preeminent landscape ecologist, has produced a unique book that examines urban regions. Unlike the urban ecology books cited above, *Urban Regions: Ecology and Planning Beyond the City* follows more in the footsteps of his earlier *Land Mosaics: The Ecology of Landscapes and Regions* (Forman 1995) and draws primarily on concepts from the subdiscipline of landscape ecology. This new book focuses on analysing 38 urban regions from around the world principally from a planning and management perspective, but with a strong ecological foundation. *Urban Regions* will no doubt influence the way ecologists, social scientists, conservationists, land managers, and policy-makers view and manage urban regions in the future.

Alberti (2008) has written what I would consider the premiere urban ecology text book to date. In this book, entitled *Advances in Urban Ecology: Integrating Humans and Ecological Processes in Urban Ecosystems*, Alberti explores the conceptual frameworks that underpin the science while also describing in detail the many ways ecologists and social scientists study both the ecological and human dimensions of urban ecosystems. Of particular note is her synthesis of the current state of the discipline of urban ecology at the end of the book.

Finally, I would be remiss if I did not mention books that have increased our knowledge of urban environments, but were not written under the banner of urban ecology, they are, however, now clearly perceived as important contributions to the science. These include books on urban geography (Douglas 1983), landscape design (Spirn 1984) and management (Hitchmough 1994), urban forestry (Bradley 1995), wildlife management (Adams *et al*. 2006), sustainable cities (Newman & Jennings 2008), and healthy cities (Frumkin *et al*. 2004).

The journal entitled *Urban Ecology* was first published by the International Association for Ecology (INTECOL) in 1975 with the aim of publishing original research on the ecology of urban areas. One of the primary objectives of the journal was to facilitate the exchange of ideas between the ecological science community and the practitioners of urban planning and design (LaNier 1975). The scope of its audience and its content was very broad including the social, physical, and life sciences, engineers, landscape architects, planners, and administrators of urban municipalities. *Urban Ecology* published 9 volumes between 1975 and 1986 at which time it was incorporated into *Landscape and Urban Planning* which is still one of the most highly regarded journals in the field today. To fill the growing need for outlets to publish urban ecology studies, Chapman and Hall published the first volume of *Urban Ecosystems* in 1997. This journal is committed to publishing scientific investigations of the ecology of urban environments and their policy implications. It has a new publisher (Springer) and continues to provide an important role in publishing the results of inter- and transdisciplinary urban ecology research. Over the last few decades, as interest in urban ecology research grows, new journals have been launched including: *Cities*, *Cities and the Environment*, *Urban Habitats*, *Urban Forestry and Urban Greening*, *Urban Environment and Urban Ecology*, *Journal of Urban and Environmental Engineering*, and *Theoretical and Empirical Research in Urban Management*.

Recent developments and emerging directions in urban ecology

As the science of urban ecology emerged, researchers borrowed concepts, terminology, approaches, methodologies, and tools from a variety of other disciplines (McDonnell & Pickett 1993; Alberti 2008; McDonnell *et al*. 2009). Over the last 30 years, the discipline has grown and now possesses a unique assortment of approaches, frameworks, study locations, and methodologies that delineate urban ecology from other disciplines. The other chapters in this book give a full account of the evolution and current status of the discipline. To wind up this short history of urban ecology, I will briefly acknowledge what I believe are the recent developments and exciting new research directions in urban ecology.

Two approaches to the study of urban ecosystems that can be expressed as 1) the ecology 'in' and 'of' cities and 2) the ecology of urbanization gradients are new concepts unique to the discipline of urban ecology. The recognition by urban ecologists of the difference between the ecology 'in' and the ecology 'of' cities has proved to be a significant conceptual leap forward for the discipline (Grimm *et al*. 2000; Pickett *et al*. 2001; Alberti 2008; Wu 2008b). Studies of the ecology 'in' cities are typically single discipline, small scale, and located within a city, while ecology 'of' cities studies are interdisciplinary and multiscale incorporating both the ecological and human dimensions of urban ecosystems (Grimm *et al*. 2000; Pickett *et al*. 2001). The majority of urban ecology research to date falls into the category of the ecology 'in' cities (Alberti 2008; Hahs *et al*. 2009). There are only a few excellent examples of ecology 'of' cities studies (Alberti 2008; Hahs *et al*. 2009). If the discipline of urban ecology is to advance and enhance our understanding of urban ecosystems, it will require the active development of more inter- and transdisciplinary ecology 'of' cities studies (Alberti 2008; McDonnell & Hahs 2009). The application of the urban–rural gradient

approach to the study of urban environments (McDonnell & Pickett 1990) has proved a useful concept to ecologists around the world (Theobold 2004; McDonnell & Hahs 2008). It has also inspired the development of such useful concepts as the wildland–urban interface (Radeloff *et al*. 2005). In addition, the study of urbanization gradients has provided a foundation for the future development of the comparative ecological study of cities and towns at regional and global scales (Niemelä *et al*. 2009; McDonnell & Hahs 2009).

Urban ecologists have been building on existing, as well as creating new and unique, conceptual frameworks in which to study urban ecosystems. For the discipline to advance in the future it will need to enhance, refine, and embrace several conceptual frameworks including the human ecosystem model (Pickett *et al*. 2001, 2008), urban avoiders and adaptors model (McKinney 2002, 2008), ecosystem services (Bolund & Hunhammar 1999; Jim & Chen 2009), sustainability (Newman & Jennings 2008), and resilience (Berkes & Folke 1998; Alberti & Marzluff 2004; Pickett *et al*. 2004).

Historically, urban ecologists have focused on terrestrial environments in developed countries (Chapman & Underwood 2009), but new and exciting advances in understanding the ecological and human dimensions of urban ecosystems will come from the study of remnant vegetation (Florgård 2004), landscaped gardens (Gaston *et al*. 2005; Felson & Pickett 2005; Tratalos 2007), green roofs (Oberndorfer *et al*. 2007), marine environments (Chapman & Underwood 2009; Chapman *et al*. 2009), freshwater ecosystems (Paul and Myers 2001), and studies of human health (Frumkin *et al*. 2004, Tzoulas *et al*. 2007), aesthetics and recreation (Tyrväinen 2003), as well as urban environments in developing countries in general (Conceicao 1994; Escobedo *et al*. 2006; Cilliers *et al*. 2009; Song & Gao 2008).

A significant amount of the research conducted on urban ecosystems has been directed at the population and community level with most of these studies focused on the distribution and abundance of organisms (i.e. patterns). Shochat *et al*. (2006) propose the need to develop more mechanistic studies of urban ecosystems. Urban ecologists will discover rich veins of research opportunities in the future if they explore the study of such subjects as biogeochemistry (Kaye *et al*. 2006), biodiversity (McKinney 2002, 2008; Luck 2007), urban forestry (McPherson 1997; Nowak *et al*. 2003), and landscape ecology (Forman 2008) in urban environments. I also encourage students and practitioners of urban ecology to refine existing, and develop new, tools so that they can participate in the development of solutions to solve the many problems facing human settlements today. Examples of useful tools that need future examination and application include the UFORE model that assesses the ability of urban forests to reduce air pollution and ameliorate local climate (Nowak *et al*. 2003), the enhancement and analysis of new GIS methods (Cadenasso *et al*. 2007; McDonnell & Hahs 2009), and the application of non-parametric Bayesian statistical tools (McCarthy 2008) in the design and analysis of experiments.

Finally, to truly advance the discipline of urban ecology requires the creation of new hypotheses and the identification of confirmed generalizations (McDonnell & Hahs 2009; Pickett *et al*. 2009). Confirmed generalizations are formed when a body of tested facts results in a new, universally accepted, level of understanding of how urban ecosystems are structured and function. For example, one of the most compelling confirmed generalizations in urban ecology is the relationship between the amount of impermeable surfaces in a watershed and the health of streams (Paul & Myer 2001). When a watershed is composed of more than 20 per cent impermeable surfaces there is a significant decrease in stream biota and health (Paul & Meyer 2001). Hence, the challenge to all urban ecologists in the future is the development of a collection of confirmed generalizations or principles which will motivate basic research in the field while also informing practitioners working to design, build, and manage sustainable human settlements in the future.

Summary

Urban ecology emerged as a subdiscipline of ecology in the early 1970s due, in part, to the fact that human impacts on the planet were becoming well-documented and the growing size of human settlements was resulting in serious environmental problems that threatened the health and well-being of both urban and non-urban dwellers around the

world. Influenced by these events, and coupled with the demise of the 'balance of nature' paradigm, ecologists have acknowledged that human settlements are legitimate subjects of ecological study. The creation of the UNESCO Man and the Biosphere Program (MAB) in 1974 and the establishment of two urban LTER programs by the US National Science Foundation in the late 1990s were instrumental in encouraging the study of the ecological and social components of urban ecosystems around the globe. Urban ecology has evolved as a unique field of study through the integration of several disciplines that investigate the ecological and human dimensions of urban ecosystems. Urban ecologists can be engaged in basic (i.e. fundamental) research focused on understanding the structure and function of urban environments, or they can be engaged in applied (i.e. practical) research that is focused on solving important environmental problems. The discipline of urban ecology is at the forefront of creating the knowledge base, conceptual frameworks, and tools that are crucial for building and maintaining sustainable and resilient cities and towns in the future.

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