Urban ecology

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The intellectual and social context

Urban ecology is the study of urban areas as a series of habitats for human beings and other organisms; the relationships between all these organisms under changing urban environmental conditions; and the interactions of living things with natural and human-made flows of energy, water, and materials, both deliberate and accidental, in the varied and diverse conditions of the world's towns and cities. It integrates both theoretical and applied aspects of the natural and social sciences in analyzing, understanding, and managing the diverse ecological conditions encountered in urban areas.

Urban ecology is firmly rooted in ecology, the science studying the processes influencing the distribution and abundance of organisms, the interactions between organisms, and the interactions between organisms and the transformation and flux of energy, matter, and information. It embraces all the sociopolitical, cultural, and economic factors that affect ecological processes in urban areas, paying particular attention to the way those factors continually modify the abundance and diversity of organisms found in particular urban places. Urban ecology also examines specific ecological situations within towns and cities, as well as how urban demands for food, water, energy, and materials and disposal of wastes affect other ecosystems at all scales from entire oceans to individual organisms.

People from many academic and technical backgrounds have written about nature in cities, urban ecosystems, the flora and fauna of towns, the species colonizing newly vacant urban land, and the human benefits from contact with wildlife in built-up areas. Broadly, four general themes emerge from these diverse points of view:

- The *ecology of health in urban areas*: towns and cities as habitats for humans and disease vectors, including the role of urban nature in human wellbeing.
- *Ecology in towns and cities*: urban areas as habitats for wildlife, plants, and other organisms, from coyotes in Californian cities to crocodiles in Darwin, Australia, and monkeys in Malaysian towns, and including molds on food and kestrels on skyscrapers.
- The *ecology of cities as a whole*: the flows of energy, water, materials, and information into, within, and out of urban areas and their internal and external impacts; differentiation within urban areas; rural–urban gradients; and the analysis of complex urban socioecological systems
- *Ecology for cities*: enhancing the ecosystem services provided by urban green infrastructure to help build resilience to change, including environmental change, and to increase urban sustainability and improve community cohesion.

The public health theme looks at urban areas as habitats that may improve or threaten human health and wellbeing. Good urban design can reduce the urban heat island effect that leads to

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excess deaths during extreme hot spells. Urban street trees and gardens may alleviate stress and anxiety for some people, and create fear among others. Conversely, poor housing and sanitation can support disease vectors that carry malaria and dengue fever as well as lead to the spread of cholera and viral gastroenteritis. Climate change is allowing disease vectors to extend their range, especially with large urban areas often being warmer than their surrounding countryside. Many zoonoses (diseases transmitted from animals to humans under natural conditions) come into urban areas with pets, farm animals, and imported meat. Thus analysis of ecological conditions reveals urban habitats for disease-bearing organisms, helps establish where risks to health are increasing, and heightens awareness of how social factors, such as poor housing and sanitation, lead to conditions that favor human ill-health.

Urban ecosystems continue to be a major focus for an immense range of biological work on particular urban influences on plants, animals, fungi, and other organisms. Local natural history societies developed in the mid-nineteenth century, many of them concentrating on plants and animals in and immediately around urban areas, for example the London Natural History Society. From such beginnings, ornithologists, for example, have built up great databases on changes in urban bird populations that enable their behavior and ecology in towns and cities to be analyzed in detail. Similarly many invasive plant and insect species are well documented, particularly in cities where large areas of vacant land were created by wartime bombing or industrial dereliction. Such studies often focus on particular species or types of species, but many also examine interactions with the built environment, pollutants, and human behavior. This is the classic urban ecology of Europe: the study of the interactions of various organisms with each other and with their diverse urban surroundings. Similar work is found in many other parts of the world, especially in China (Li *et al.* 2008) and India (Nagendra and Gopal 2011; Khera, Mehta, and Sabata 2009), and particular attention has also been given to the social aspects of urban biodiversity in developing countries (Cilliers 2010).

The view of urban areas as single systems integrated with their immediate surroundings (the city-region) sees the city-region ecosystem as a life-support system for all the organisms within the urban settlement. It provides ecosystem services such as water supplies, sources of aggregates, areas for landfill, recreation zones, watershed protection, greenhouse gas uptake, biodiversity, and some food supplies. This point of view is often discussed in terms of the ecology *of* cities or as urban metabolism (a somewhat criticized organic analogy).

The same urban settlement can be seen as creating demands for energy, food, water, and materials that may have widespread, even global, implications. Accessing supplies of coal, natural gas, or oil, of grain, fruits, vegetables, fish, meat, and other foods, and of manufactured goods from distant regions has a global outreach with impacts on other ecosystems, from fine particles of plastic frozen in Arctic ice to residues of agricultural chemicals and mining wastes contributing to the eutrophication of rivers, lakes, and reservoirs in distant countries. This global impact, or ecological footprint, is one expression of the widespread effects that these complex socioecological systems have around the world.

History of urban ecology

Urban ecology has diverse roots. One stems from nineteenth-century public health investigations of the relationships between human living conditions, the spread of disease, and the wide variety of disease vectors in urban areas leading to a

vision of cities as socioecological systems that still resonates strongly with twenty-first-century views of urban ecologists about people and nature in urban areas.

A second strand of urban ecology stems from landscape design and urban planning. Changed ideas about housing and sanitation in the nineteenth century included the belief that exercise in the open air improved people's health. Thus, the goals of the first public parks in England, Paxton's Princes Park in Liverpool and his Birkenhead Park across the Mersey Estuary, built in the 1840s, were to provide open space for the benefit of townspeople and local residents in areas being rapidly built up, and to develop attractive designed landscapes as a setting for the suburban residences. Frederick Olmsted took on board some ideas from a visit to Birkenhead in his 1857 plans for Central Park in New York. The many important ecological attributes in such urban landscape formation were incorporated into Olmsted's sophisticated design combining wastewater management and recreational amenity in the Riverway and Back Bay Fens in Boston, Massachusetts, a forerunner of today's sustainable drainage.

Eventually this stimulated ideas of planning new towns as garden cities, beginning with Ebenezer Howard's garden cities at Welwyn and Letchworth in England at the end of the nineteenth century. The subsequent garden city movement influenced the design of suburbs, new towns, and federal capital cities. It had no particular emphasis on planning for wildlife or children's access to urban nature, but it did have a city-region approach emphasizing a green belt of intensive food production around each garden city. The emphasis was on healthier living spaces for people, workplaces close to homes, and easy access to high-quality community services. Even so, garden city designs, with their diversity of urban planting schemes, gardens, and horticulture, created mosaics of habitats for other organisms, producing novel combinations of species in emerging ecosystems. Workers' housing with individual gardens, for example the 1930s council estates in the United Kingdom, arose from the garden city movement. Crises such as World War II saw parks, sports grounds, and golf courses used for growing a wide range of crops in patches of land ranging from domestic vegetable plots to large wheat fields. This intensive agriculture helped to increase urban biodiversity and plant productivity. After 1945, most of the open spaces were returned to their recreational uses, but the urban food-growing tradition remained strong in Europe, with many residents choosing to cultivate family gardens or allotments. The value of urban nature for human physical and mental health remains a central concern of government and civil society organizations involved with urban green spaces and urban wildlife today.

Urban agriculture is even more significant in poorer countries, where urban growers supply as much as one-third of all the food consumed in some cities. Here food growing is necessary for survival, often using public lands and illegally occupied vacant areas, and forming a key component of the urban ecology of most of the world's fastest-growing cities. The value of urban nature for human physical and mental health remains a central concern of government and civil society organizations involved with urban green spaces and urban wildlife today.

By the mid-twentieth century, surveys of introduced and invasive species began to appear in Europe, and specialized work on synanthropic plants and animals in urban areas began to form a third foundation of urban ecology. The rapid ecological changes on bombed sites after 1940 added a further stimulus to modern urban ecology. Derelict bombed sites were invaded by unusual plants and insects, creating new habitats

for birds and leading to novel combinations of flora and fauna. Major studies in many European cities examined the results of this tremendous natural experiment and stimulated notions of novel ecosystems, some of which were considered worth preserving so that city dwellers could see natural vegetation close to their homes. However, the work was essentially on the rubble left after bombing and on derelict industrial land. It concentrated on the newly naturalized plants, the dispersal strategies of particular species, succession under various site conditions, and the formation of new plant communities. It produced the first peak of activity in urban ecology and had a major impact on attitudes to nature in urban areas. Such was the biodiversity on some of these sites that many local groups campaigned to have some remnant areas protected as ecology parks or urban nature reserves. The demands for regeneration and rebuilding after 1945, and the emphasis on creating national parks and protecting the countryside, drew attention away from urban wildlife. However, industrial change, following the replacement of coal by natural gas and the decline of heavy manufacturing industry, left much derelict land that was colonized by unusual combinations of plants. Old factory sites and coal mine waste tips were converted in the public open spaces, and the reclamation of derelict sites created new opportunities for the deliberate planning of new ecosystems. Restoration ecology developed. People began to see the opportunities for allowing natural recolonization to proceed at some sites. By the 1970s urban ecological projects were underway in several European cities and urban ecology parks began to be established. A book on *Nature in Cities* by Ian Laurie was published in 1979 and the first European symposium on urban ecology was held in Berlin in 1982. The journal *Urban Ecology* began publication in 1975, and was incorporated into *Landscape and Urban Planning* in 1986. Now there are at least eight scientific journals concentrating on urban ecology.

Somewhat detached from European developments, studies of urban forests and wetlands in North America developed after the 1969 US Environmental Protection Act stimulated work in urban forestry that has played a major role in establishing methods of evaluating urban ecosystem services and encouraging investment urban greenways and green infrastructure. The 2009 report on *Planning the Urban Forest: Ecology, Economy, and Community Development* (Schwab 2009) set out the following benefits of the urban forest:

- *environmental*: providing green infrastructure; treating stormwater runoff; shading and cooling the urban heat island; reducing air pollution; providing wildlife habitat;
- *social*: health benefits; environmental justice;
- *economic*: value of trees in business district; influence on property prices; added value from parks.

These benefits interest urban ecologists and indicate how people have come to examine interrelated urban environmental issues from many different disciplines. They also demonstrate how the concept of green infrastructure has become prominent since 2001. So the examination of particular species and special habitats in cities has now grown into a much broader consideration of the place of nature in the city and its benefits to urban inhabitants.

The fourth root of urban ecology extends into the view of the city as a whole ecosystem with inputs and outputs and with its own metabolism. Ideas on cities as dependent ecosystems expanded from William Cobbett's 1829 description of the impact of London's food and timber requirements on life in villages 100 km away, to Wolman's landmark 1965 paper

on the metabolism of cities. Their ecological significance was first emphasized by the 1972 publication on Sydney as an ecosystem. A new standard was set by Stephen Boyden's team's work on Hong Kong in the 1970s. Their book provided an intellectual framework for the research; analyzed empirical data from a wide range of sources to understand the dynamics of the city; explained both ecological and social problems affecting the dynamics of the urban area; and set out the first model for integrating social and ecological process into an urban socioecological system. It became a pilot project of UNESCO's Man and the Biosphere Programme Project 11 (MAB 11), in which ideas of analyzing urban energy, water and materials budgets, and their ecological impacts eventually expanded into both the industrial ecology and the urban ecology of the early twenty-first century. MAB 11 helped to develop views on the ecological aspects of urban systems, particularly in Rome where the psychological dimensions of urban relationships with nature received much attention. The dependency of urban areas on external ecosystems became well understood, particularly through the readily grasped, but sometimes misinterpreted, concept of the urban ecological footprint. Probably the most significant element of the urban footprint approach is the comparative per capita area of land needed to support an inhabitant of a particular city at its present rate of consumption. Around the year 2000, it ranged from 0.8 ha per person in an informal settlement in Delhi, India, to 11.0 ha per person in Calgary, Canada.

The urban ecological footprint is a modern example of the organic analogy or allegorical use of ecology. An earlier instance arose at the University of Chicago in the first decades of the twentieth century, where pioneering ecologists developed ideas of evolving plant communities and plant succession in the dune systems at the southern end of Lake Michigan. These biological ideas were noted by Chicago sociologists who saw possibly similar changes in human communities and the successions of occupation of various parts of the city by different social groups. This human ecology of urban areas, known as the Chicago School, was termed "urban ecology" by the 1950s. Urban ecologists then studied the spatial organization of the urban community and the changing patterns of segregation and occupation of different districts by various social and cultural groups. With the advent of computers to analyze large quantities of census tract data, urban ecology within sociology developed into social area analyses and factorial ecologies, which engaged many geographers and sociologists in the 1950s and 1960s. While this work continues in public health investigations, others subsequently concentrated on how the socioecological character of their nonwork relationships and interactions influence urban people's lives.

Since 1990, urban ecology has moved into an era of high-level cross-disciplinary comparative and analytical work, building on MAB 11 and given a major boost by the establishment in 1997 of two US research sites, the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project and the Baltimore Ecosystem Study (BES). The BES aims to understand metropolitan Baltimore as an ecological system, bringing together researchers from the biological, physical, and social sciences to collect new data and to synthesize existing information on how both the ecological and the engineered systems of Baltimore work. CAP LTER is a multidisciplinary, urban ecological investigation of the socioecological systems in central Arizona. The basic questions guiding the research are: How do the services provided by evolving urban ecosystems affect human outcomes and behavior, and how does human

action (responses) alter the patterns of ecosystem structure and function, and ultimately urban sustainability, in a dynamic environment?

Modern urban ecology

Today, a broad cross-disciplinary endeavor is helping to change the appearance of urban areas by improving understanding of urban ecosystem functioning and assisting the design and management of urban areas for human wellbeing, biodiversity, and other ecosystem services. For urban ecology such work is a challenge, requiring the coupling of science with practice to address many of the wider issues faced by humanity.

Although modern urban ecology emphasizes the integrated view of complex socioecological systems, scientific publications tend to deal with parts of systems and it is convenient to examine the contemporary scene in terms of the four themes set out in the introduction: the ecology of health in urban areas, ecology in cities, ecology of cities, and ecology for cities.

Ecology of health in urban areas

The relationships between people and nature in cities are many and varied. Humans have profound effects on species survival, population structure, reproduction, behavior, and evolution; and, at the same time, nature also has profound effects on the health and wellbeing (both positive and negative) of people. As urban areas increase in number and size, so the frequency and intensity of interactions between humans and urban wildlife also increases. These interactions can be with individual animals or plants, or with the habitats in which these species live (such as parks, gardens, and ponds).

The diseases carried by animals (disease vectors) and the diseases occurring in animals that can be passed on to humans are some of the main hazards associated with animals. Attention to zoonoses has greatly increased with the rapid expansion of intercontinental air travel and the movement of animals around the world. Disease can be transmitted rapidly. Climate change is also permitting disease vectors to move into areas that were previously climatically inhospitable. Increasing urban populations, pet ownership, travel, and activities that bring people closer to wildlife are raising the possibility of the rapid transmission of wildlife diseases to, and within, urban environments. Particularly severe in their consequences are exchanges between people and nonhuman primates such as herpes simian B virus and monkey pox (through animal bites) and Ebola (through hunting and butchering). More significant in terms of numbers of people, especially in urban areas, are the diseases carried by nonprimate animals that are close to humans, including dogs and rats. Alligators and large snakes, birds, mosquitoes, and ticks all carry diseases or pose other health risks. Rats (*Rattus* sp.), for example, cause several possibly fatal diseases including Weil's disease, salmonella, tuberculosis, cryptosporidiosis, *E. coli*, and foot and mouth disease (*Aphthae epizooticae*). Urban birds exploit the built environment extensively. However, they also spread disease by spores from their droppings that are carried on the wind and inhaled as dust. Symptoms of the diseases involved, such as chiamdiosis, a virus similar to influenza, and psittacosis, which is similar to pneumonia, may be minor in healthy adults but are a more serious problem for those with low immunity.

Many insects are disease vectors. The role of mosquitos in malaria transmission is well known, but they can also carry other diseases, such as dengue fever. Ticks carry many diseases of which Lyme disease and tick-borne encephalitis are among the best known. Some diseases are carried by more than one species of tick, and some ticks transmit more than one disease. Venomous

spiders are a hazard to many people and insect vectors carry diseases, including malaria, that affect people and other animals, whether those animals are pets, domesticated, or wild species.

Some plants cause more direct harm to people. Plant sap sometimes contains toxic chemicals known as furanocoumarins, which in the presence of sunlight cause phytophotodermatitis: a reddening of the skin, often followed by severe burns and blistering. The burns can last for several months, but even the skin can remain sensitive to light for many years. Toxic plants and fungi may enter the human food chain by being mistaken for edible varieties.

Much emphasis has been placed on the positive aspects and health benefits of urban greenspace. The health effects of nature are usually discussed in terms of stress reduction and attention restoration theories. Even passive viewing of natural environments after psychophysiological stress helps to reduce stress and may later confer health benefits. Contact with nature, or natural views, can confer psychological wellbeing benefits through attention restoration. Thus stress recovery and attention restoration may be central to understanding other psychological wellbeing benefits gained from contact with vegetated urban spaces.

As people have become more aware of the dangers of obesity, heart disease, and high cholesterol levels in urban societies, the lists of the positive health and wellbeing aspect of activity and exercise, of the gentlest kind, in blue- and greenspaces in towns and cities have grown markedly. These benefits are now being expressed in the terms of hypotheses that urban ecology research should be able to test, confirm, or refute.

The way vegetation is arranged and managed in parks and neighborhoods considerably affects how people engage in health-promoting physical activities. Theories relating to visual aesthetics can be linked to visual concepts that are important in landscape design and landscape architecture as they shape the landscapes that are produced. Often the most important issue is that of the perceived safety of the place used for the physical activity. High levels of vegetation do not necessarily equate with more physical activity. The pattern of this vegetation is critical; if vegetation is planted and allowed to grow in ways that limit the ability to visually and physically access one's immediate surroundings, then fears of being in a potentially unsafe environment may override any motivation to use the space for physical activities.

Urban agriculture provides multiple ecosystems services, helping to improve health by providing better nutrition and by the exercise involved in cultivating the crops. In more developed countries urban household gardens supplement dietary intake and reduce overall household expenditures on food. In poorer cities, urban agriculture provides food that people cannot afford to buy.

Recreational gardening helps people to relax and releases stress. It is widely used in prisons and hospitals to help inmates and patients recover. General public health is improved by involvement in converting run-down, unkempt, garbage-laden urban neighborhoods into vegetable gardens. Such beneficial interactions of ecological and social change are now at the heart of urban ecology. When low-income neighborhoods and market gardeners become involved in transforming their urban landscapes and claiming for themselves a sense of pride and place, urban agriculture becomes a forceful empowerment strategy for community participation and social change.

Poor housing conditions create urban habitats that affect public health. They are associated with a wide range of health conditions, including respiratory infections, asthma, lead poisoning,

injuries, and mental health. Specific relationships are well understood; for example, hospital admissions for chronic obstructive pulmonary disease (COPD) are often higher from crowded older buildings in the heart of a city where urban heat island intensity, and vehicular traffic and air pollution levels, are also higher than elsewhere.

Ecology in cities

Modern urban ecology drew its inspiration from detailed studies of urban flora and fauna, particularly in Berlin where Herbert Sukopp established the Institute of Ecology, which concentrated largely on botany and vegetation, with a strong emphasis on the phytosociology of urban areas (Sukopp 2008); and in Warsaw where Maciej Luniak (2004) and colleagues concentrated mainly on animal ecology. Comprehensive biotope mapping in Berlin provided the ecological basis for a land-use plan that incorporated nature conservation. No other city has been subject to such close ecological investigation, which has laid firm foundations for studying plant ecology in urban areas. In Warsaw, since about 1970, at least 12 new bird species and two mammal species have colonized densely built-up areas. In Europe as a whole, the most well-known species that have been more successful in urban areas than in their native natural habitats are the blackbird, magpie, hooded crow, kestrel, grey squirrel, striped field mouse, rabbit, and red fox. This process of synurbanization shows that there are chances for some kind of coexistence between nature and the expansion of urban civilization. Nevertheless most cities show some loss in species diversity as many birds and mammals disappear from the new suburban areas where they once lived.

In terms of flora, central European urban areas are rich in alien plants, which account for a mean of 40% of all species, their representation being 13.7% higher than their representation in the total species pool available in the region (Pyšek 1998). Compared to natural habitats, the difference is greater, a group of Czech nature reserves having an average of 9.8% aliens. The cities are thus the habitat that is richest in alien species, and serve as an important source of aliens (often invasive) for smaller settlements and further spread into rural areas.

The changes in urban flora depend on the pattern of succession on particular substrates, emphasizing the importance of natural and artificial soils (often termed "made ground") in the character of naturally colonized urban vegetation. For example, in the Czech Republic, after 12 years of succession, native woody species dominated ruderal (landfill) sites, with *Populus tremula* on nutrient poor sites and *Sambucus nigra* and *Salix caprea* on moderately rich nutrient sites. Similar trends over five years were noted in a Berlin experiment, with *Betula pendula* and *Populus nigra* succeeding on sandy soils, and annuals giving way to biennials and perennials on topsoils. Work of this type generally leads to two hypotheses: the urban environment and land transformation create unique environmental conditions to which species have to adapt to survive and mature, and the loss of native species and increase in non-native species, with increasing urbanization, leads to biotic homogenization with the same urban-adaptable species being found in widely separated cities.

The hypothesis of unique environmental conditions needs testing by paying attention to urban geomorphology and urban soils, looking at the ground on which the city is built and in particular paying attention to the deposits and surface materials created by past urban land uses. In this way urban ecology has links to geological concerns for the Anthropocene and geomorphological concerns about artificial landforms and sediments. Above all, the species occupying particular sites reflect the local biogeochemistry.

Gardens are a particular type of Anthropocene environmental change. They reflect cultural aspirations, human needs for food and relaxation, ambitions to acquire the novel and exotic, and desires to express personality and wealth. Sometimes they are made up entirely of materials, including soils and rock, brought onto the site and are planted with exotic non-native species. At others they are but the slightest modification of what would have been there naturally. Detailed work from 1972–1986 in a garden in Leicester, England, noted 2204 species, including 422 species of plants, 1602 insects, 121 other invertebrates, and 59 vertebrates. Further work on the mosaic of habitats and landscape in suburban gardens has found 1166 vascular plant species, of which 30% were natives, together with some 80 lichen species and 68 bryophyte species across 61 gardens in the United Kingdom. Generally along rural–urban gradients, the species richness of some major taxa (particularly plants and birds) commonly exhibits a peak in suburban areas where there is greater habitat heterogeneity, much of it contributed by suburban gardens.

The manipulation of habitats in urban areas provides opportunities to experiment in designing with and for nature. These planned interventions include restoration ecology and creative conservation, and lead to recombinant ecology. Restoration ecology seeks to provide a scientific basis to inform the practitioners working to restore areas affected by overexploitation, farming, industry, or natural catastrophe. The conservation of existing habitat and the restoration of degraded, damaged, or destroyed habitat, through restoration ecology, provide ways to address the trend for habitat loss, species extinction, and the decline of ecosystem services. Practitioners of ecological restoration employ a wide range of techniques including removal of non-native species and weeds, revegetation of disturbed areas, reintroduction of native species using stock with a known local provenance (to ensure, as far as possible, that the genetic diversity of the introduced plants and animals is as close to the naturally occurring population as possible), reforestation, erosion control, daylighting streams, as well as habitat and range improvement for targeted species. Restoration ecology uses ecological theories that guide landscape managers and others to put degraded and disused land into a better ecological condition which will provide habitats for plants and wildlife. Restoration ecology draws on a wide range of ecological concepts, including those of disturbance, succession, fragmentation, ecosystem function, adaptive capacity, and resilience (Pickett, Cadenasso, and McGrath 2013).

Restoration can aim simply to restore and enhance biodiversity, or it can be seen as integral to urban regeneration and environmental improvement, for example in assisting towns and cities to adapt to climate change. Specific examples of the benefits of ecological restoration include the development of wetlands to control water distribution and quality, and of wildflower meadows to enhance the attractiveness of former mown urban grassland, and the establishment of urban forests to provide both wildlife habitat and the potential for wood production by coppicing. Ecological restoration is of great value in areas of changing land use, such as abandoned landfills and mine waste tips, contaminated land, and former industrial sites.

Creative conservation is the introduction of species to new situations and the reintroduction of species to habitats where they have become extinct. In many cases it is simply conserving nature in an adaptive fashion so that ecosystems can respond to changing environmental conditions. In others, it is the reworking of land to introduce either animals that have been bred in captivity for reintroduction to the wild, or plants, particularly wildflowers, that have been

prepared in nurseries or experiment stations to yield seeds or seedlings to be sown in specially prepared areas.

In the United Kingdom creative conservation establishes novel ecosystems that may be totally different from what existed before urbanization or may reintroduce native species onto previously used urban sites (brownfield land). It differs from restoration ecology in not directly attempting to put areas back to some ideal previous condition, but to make an area more attractive to both the local human population and wildlife, such as planting wildflowers meadows around the apartment blocks and row houses of social housing estates. It redesigns the urban landscape for both ecological and social goals.

Ecology *in* cities thus involves classic botany, zoology, and habitat analysis, but looks in particular at the diversity of ecological situations in urban areas and at ways of improving and managing those habitats for the benefit of wildlife and people. In creating novel ecosystems and deciding what to do about those that have developed naturally, urban managers have to balance people's landscape tastes and preferences against municipal and private budgets for greenspace care and management. In so doing they are designing future urban geographies under constraints that are often external to their own environment and beyond their control.

Ecology of cities

Studies of the ecology of cities are interdisciplinary and multiscale, incorporating both the ecological and the human dimensions of urban ecosystems. They comprise three broad categories of thinking:

1 *ecology of the physical urban system*, including the wide range of people-impacted or modified environmental patterns and physical flows, affecting organisms and their habitats, in and through the city, and through urban systems on a regional, national, and global scale;
2 *ecology of the social-economic urban system*, involving the range of human activities that are in various ways associated with ecosystem and environmental processes, including industrial ecology, ecological design, and ecosystem service markets;
3 *ecology throughout the human–environment system*, embracing social, economic, cultural, and political patterns and relationships in the human ecology sense of a community of interdependent processes in both human systems and ecosystems.

The CAP LTER studies in central Arizona examine how, in a dynamic environment, the services provided by evolving urban ecosystems affect human outcomes and behavior, and how human actions (responses) alter patterns of ecosystem structure and function, and ultimately urban sustainability.

Ecology for cities

Urban ecosystem services involve scientific, philosophical, political, and practical concerns for urban ecology because, although it is clear that nature provides benefits to humanity and that without those benefits human development cannot continue, organizations promoting nature in cities are being asked to quantify the value of urban greenspaces in terms of the provision of those services. Many of the services are appreciated only by sections of the total population, so valuation is linked to preferences that are difficult to establish equitably. Many of the commonly cited environmental benefits of urban greenspaces remain poorly supported by empirical evidence. Benefits to one group of

people may be ecosystem disservices to another. Some social groups seldom use particular parks, and for many individuals urban woodlands can be "landscapes of fear." Thus the complexity of urban socioecological systems impinges directly on applying urban ecology.

Local issues of urban design are but one concern. Urban ecology has a central role in the debate about urban futures. Preparing urban settlements for the future involves both creating new eco-towns or eco-cities embodying sustainable lifestyles and smart technologies, and adapting existing settlements to environmental, social, and economic changes by increasing their resilience and sustainability. Green technologies and green spaces are integral to both processes, involving everything from green roofs and green walls to sustainable drainage and urban wildlife reserves.

Globally, urban ecologists are asked to contribute to establishing sustainable and resilient urban areas. Planners, architects, designers, decision-makers, and society expect urban ecologists to be able to offer guidance based on locally relevant ecological information; and, from that, they expect to derive general principles that can be applied more widely, even globally. This is no small challenge. It requires an understanding of the ecological patterns found within urban areas and the processes operating in them, which are very different from the traditional study of urban ecology.

Urban ecology is evolving rapidly with developments in both theory and practice. In working with complex socioecological systems, it is developing new opportunities for sound practice and good urban management. Some of the key elements of an emerging philosophy of adaptive practice for ecological design to help develop existing urban areas into resilient future cities (Pickett, Cadenasso, and McGrath 2013) include:

- using ecological knowledge to improve ecological urban design and to avoid dependence on green, or "eco," ideology;
- recognizing that urban agglomerations or metacities (complexes of cities, suburbs, peri-urban and ex-urban areas) are spatially extensive, dynamic mosaics, in which flows, distant connections, historic legacies, and the impacts of innovation, redevelopment, and crisis act in localized explicit ways;
- seeing how design affects flows, creating both obvious and inconspicuous or unintentional feedbacks, some of which have the potential to enhance the adaptive capacity of affected areas;
- avoiding the unintended or inconvenient negative effects of designs that produce environmental injustice for sectors of the population;
- using art as a powerful tool for linking design with its ecological implications, to engage the public and decision-makers in the environmental flows and feedbacks that exist in urban systems;
- using socially and politically constructed narratives to help incorporate ecological awareness and knowledge into design processes;
- anticipating changes resulting from feedbacks and from wider-scale factors such as climate, human and biotic migrations, and shifting economic investments in order to include adaptive processes and structures in metacities (urban agglomerations of over 10 million inhabitants) by design as a key tool for resilience;
- using landscape as a shared medium, coupled with the consideration of designs as experiments, to make the learning aspect of design more explicit;
- assessing the ecological effects of proposed projects as part of a process of evaluation–feedback–revision in design and construction;

- constantly appraising impacts of urban growth, change, and adaptation on the hydrological systems to cope with floods and droughts, contamination, treatment, storage, sea level rise and coastal change.

Urban ecology for future cities

Urban ecosystems depend on both natural and anthropogenic substrates, and are highly affected by air, soil, and water pollution. They help to control runoff and reduce the urban heat island effect. They contribute to human health. Although some air and water pollutants may be trapped by trees and aquatic vegetation, in terms of air quality the benefits of urban tree planting programs may be overstated. The great scientific challenges in urban ecology are coupled with the social, cultural, political, and economic challenges of fitting proposed actions into socioecological systems. Studies of urban socioecological systems, for example in Baltimore, United States, and in Cape Town, South Africa, reveal that many urban ecological hypotheses, such as that biodiversity is lower in urban areas than in rural areas, are not valid. They emphasize that the diversity of urban areas has arisen through cultural and social diversity and the different values people place on particular urban greenspaces. Within large urban settlements, biodiversity and biogeochemical characteristics may differ along gradients between the truly rural and the intensely built-up urban core. New frameworks for urban ecology are being proposed to cope with this diversity and complexity, but they are not necessarily transferable from one continent to another in an age where the largest and densest urban populations tend to be found in the high-density but low-rise cities of Asia and Africa. The human impacts of environmental and ecological conditions and changes are most severe in the poorest cities, but the bulk of research on urban ecology is carried out in the more affluent cities. As in many areas of geography, the most salient urban ecological work in Asia, Africa, and South America is on immediate applied issues, aiming to alleviate the worst conditions and to improve health and wellbeing through environmental and changes. Many lessons can be learned from past experiences elsewhere, but all too often political action only happens after a local disaster. Urban ecology can help to avoid some of the disasters, but without relevant local case studies it is difficult to persuade decision-makers that things can be improved. There are real opportunities and challenges in setting new priorities for urban ecology, for action not criticism, for solving problems not political theorizing.

Globally, urban ecologists are asked to contribute to establishing sustainable and resilient urban areas. Practitioners and society generally expect urban ecologists to offer guidance based on locally relevant ecological information, and from that to derive general principles that can be applied more widely, even globally, despite the major differences in natural and social conditions affecting the world's urban places.

SEE ALSO: Built environments; Chicago School; Climate change adaptation and social transformation; Ecological footprint; Ecosystem services; Health and wellbeing; Sustainable cities

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