Chapter 1 Foundations

> In short, then, it takes the whole region to make the city.
>
> *Patrick Geddes,* Cities in Evolution*, 1914*

> But for all our buildings and lights and roads, for all our signs and words, that human presence is only a thin film stretched over mystery. Let sunlight flame in a blade of grass, let night come on, let thunder roar and tornado whirl, let the earth quake, let muscles twitch, let mind curl about the least pebble or blossom or bird, and the true wildness of this place, of all places, reveals itself …
>
> *Scott Russell Sanders,* Staying Put: Making Home in a Restless World*, 1993*

Imagine a glorious day in your favorite city being energized at every turn. Sparkling clear air. Hardly any traffic. People alive, interesting. Appealing architecture and gardens (Figure 1.1). Amazing cultural events. Delightful diverse shopping. Food the best. Saw everything … relished it all.

Suddenly a friend appears, an ecologist. Comparing notes, she or he is equally enthusiastic. Luxuriant native street trees with lots of lichens. Clear water in the city pond. Bicycle routes and long walking routes busily used. Songbirds zipping along a shrubby tree strip between parks. No dog droppings. Wind blowing the smokestacks' noxious air out of the city. Green walls and balconies facing each other over streets. Restaurants with rat-proof dumpsters. Elongated grass-and-flower depressions for riverside floodwaters. The intriguing list goes on. Chuckling, together you have seen almost everything, yet seemingly in two different cities.

But what about the invisibles? The what? We saw "everything" but maybe we missed some important things. For instance, in this urban ecology no-one directly sees the sounds and vibrations around us (Figure 1.2). The smells and gases we breathe are invisible. Turbulent and streamline air flows hit us unseen. We do not see what happens in tree canopies over us, on the roofs of buildings, or in the atmosphere with organisms further overhead. Nor is the soil just under us visible, the deeper underground infrastructures, the fish movements in the river, the river bottom, or the far side of the city. Indeed, we cannot even see the multitude of microbes right around, on, and in us. We mainly miss the active organisms and processes at night. And we do not have the time or patience to see the really slow flows and slow changes eternally occurring around us.

Interesting, but are all those things important compared with what we see? Well, consider a few examples. Up in that atmosphere, pollen and seeds and even spiders with tiny parachutes move across the city, ozone smog forms, and sky radiation is generated. The tree canopies contain bird nests and numerous insects, and evapo-transpire water to the air. Traffic noise inhibits successful avian reproduction, while vibrations from traffic and trains compact soil. Soil itself is a cornucopia of roots, microbes, and soil animals, with water and oxygen flowing downward, and carbon dioxide upward. The underground urban infrastructure contains raceways for cockroaches and rats to reach buildings, as well as stormwater and sewage wastewater to enrich water bodies. Underwater fish are feeding, being eaten, even migrating. Harbor and river bottoms boast a rich interacting mix of sediment, worms, pollutants, carbon dioxide, even sometimes oxygen. At nighttime, migrating songbirds are hitting towers and skyscraper windows, cats are roaming, slugs are eating plants, nighthawks are catching insects, and garbage is being ravished. Slow flows and changes are also really hard to see – plants growing, termites chewing, water-table dropping, species diversity changing, plants adapting, pests becoming pesticide resistant, species ranges expanding, pipes rusting, wood foundations decaying, and sea-level rising. While the list of invisible organisms, interactions and processes could go on and on, do these examples seem important ecologically? And for society?

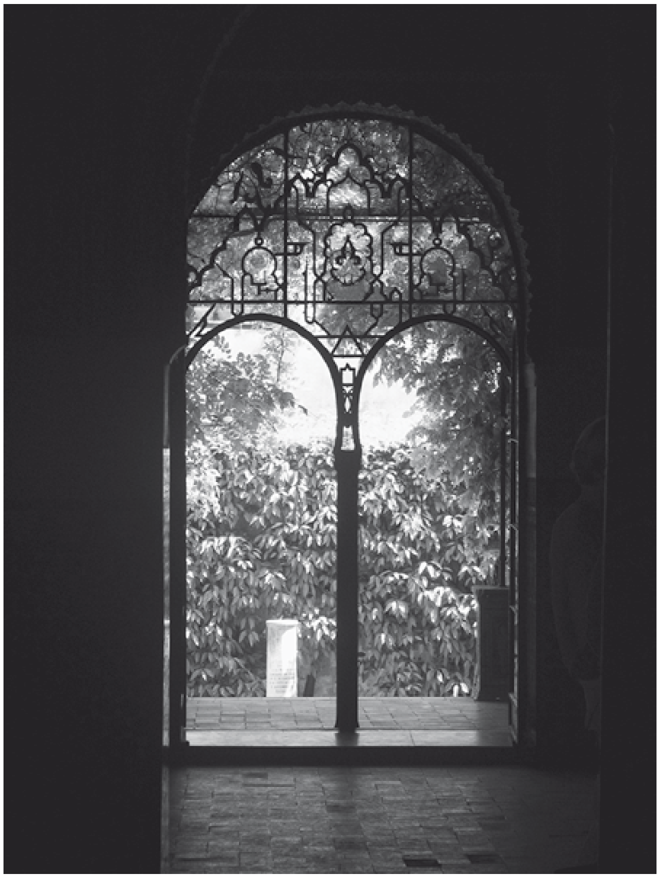

Figure 1.1. Glimpsing a garden of nature in a city center. A wide range of planting designs, architectural forms, and urban patterns provides rich experience for people, and microhabitat diversity for species. Sevilla, Spain. From R. Forman photo.

Let's find a little restaurant with something to drink and explore this urban ecology a bit more. Maybe a book on the subject would highlight lots of invisibles and visibles, opening doors to insight and delight all around us. Indeed, these revelations could be foundations for making where we live much better.

Urban ecology concept

We have just become an urban species, *Homo sapiens "urbanus*." Half the human population now lives in urban areas. The proportion grows, and the number of urbanites skyrockets. The next two billion people will all be urban, half joining today's urban poor. These newcomers will squeeze in now within a single generation. How welcoming is our land, our urban space, our planet?

Meanwhile two mammoth changes are engulfing us. First urbanization, the "urban tsunami," easily visible today, sweeps swiftly and powerfully across the land. Seemingly inexorable, yet not. And second, natural systems degrade – freshwater dries up, biodiversity plummets, climate changes, soil thins, and unpolluted places disappear. Two familiar drumbeats. We pick at the problems. Or simply shrug, and consider them too large, too complex to solve.

Addressing such trajectories requires understanding of natural areas, forestry areas, agricultural areas, and dry areas of the globe. Ecologists for over a century have analyzed and educated us about natural systems

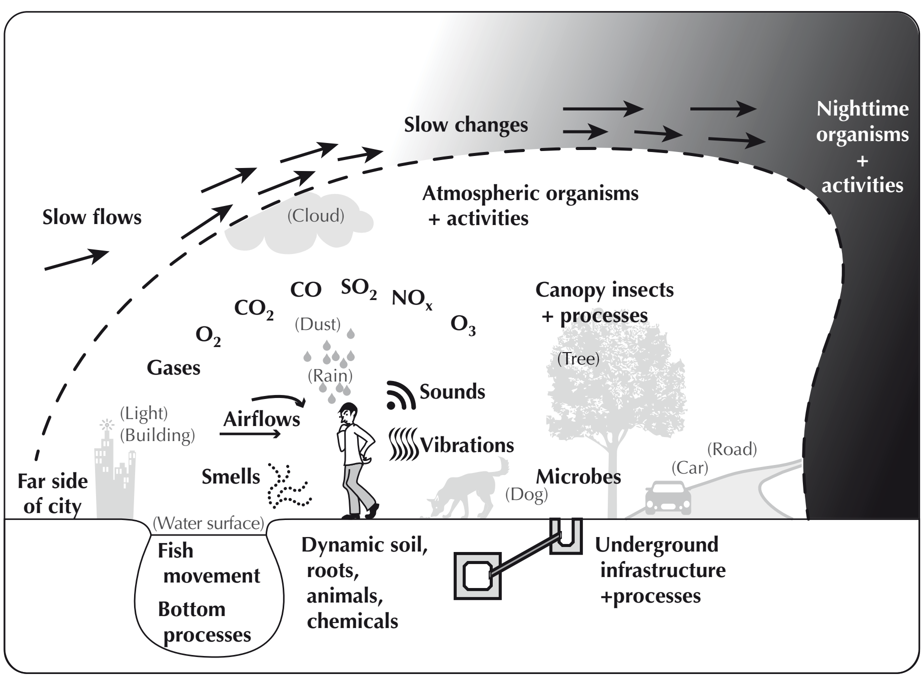

Figure 1.2. The invisibles and visibles for understanding an urban area. Invisible objects in bold type; visible objects in light type and parentheses.

there. Yet the overlooked ecology of built areas has now emerged as of core importance. Urban ecology is the ecology of right where we live.

Envisioning the subject at two spatial scales is a useful way to start. First, cities lie at the center of urban regions (Forman, 2008). In effect, an essentially all-built metropolitan area visible from outer space is surrounded by a ring-around-the-city. The metro-area and its urban-region ring are interdependent, that is, tied together by in-and-out flows and movements. Cities are no longer viable units, no longer make sense, whereas urban regions make good sense. An ecology of urban regions.

Second, urban areas are mosaics. The spatial pattern or arrangement of patches and corridors is extremely diverse and ecologically important (Forman, 1995, 2008; Wu, 2004; Pickett *et al.*, 2009). Indeed, most people and most decisions focus on these finer-scale spots or areas within the urban region. Urban ecology highlights all the spaces, not only parks and other greenspaces, but also the rich variety of built spaces. An ecology of these spatial patterns, especially where most of us live in metropolitan areas, is the topic at hand. An ecology of urban mosaics.

To some, urban and ecology are contrasts (McIntyre *et al.* 2000), or even an oxymoron. Recent work by urban ecologists should dispel this perspective. The two concepts overlap and are quite compatible. Another familiar ecological perspective is that the urban or human component is "bad," that is, has a negative effect on nature or ecological conditions. No such assumption is made here. People can have both negative and positive effects on nature. Furthermore, nature has both negative and positive effects on people (Forman, 2010a).

Ecologists have focused on understanding "natural" patterns and processes, those minimally affected by humans, and thus have largely avoided urban areas. For example, of 6157 articles published during 1995–2000 in nine leading ecological journals, only 25 (i.e., 0.2%) dealt with cities (Benton-Short and Short, 2008). As seen in the previous section, the core of urban ecology must focus on, and understand, the central patterns and processes of urban areas.

Ecology is the study of organisms interacting with the environment. "Environment" here is overwhelmingly understood by ecologists to refer to the physical environment dominated by air, water, and soil (not the built environment of roads and buildings). With research mainly in relatively natural areas, "organisms" has normally meant plants, animals, and microbes (microorganisms).

Although humans are obviously organisms, ecologists have mainly excluded people in their research, or considered humans as an outside factor causing effects. A humans-as-inside-or-outside-of-an-ecosystem discussion is endless (McDonnell and Pickett, 1993; Alberti *et al.*, 2003; Head and Muir, 2006). Meanwhile lots of major disciplines, including economics, sociology, transportation, engineering, and architecture, all focused on human activities and including interactions with the environment, carry on. One could include humans as a key part of ecology, and then much of the field would be logically subdivided and dispersed into pieces within these other big human-centered disciplines. However, it seems wiser to maintain and further build on the core strength of ecology, with its basic focus on plants, animals, and microbes.

Sister disciplines and professions will welcome and use principles developed by a strong vibrant urban ecology. Tying these conceptual threads together leads nicely to the following urban ecology concept (Figure 1.3):

> *Urban ecology* studies the interactions of organisms, built structures, and the physical environment, where people are concentrated.

Organisms refer to plants, animals, and microbes. Built structures are buildings, roads, and other human

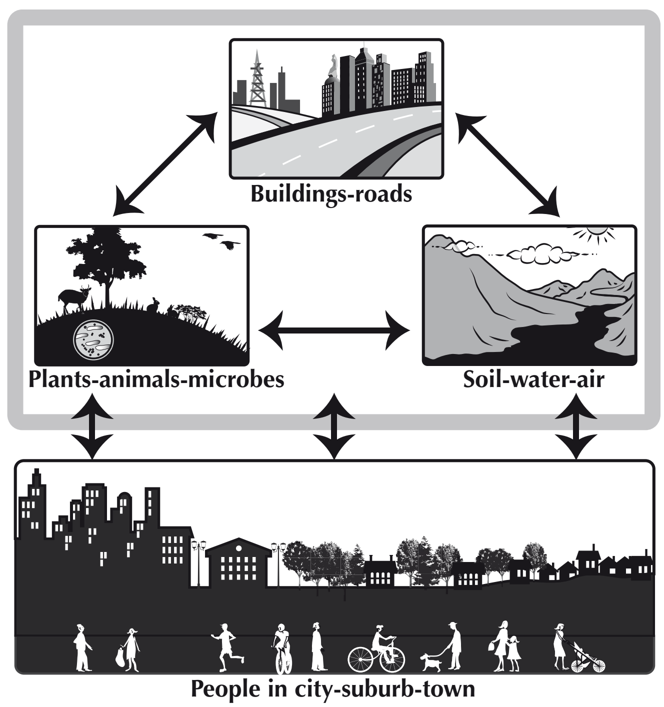

Figure 1.3. Urban ecology concept. Interactions of organisms, built structures, and the physical environment, where people are aggregated. Adapted from Forman (2010a).

constructions. The physical environment refers to air, water, and soil/earth. Where people are concentrated primarily refers to cities, suburbs, and towns.

Built structures are a key to urban ecology. Organism–environment interactions are simple ecology, whereas inserting buildings and roads in the interactions transforms the subject to urban ecology.

Urban ecology is useful for many allied fields focused on different interacting factors. Sociology highlights people–people interactions. Recreation and aesthetics commonly focus on people–organisms interactions. Architecture, housing, and transportation emphasize people–built structure interactions. Engineering and weather reports focus on people–environment interactions. Economics concentrates on people–environment–built structure interactions, while public health highlights people–organisms–built structure interactions. The distinctiveness of urban ecology promises much of use to each of these major human-centered fields.

Appealing metaphors and symbols often enhance understanding, though normally are not conceptual research frameworks (Grove and Burch, 1997). City as powerhouse. City as system of arteries. City teeming like an anthill. City as "second nature." City mimicking the human body. Urban development as natural process. Neighborhood change as ecological succession. City as living system or natural system. Ecosystem health. City functions like a tree. Metaphors catch one's attention, but to be useful must then lead to specific patterns, mechanisms or changes.

Urban ecology for planners typically emphasizes providing environmental amenities for people, while ideally decreasing environmental impacts. In contrast, ecologists usually study species and habitat patterns, and may include chemical flows, animal movements, and patterns of change. With the concept of urban ecology highlighted above, ecologists are less likely to try to fit traditional ecological frameworks to urban patterns, and more apt to study and build principles around the central distinctive characteristics of urban areas. This approach should make a stronger, more useful urban ecology, as well as expand the frameworks of the field of ecology itself.

Coalescence of the preceding themes leads to the intellectual core of urban ecology. Specifically, urban areas are mosaics of diverse spatial pattern. Organisms, built structures, and the physical environment interact. Flows and movements through the mosaic create a dynamic system. Urban areas markedly change over time. Urban ecology theory and principles lead to applications for society.

Routes to the present

Three intriguing and brief histories bring us up to date: (1) cities; (2) ecology and environment; and (3) urban ecology.

Cities and history

We begin with the population growth of cities. Then the key concepts and terms used to understand urban ecology are spelled out.

Changing city size

The first population centers that might be called cities appeared some 5000–6000 years ago in at least Mesopotamia (today's Iraq), Egypt, and the Indus Valley (today's Pakistan) (Pacione, 2005; Benton-Short and Short, 2008). Early cities also emerged in the Huang Ho Valley (today's China), Greece, Rome, and Maya land (today's Middle America). Damascus might be the oldest continuously inhabited city. Over time, the largest city worldwide has moved around, e.g., Constantinople (now Istanbul) with 700 000 people in 1700, to Peking with 1.1 million people in 1800, to Tokyo today (Berry, 1990). By the end of the 19th century the UK and Australia were largely urban nations.

In 1850 human history had produced 1 billion people on Earth (Platt, 2004), 10% of whom were urban. Two billion and 20% urban were reached 80 years later; 3 billion and 30% arrived 30 years after that. Each new billion people thereafter arrived in only 12–15 years. Today the 6.5+ billion people on Earth are half urban. More than 4% of the Earth's land surface is urban.

The next billion is coming fast. United Nations statistics point to an Earth in 2040 with 8.5+ billion, approaching two-thirds urban. Since the rural population worldwide is expected to remain essentially constant at 3 billion, the next 2 billion people will join the existing 3 billion urban people. Of the new urbanites, half will be middle-income and wealthy, perhaps mainly settling in suburban/exurban/peri-urban areas and near city center. The other half of the arrivals, 1 billion, is expected to double the population of urban poor to 2 billion. The rapidly growing informal- or squatter-settlement component of the urban poor particularly targets and covers urban greenspaces.

Where on Earth are we humans, and where will we soon be? In 1970, Asia had 37% of the world's population, rising to about half in 2005 (UN-Habitat, 2005). For Europe the comparable figures dropped noticeably from 31% to 19%. Northern America (USA and Canada) figures also dropped. Latin America (and the Caribbean) changed little. Africa increased from 6% to 10% of the world's people. Overall these relative growth rates are expected to continue for the upcoming few decades.

Today Europe, Northern America, and Latin America each have about 75% of their population urban. In sharp contrast, Asia and Africa are each about 40% urban. Megacities are commonly highlighted as centers, powerhouses and hubs. However, small cities are much more numerous, remain widely distributed across the land, and provide quite different human benefits and ecological characteristics.

The size of population centers is yet more informative. For instance in the USA, nine cities have >1 million people, 52 have 250K (250 000) to 1 million, 172 have 100K–250K, 363 have 50–100K, 644 have 25–50K, 1435 have 10–25K, and 16 772 population centers have fewer than 10 000 people each (Platt, 2004). Also, a rather constant 15% (±2%) of the total 300 million population live in each community-size category (see equations, Appendix B). Thus, virtually the same number of residents lives in large cities as in tiny communities.

The 22 *megacities* worldwide with >10 million population are currently most abundant in Asian regions (cities listed by population size in each region) (UN Population Division, 2007; Benton-Short and Short, 2008): East Asia area (Tokyo, Shanghai, Osaka, Beijing, Seoul); South Asia (Mumbai, Delhi, Kolkata, Dhaka, Karachi); Southeast Asia (Jakarta, Manila); Latin America (Mexico City, Sao Paulo, Buenos Aires, Rio de Janeiro); North America (New York, Los Angeles); Europe/Russia (London, Moscow); and Africa (Cairo, Lagos). Still, more than half of the world's urban people live in cities of less than 500 000.

Plato in the 4th century BC said that when a city reached 50 000 people, that is enough … a new city should be founded. A few decades ago a leading urban planner suggested 25 000 to 250 000 as the optimum city size (Lynch, 1981). Cities commonly grow for long periods and decrease for short periods (e.g., Leipzig, Detroit, Baltimore, Sao Paulo, Mexico City). Recently some megacities, after rapid population growth, have grown little (Newman and Jennings, 2008). This may be a temporary pause or may reflect some limit to concentrated population growth. Are there limits to city population size?

Some scholars have suggested that travel time might provide an answer. The "Marchetti constant" of an average of approximately one hour of travel per person per day seems to apply in many cities of different types and sizes (Kenworthy and Laube, 2001). Travel time has widely shaped the size and form of cities, so many remain "one hour wide" (Newman and Jennings, 2008). People can get to most places they need by transit or traffic in less than a half hour. Thus, high-density cities can become larger without being "dysfunctional," whereas low-density cities reach the apparent travel-time threshold at a smaller population size. The density of buildings or people in an urban area (Theobold, 2004; Pacione, 2005) is of particular ecological importance, both for the area and its surroundings.

The size of land-use units or districts within a city also affects city size. Indeed, "mixed-use patterns," rather than large separate residential, industrial, and shopping areas, reduce transportation time and cost. Planning that arranges people's primary needs in proximity reduces the travel-time limitation on city population size.

Bioregional limits constrain city size as well (Newman and Jennings, 2008). Thus, local water supply, food, energy, and materials from the ring-around-the-city are cost effective and reduce dependence on imports. The carrying capacity idea of a city in balance with the resources of its urban region is an especially appealing goal (Mumford, 1961; Rees and Wackernagel, 1996, 2008; Forman, 2008). Reducing consumption, waste production, and air and water pollution should also affect city population size.

As the major concentrations of human residential, commercial and industrial activity, cities inherently are the primary users of energy and residential water, and the primary emitters of greenhouse gas. One may ask whether all cities today are in "ecosystem decline." That is, has the human use of environmental resources exceeded the environmental carrying capacity everywhere? Have ecological footprints outstripped the land, so we need more than one Earth's surface to sustain today's human population (UN Population Division, 2007)? Are any cities living effectively within environmental limits? If so, we should learn from them.

Many cities have a published natural history describing especially the key greenspaces, plants, and animals present (Kieran, 1959; Houck and Cody, 2000; Forrest and Konijnendijk, 2005; Wein, 2006). Yet apparently the "history of a city's nature" is rare. Thus, for Boston's four centuries, the dramatic changes in greenspaces, water bodies, wildlife, bird populations, and much more are elucidated (Mitchell, 2008). This provides a much-needed complement to the familiar sequence of military, economic, social and other human changes constituting most histories. Indeed, Boston's natural history also highlights the changing efforts and successes in protecting, even enhancing, natural conditions over time.

Key concepts and terms for urban areas

As for all major subjects, a few key terms are particularly useful in understanding cities and urban areas (Forman, 2008). To sense the problem of choosing terms useful worldwide, consider some common land-use terms in particular countries: tip (UK), biotope (Germany), rodeo (USA), bush (Australia), rink (Canada), feng-shui (China), favela (Brazil), shrine (Japan), allotment (South Africa), and polder (The Netherlands). In the UK, a city with a cathedral may be an urban area, and sprawl refers to unregulated (by government) rather than low-density spread of housing.

As much as practical, concepts and terms in this book are used for clarity and applicability worldwide. "Urban" pertains or relates to city. I extend the concept slightly in using the general term, *urban area*, referring to city- or town-related spaces where people and buildings are concentrated (*Webster's College Dictionary*, 1991; Hartshorn, 1992; World Resources Institute, 1996; Hardoy *et al*., 2004; UN-Habitat, 2006). Thus, urban area applies broadly at different scales to, for instance, megalopolis, urban region, city, suburb, neighborhood, or housing development.

Specifically, *megalopolis* refers to a group of adjoining urban regions (such as Washington-Baltimore-Wilmington-Philadelphia-New York-Hartford-Boston or Amsterdam-Utrecht-The Hague-Rotterdam) (Hanes, 1993). *Urban region* is the area of active interactions between a city and its surroundings (e.g., the 80-km-radius irrigated-rice floodplain encompassing Bangkok, or Philadelphia and its surrounding farmland areas now squeezed by New York, Wilmington, and other regions) (Figure 1.4). *Metro area* (metropolitan area) is the continuous essentially all-built area of a city and its adjacent suburbs (e.g., as seen in a satellite image). [Note that this spatial concept applies in all regions, and avoids the USA sprawl-and-car concept of a "commuter shed" (Hartshorn, 1992); in most nations working in a city also means living in or adjacent to it]. A *city* is a relatively

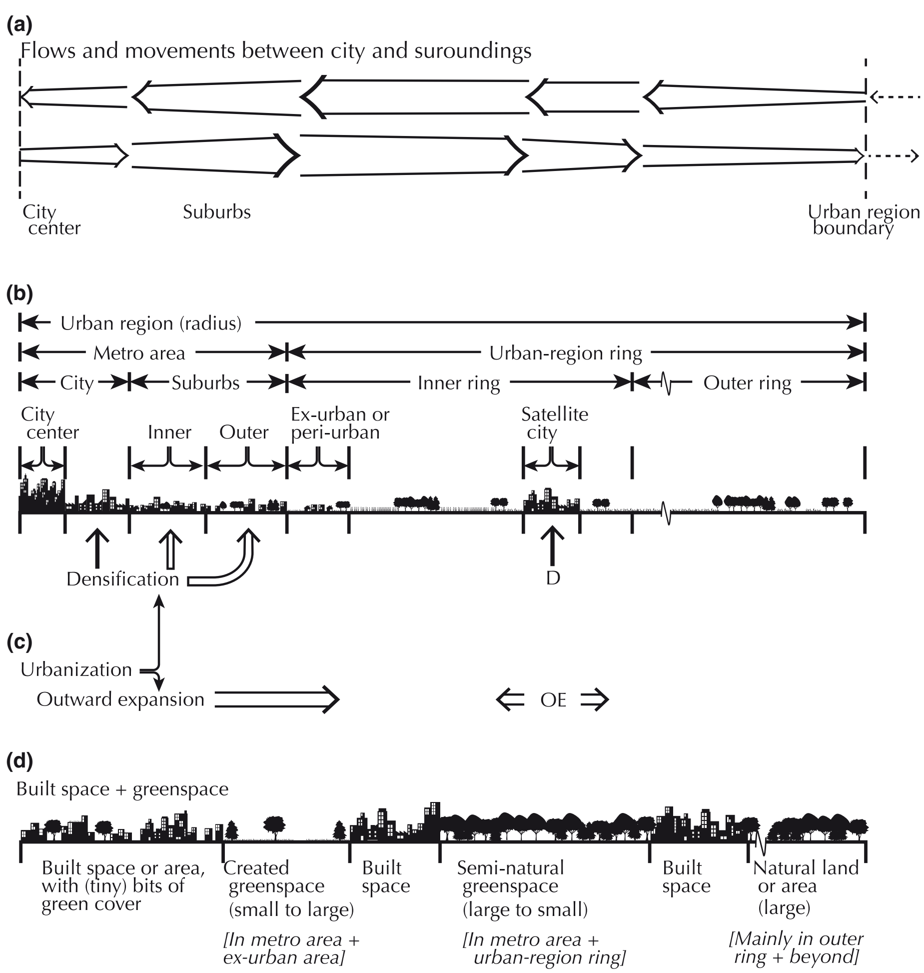

Figure 1.4. Concepts and terms for urban ecology. Metro area extends outward to the edge of the essentially continuous all-built area. Some suburbs extend beyond the metro area, and include some or all of the exurban or peri-urban zone. The urban-region ring also contains separate towns and villages. (a) Width of arrows roughly proportional to amount of flows and movements. (b) Concepts and terminology used in this book. (c) The two components of urbanization in different areas [see (b)] of the urban region. (d) Examples for bits of green cover (in built space) = window box, street trees, back yard space, green roof; examples of created greenspaces = city plaza/square, cemetery, vacant lot, dump, waterworks, golf course. Based on Forman (2008) and other sources.

large or important municipality or population center (*Webster's College Dictionary*, 1991; Hardoy *et al.*, 2004; UN-Habitat, 2006). A *suburb* is a mostly residential municipality or town close to a city, and may be within, partially within, or outside the metro area.

Three terms describe the area outside the all-built metro area (Forman, 2008). The *urban-region ring* refers to the area between the metro-area border and the urban-region boundary. A usually narrow zone adjacent to or close to the metro-area border, typically characterized by some recent housing developments and other evidence of urbanization, is perhaps best called *exurban*. If the narrow zone contains considerable agriculture, it can be called either *peri-urban* or exurban, whereas if natural land predominates, exurban seems to be the more appropriate term (Theobold, 2004; Pacione, 2005; Vince *et al.*, 2005; McGregor *et al.*, 2006; Tacoli, 2006; Maconachie, 2007).

Urbanization is a land-change process of densification and/or outward expansion (Figure 1.4c) (Pacione, 2005; Forman, 2008). *Densification* refers to increasing the density of people or buildings (e.g., by changing low-rise to high-rise housing or the conversion/loss of greenspace to buildings, as in Portland, Oregon, USA). *Outward expansion* refers to city-related development beyond the metro-area border, effectively a suburbanization process. The expansion may occur in many different ways, including development along transportation corridors (e.g., Grenoble, France), by bulges around the metro-area border (history of London), or by dispersed sprawl [e.g., Las Vegas (USA) and Chicago] (Forman, 2008). Consistent with the dictionary concept, *sprawl* is the process of distributing built structures in an unsatisfactory ("awkward") spread-out (rather than compact) pattern. Compact-nucleus expansion, illustrated by concentrated growth on the edges of many European towns, is an urbanization alternative to sprawl.

An urban area is basically covered by two components, built spaces or areas and greenspaces. Both are exceedingly diverse and important. *Greenspaces* are mainly covered by plants and, though publicly or privately owned, are large enough to be public greenspace. *Built spaces* or areas are mainly covered with human-made structures, but commonly contain small areas of plant cover (Figure 1.4d). Thus, greenspaces include golf courses and most abandoned sand/gravel-extraction sites and capped dumps, while built spaces include most housing developments, active dumps, and parking lots.

The familiar general term, "land use," is used as equivalent to the slightly more-technical term, "land cover," which refers to the area where a specific type of greenspace or built space predominates (Breuste, 2009). Thus, a particular *land use* is considered to be a single land cover with one or more uses or roles.

Three types of "environment" may be recognized (Hardoy *et al.*, 2004): natural environment (dominated by organisms, and with little human influence); physical environment (air, soil, or water characteristics predominant, with little role of organisms); and built environment (area dominated by buildings or other human artifacts). *Nature* refers to what humans have not made or strongly altered (*Webster's College Dictionary*, 1991; Forman, 2008). *Natural system* focuses on the structure and functioning of nature (dominated by air, soil, water, plants, animals, and/or microbes), and *ecosystem* highlights a natural system where organisms play central roles (in contrast to groundwater, earthen fill, and atmospheric systems). *Habitat* refers to a relatively distinct area and its environmental conditions, where an organism or group of organisms mainly lives.

Natural habitats or systems are found in four easily recognized forms: built area; created greenspace; semi-natural greenspace; and natural area (Figure 1.5) (Forman, 2008, 2010a). As suggested above, a *built area* contains continuous closely spaced buildings typically with roads and other human structures present, as in various residential and commercial areas. Within the built area, tiny spaces covered with plants are described as *green cover*, as for example a grassy entranceway to a building, street trees, backyard of a house plot, or a tiny unmaintained weedy patch. A *created greenspace* is a small or large area mainly covered by plants that was formed by, or is intensively used or maintained by, people, such as a grass-tree city park, golf course, or farmland. A *semi-natural area* is a large or small space resembling a natural ecosystem but significantly altered or degraded by people, sometimes with created unbuilt spaces intermixed, such as a woodland park (Figure 1.5), or greenway, or wetland for pollutant treatment (Haber, 1990; Millard, 2008; Cilliers and Siebert, 2011). A *natural area* is unplanted and without intensive human management or use, such as a relatively large marsh, forest, or shrub area with little human usage, usually in the outer urban-region ring (Peterken, 1996; van Bohemen, 2005; Kowarik and Korner, 2005). These four categories, from built to natural, represent a broad sequence of ecological alteration or degradation, where human activities decrease

Figure 1.5. Semi-natural oak woods (*Quercus*) in a city park. Rather dense canopy, understory, shrub layer, and herbaceous layer suggest natural conditions, whereas the paths, bench, constructed pond, and overflowing trash bin indicate a significant human impact. London. R. Forman photo courtesy of Jessica Newman.

natural vertical structure, horizontal pattern, and/or flows and movements.

Ecology, environment, and history

Barely a century and a half old, ecology as a discipline catapulted to the front line for society in the 1960s when an "environmental crisis" was suddenly recognized (Carson, 1962; Bartuska and Young, 1994; McNeill, 2000). Ecology was highlighted as a core subject for both understanding and solution. Quickly it became a familiar word in kitchens, drinking places, and diplomats' conferences.

Ecology appeared in the 1860s in Germany, and by the 1890s was a recognized scientific discipline in Europe, tying together animal and plant ecology plus freshwater and marine biology (Worster, 1977; McIntosh, 1985; Forman, 2010a). In the USA the field emerged in the Midwest about 1900, focusing on ecological succession. Professional societies and journals were founded in 1912–15, and modern ecology emerged in the 1940s–50s, highlighting ecosystem, theoretical, evolutionary, community and systems ecology. Many subspecialties have evolved over time, including the recent development of landscape ecology, conservation biology, and urban ecology. These diverse flavors of ecological science naturally have generated variations in defining ecology, e.g., in emphasizing vegetation, population dynamics, ecosystem flows, evolutionary adaptation, or interaction with the physical environment. Fortunately, despite these variations, ecologists of diverse types almost all ascribe to the traditional core concept of ecology, as the "study of interactions of organisms and the environment."

In a two-century history of society's "big ideas" – religion, science/rationalism, nationalism, hard-work-makes-land-productive, communism, and economic growth – the idea of environmentalism barely made a sound (McNeill, 2000). But it hit the headlines and became a household word in the 1960s–70s, associated with a whole set of issues – wetlands, wolves, foaming rivers, and choking air – and in the wake of Rachel Carson's 1962 book, *Silent Spring*. Environmental organizations, political parties, laws, regulations, and some visible successes rapidly followed in developed and certain developing nations. International conferences and treaties further spurred environmentalism into our consciousness.

Then suddenly in the 1990s–2000s, urbanization (especially sprawl) and global climate change further pushed environmentalism to the forefront, as one of the big ideas of history. The primarily scientific component of this, ecology, emerged as a core field for societal solutions. Within this, embryonic urban ecology is growing rapidly.

Not surprisingly, diverse subjects and terms have also appeared in the overlap areas of ecology and other fields. Consider environmental engineering, eco-criticism, social ecology, political ecology, environmental design in architecture, ecological/natural-resource/environmental economics, human ecology, global ecology, eco-city and ecopolis, sustainable development, road ecology, green infrastructure, industrial ecology, deep ecology, even green marketing (Park *et al.*, 1925; Ma, 1985; Costanza *et al.*, 1997a, 1997b; Roseland, 2001; Buell, 2001, 2005; Steiner, 2002; Forman *et al.*, 2003; Babbitt, 2005; van Bohemen, 2005; Allenby, 2006). Together such subjects represent hybrid vigor, the opening of frontiers of discovery and knowledge, and importance to society.

Eight major concept areas today describe the field of ecology (Smith, 1996; Cain *et al.*, 2011; Morin, 2011):

(1) physiological organism–environment ecology; (2) population growth and regulation; (3) competition and predation; (4) community/habitat and succession; (5) ecosystem and biogeochemical cycling; (6) freshwater ecology; (7) marine biology; and (8) landscape, regional, and global ecology. Professional journals, organizations, meetings, academic programs, courses, research grants, and research programs sustain these subfields and their growth. More than 25 000 people today identify themselves primarily as ecologists.

Urban ecology and history

Early phases

The roots and development of urban ecology are highlighted in two recent reviews (Sukopp, 2008; McDonnell, 2011). The term was used in the 1920s by a group of sociologists drawing analogies from the science of ecology (Park *et al.*, 1925). However, urban ecology as a scientific discipline really emerged in the 1970s–80s (Stearns, 1970; Nix, 1972; Duvigneaud, 1974; Stearns and Montag, 1974). Thus, although overlaps exist, it is convenient to briefly consider the pre-1970 period and the post-1970 period.

Floras of urban botanical gardens, cemeteries, tree-planted spaces, and indeed of whole cities [e.g., in German cities, Montpellier (France), and Leningrad] were published from the 1500s on (Sukopp, 2002, 2008). Floras of castles, ruins, and urban areas (Rome, Paris, Palestine, London) appeared from the 1600s on. Urban plant migration studies, especially by a Swiss botanist A. Thellung in the 1910s, were published from the 1700s on (Schroeder, 1969; Pysek, 1995b). Urban bird and mammal studies appear from the 1800s on, though studies of animals of economic importance appear >1000 years ago (Gilbert, 1991; Owen, 1991; Klausnitzer, 1993; Erz and Klausnitzer, 1998; Sukopp, 2008). Urban vegetation studies appeared from the 1950s on [Berlin, Prague, Brno (Czech Republic)] (Murcina, 1990; Pysek, 1993; Sukopp, 2002). Urban environmental conditions relative to ecology are also important in urban ecology, including studies of phenology from the 1700s, and of microclimate, soils, and air pollution from the 1800s (Sukopp, 2008).

Ecological studies of World War II bombed sites and rubble surfaces from the 1940s on highlighted flora, fauna, and vegetation dynamics (Salisbury, 1943; Pfeiffer, 1957; Gilbert, 1992), and represent an important step underlying modern urban ecology. Newer studies of whole cities from the 1940s–50s on emphasized distinctive urban sites, plant communities, and changing species composition (e.g., London, Paris, New York, Vienna) (Sukopp, 2008).

Ecosystem studies of urban areas, in some cases by teams of researchers focusing on flows of nutrients and materials, appeared in the 1970s–80s (e.g., Brussels, Berlin, Hong Kong) (Nix, 1972; Duvigneaud, 1974; Stearns and Montag, 1974; Boyden *et al.*, 1981; Sukopp, 1990). A focus on urban trees also appeared from the 1970s on (Grey and Deneke, 1992; Rowntree, 1986). Vegetation and the ecosystem concept were linked in Tokyo (Numata, 1982). A particularly nice balance and synthesis of urban microclimate, soil, water, plants, vegetation, and animals was published mainly for UK cities (Gilbert, 1991).

Also since at least the 1970s, urban nature has been scientifically linked with human health, welfare, and culture, highlighting a human ecology dimension (e.g., Tokyo, Hong Kong) (Boyden *et al.*, 1981; Numata, 1998). Human ecology as a field linking urban planning and social patterns with ecological science has continued to evolve (Steiner and Nauser, 1993; Steiner, 2002).

The major linkage between the 1970s–80s urban ecology work and the current phase goes through Berlin and Central Europe, especially the work of H. Sukopp, P. Pysek, and later I. Kowarik (Sukopp *et al.*, 1990, 1995; Pysek, 1993; Pysek *et al.*, 2004; Breuste *et al.*, 1998; Kowarik and Korner, 2005; Sukopp, 2008). An active researcher, editor of books, and catalyst for the field, especially in Northern and Central Europe, Sukopp highlighted the changing urban vegetation and flora, but welcomed contributions from diverse researchers, ecological fields and geographies. Vegetation or "biotope" mapping in cities was a foundation of this work (Schulte *et al.*, 1993; Pysek, 1995a; Schulte and Sukopp, 2000). In 1995 Berlin and London were probably the best known major cities ecologically.

The current phase of urban ecology

Throughout both the early phase and the current phase, dispersed perceptive pioneers have contributed, and continue to contribute, an unending sequence of diverse insights and important results to our understanding of urban ecology. These individual scholars or small groups work in large and small cities, different geographic settings, and diverse cultures. Examples are: M. Soule *et al.* (1988), top predator effect on urban species diversity; A. von Stulpnagel *et al.* (1990), park size and air cooling; J. Owen (1991), ecology of a house plot or garden; M. Godde *et al*. (1995), urban habitats and plant/animal diversity; and, yes, R. Forman and D. Sperling (2011), netway system for reconnecting the land.

The current phase of urban ecology perhaps emerged in the late 1990s with the establishment of multidisciplinary, integrative and long-term studies of a few temperate-zone cities (Grimm *et al*., 2000; Wu, 2008): New York, Baltimore, Phoenix, Seattle, and Melbourne. Research in Sheffield/London is similar in scope. This work added impetus and integrated knowledge. It changed the field from the domain of dispersed individual scholars to the initial coalescence of an embryonic field.

Numerous edited books from the 1980s to 2010s have catalyzed the field and effectively sketched out its current and evolving core (McDonnell, 2011): Sukopp *et al*. (1990, 1995), Platt *et al*. (1994), Breuste *et al*. (1998), Konijnendijk *et al*. (2005), Kowarik and Korner (2005), Carreiro *et al*. (2008), Marzluff *et al*. (2008), McDonnell *et al*. (2009), Gaston (2010), Muller *et al*. (2010), Niemela *et al*. (2011) and Richter and Weiland (2012). Also key books on urban climatology (Gartland, 2008; Erell *et al*., 2011), soils (Craul. 1992, 1999; Brown *et al*., 2000), water (Baker, 2009), and geography (Hartshorn, 1992; Pacione, 2005) provide important components for urban ecology.

Five books with the benefits of single authorship offer valuable integration and depth in key areas. O. L. Gilbert (1991), as mentioned, highlights the basic ecological components of urban ecology, especially for UK cities. C. P. Wheater (1999) has a similar content but is less detailed and appeals to audiences beyond ecology. M. Alberti (2008) highlights concepts from ecology through the eyes of a planner, and provides many stimulating ideas. R. T. T. Forman (2008) highlights the urban region, within which a city functions, as a key viable unit for ecological analysis and planning. F. R. Adler and C. J. Tanner (Adler and Tanner, 2013) usefully apply some basic ecological concepts to the built environment. The book in your hand thus delves into urban areas from megalopolis to micro-site, developing ecological principles based on the urban characteristics.

The present book focuses squarely on the science of ecology and urban areas (Grimm *et al*., 2000; Pickett *et al*., 2001; Alberti *et al*., 2003; Niemela *et al*., 2009). Naturally this science is of considerable use and value to various human disciplines. For example, engineering, planning, and landscape architecture incorporate components into their fields, contribute to the understanding of urban ecology, and may have tailored definitions to their diverse fields (Geddes, 1914, 1925; Spirn, 1984; Deelstra, 1998; Beatley, 2000b; Pickett *et al*., 2001, 2013; Hough, 2004; Alberti, 2008; Forman, 2008; Nassauer and Opdam, 2008; Musacchio, 2009; Reed and Hilderbrand, 2012). Social science does as well (Pickett *et al*., 2001; Alberti, 2008; Muller *et al*., 2010; McDonnell, 2011). At a much earlier time sociology saw promising analogies with the then-emerging science of ecology (Park *et al*., 1925; Hawley, 1944; Catton and Dunlap, 1978), and subsequent thinking from this approach may have been retained in part in the broad field of human ecology (Steiner and Nauser, 1993). The role of social science, engineering, and other fields in urban ecology will of course remain dynamic. As in the evolution of landscape ecology (Zonneveld and Forman, 1990; Forman, 1995; Farina, 2006), an ecumenical approach without attempting to draw boundaries lets the highest quality and most valuable theory-and-application work simply define the core of a field, in this case urban ecology.

Today's major urban-ecology approaches and centers of research (Sukopp *et al*., 1990; Nilon and Pais, 1997; Breuste *et al*., 1998; Jenerette and Wu, 2001; Pickett *et al*., 2001; Luck and Wu, 2002; Grimm *et al*., 2003, 2008; van der Ree and McCarthy, 2005; Kowarik and Korner, 2005; Wu, 2008; Alberti, 2008; Forman, 2008; McDonnell *et al*., 2009; Lepczyk and Warren, 2012; Richter and Weiland, 2012) include: (1) habitat/biotope mapping and related analyses (especially in Berlin and Central Europe); (2) species types and richness (Berlin, Melbourne); (3) city-to-rural gradient (Melbourne, Baltimore); (4) modeling and biogeochemical/material flows (Phoenix, Seattle); (5) coupled biophysical-human systems (Phoenix, Baltimore, Seattle); and (6) urban-region spatial patterns, processes, and changes (worldwide analyses).

The concept of a city-to-rural (urban-to-rural) gradient has been an especially useful concept in catalyzing urban ecology research (McDonnell and Pickett, 1990; McDonnell *et al*., 1993; McDonnell and Hahs, 2008; McDonnell, 2011). Just as the 19th- and 20th-century, lichenologists and botanists studied lichens and other plants along lines from outside the city to city center (Le Blanc and Rao, 1973; Schmid, 1975), numerous ecological phenomena have now been studied and compared along such gradients worldwide. This approach is familiar and convenient for ecologists and is likely to continue, even as research increasingly turns to the more difficult, but especially valuable, twodimensional studies of urban mosaics. Differentiating the ecology "in" and "of" cities (typically "in" = single component, small space, within a city; "of" = interdisciplinary and multi-scale) has helped spur broad-scale urban-ecology thinking and research (Grimm *et al.*, 2000; Pickett *et al.*, 2001; Alberti, 2008; Wu, 2008; McDonnell, 2011). Presumably, ongoing research, including multidisciplinary small-space as well as single-component multi-scale studies, will reduce the value of or need for such a separation.

Today the field is developing in two ways. First, dispersed scholars continue to publish research results from large and small cities in diverse regions and cultures worldwide. These studies crack open frontiers on an array of subjects the researchers perceive to be important. Together these provide both specific insights and broaden the field. Second, several research teams carry out relatively integrated research from a few cities on related subjects with a logical focus. These focused research studies deepen understanding in their domains, and together provide comparisons, linkages, and breadth. This dual and synergistic approach represents a strong model for developing urban ecology into the future.

Urban attributes and ecological assays

In the late 19th century, suppose the field of ecology had begun in cities, rather than in woods, shrublands, farmland, and ponds (Worster, 1977; McIntosh, 1985). Surely its central themes would have involved muddy roads and puddles, cobblestone streets, horses and dung, dust, coal-burning smoke, lots of dumps, streams/rivers for waste removal, connected backyards/garden areas, privies and human-wastewater, pigeons and house sparrows, rail facilities, rats, diseases, and blocks of burned buildings. An ecology of natural ecosystems might have evolved separately, or perhaps hand-in-hand with the ecology of cities. Irrespective, today urban ecology would be much further along.

Solidly rooted in natural areas, often with a limited or modest human imprint, how does an ecologist get started in a city? Buildings and roads are packed together. People and vehicles and an array of human-made objects cover the place. Flows and movements are channeled through networks. Flying animals and bits of green, from sidewalk mosses to whole parks, catch our attention. Where do species live in a city? Urban species, urban habitats, and their spatial arrangement. That is a good way to begin.

Distinctive attributes, hierarchical scales, and gradients

Consider a few widespread unusual or distinctive ecological characteristics. All are familiar to urban ecologists and even to the observant public.

1. *Habitats and species*
    - Usually diverse intermixed greenspaces and built patches cover the area.
    - Small sites tend to have few species, whereas large areas are often species rich.
    - Planted ornamentals, as well as spontaneous colonized species, are widespread.
    - Generalist species survive and predominate in urban conditions.
2. *Patches and areas*
    - Housing developments and house plots emphasize rectilinear repetition.
    - Boundaries are overwhelmingly straight, abrupt, and in high density.
    - Mowed grassy areas range from abundant to essentially absent.
    - Widespread impervious surfaces absorb solar radiation, generate heat, and greatly increase stormwater runoff.
    - Air and water are often heavily polluted.
3. *Corridors and flows*
    - Rectilinear road networks channel hordes of moving vehicles and people.
    - Underground branching conduits permeate and connect the place.
    - Animal movement is often along stepping stones rather than continuous strips.
    - Watercourses are channelized and flood-prone areas common.
4. *Change*
    - Many ecological changes are human-caused, rapid, and drastic.
    - Abundant species from afar endlessly arrive, while both native and non-native species disappear.
    - The city expands directionally over suburbs, and suburbs over rural land.

For a natural or agricultural landscape, these patterns would be bizarre. In urban areas they predominate.