Chapter 27

Urban Systems

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BOXES

FIGURES

TABLES

*This appears in Appendix A at the end of this volume.

Main Messages

Urbanization and urban growth continue to be major demographic trends. The world's urban population increased from about 200 million (~15% of world population) in 1900 to 2.9 billion (~50% of world population) in 2000, and the number of cities with populations in excess of 1 million increased from 17 in 1900 to 388 in 2000. As people are increasingly living in cities, and as cities act as both human ecosystem habitats and drivers of ecosystem change, it will become increasingly important to foster urban systems that contribute to human well-being and reduce ecosystem service burdens at all scales.

Urbanization is not in itself inherently bad for ecosystems. Many ecosystems in and around urban areas are more biodiverse than rural monocultures are, and they can also provide food, water services, comfort, amenities, cultural values, and so on, particularly if they are well managed. Moreover, urban areas currently only account for about 2.8% of the total land area of Earth, despite containing about half the world's population.

Urban demographic and economic growth has been increasing pressures on ecosystems globally, but affluent rural and suburban living often places even more pressure on ecosystems. Dense urban settlement is considered to be less environmentally burdensome than urban and suburban sprawl are. At the same time, urban centers facilitate human access to and management of ecosystem services through, for example, the scale and proximity economies of piped water systems.

Urban development trends do pose serious problems with respect to ecosystem services and human well-being. Ecosystem processes that provide services to urban residents tend to be neglected as a result of the continued lack of understanding and appreciation of the complex processes involved, many of which take place at some distance from the urban consumers; the difficulties that private enterprises encounter in owning, trading, and negotiating over ecosystem services (and burdens), which rarely conform to property boundaries; the difficulties that public agencies encounter in managing and regulating ecosystem services, which also tend to cross administrative and sectoral boundaries; and the fact that the people most adversely affected by the loss of ecosystem services tend to be the least influential economically and politically (such as the urban poor, future generations, and residents living far from where the decisions are being made).

The problems documented in this chapter include severe environmental health problems within urban settlements resulting from inadequate access to ecosystem services (such as clean water), the degradation of ecosystems adjoining urban areas resulting from urban expansion and demands, and pressures on distant ecosystems resulting from urban production, consumption, and trade. In affluent countries, the historical trend has been for the negative impacts of urban settlements on ecosystem services and human well-being to become more delayed and dispersed. Urban developments in other parts of the world have been taking place in a different technological and economic context, with different environmental consequences, but this trend is still globally significant.

Interrelated problems involving local water, sanitation, waste, and pests still contribute a large share of the urban burden of disease, especially in low-income countries. This typically reflects a combination of degraded or increasingly scarce ecological services generated within the urban area, minimal infrastructure (such as water pipes) tapping more-distant ecosystem services, and differential access to the ecological and derived services available within the urban area.

Problems relating to the degradation of ecosystems adjoining urban settlements are undermining their capacity to supply ecosystems services, especially in and around large, industrializing, and motorizing cities (often of middle income). This typically reflects a combination of the geographic displacement of intraurban environmental scarcities and "wastes" and increasing levels of activities using or degrading ecosystems.

The consumption and production activities that are driving long-term, global ecosystem change are concentrated in urban centers, and especially those located in upper- and middle-income countries. This typically reflects a combination of environmental displacement and increasing rates of direct and indirect consumption of energy, materials, and ecosystem services.

Although there are many examples of successful responses to urban environmental challenges, concerted responses (such as sanitary reform in many cities in the nineteenth century) have been motivated by serious crises rather than by precautionary planning and have often succeeded by displacing rather than eliminating the environmental burdens. As an increasing number of urban environmental burdens, particularly from affluent urban centers, are likely to fall on future generations and are already of global scale (such as urban emissions of greenhouse gases), past successes based on displacing the burdens spatially are of declining relevance.

When urban systems are managed more equitably and the loss of ecosystem services is purposefully addressed, the benefits to human well-being can be substantial. It is *well established* that motivated governmental and nongovernmental agencies can implement radical changes in local environmental management that reduce local burdens and benefit vulnerable groups. The experience of urban sanitary reform provides strong evidence for this. At the same time, the historical record also illustrates a tendency to displace the burdens spatially and temporally.

The regulation of urban air and water pollution, in part motivated by popular pressures, has also resulted in better air and water quality in and around cities in some parts of the world, although again there is a tendency to displace the burdens spatially and temporally.

There is comparatively little evidence of significant steps to reduce the global ecosystem burdens of cities, although there are many examples of measures that, if replicated on a large scale, would result in appreciable reductions in those burdens.

27.1 Introduction

Urban systems are centered in urban areas; in terms of ecosystem services, urban areas are primarily sites of consumption. This contrasts with the other systems assessed in this report (such as cultivated systems, drylands, and coastal systems), which primarily generate and supply ecosystem services. Urban systems exist at several scales and can be identified with individual urban settlements or networks of such settlements.

Urban settlements are agglomerations of people and their activities; although urban areas may contain a wide variety of species, it is the humans that make them urban. About half the people in the world live in areas defined as urban (see Box 27.1 for definitions), up from less than 15% at the start of the twentieth century. Combined with population growth, this has meant an almost fifteenfold increase in the world's urban population, from 200 million in 1900 to 2.9 billion a hundred years later. Over the same period, the rural population more than doubled, increasing from 1.4 billion to 3.2 billion (United Nations 2002).

The share of Earth's land area that is urban is also growing, but it remains only about 2.8% (this figure is based on the urban-rural mapping described later). Urbanization has, however, in-

BOX 27.1

Defining Urban Areas and Populations

In line with other MA systems (such as cultivated, dryland, and mountain systems), urban systems are associated with particular spatial locations, in this case urban areas. Urban areas are in turn associated with urban settlements and populations. This Box focuses on how urban areas and populations are distinguished from rural areas and populations. There are no hard and fast rules on this; although conceptual clarity is important, it must also be recognized that the dividing line between urban and rural is inevitably somewhat arbitrary. For example, many people move regularly between locations classified as urban and rural.

It is generally agreed that urban agglomerations (cities and other urban centers) tend to have larger populations than rural agglomerations (villages) do, are more likely to be the site of large facilities (such as hospitals) and higher-level administrative functions (national or local government offices, for example), and create comparatively densely settled areas, with a higher share of built-up area. Furthermore, urban residents are less likely to work in agriculture and more likely to work in industry or services. It is also agreed that there are more and less urban lifestyles and cultures. There is no international agreement, however, on the defining characteristics of urban, nor are there any scientifically accepted criteria by which to identify urban areas and populations. Moreover, many urban researchers believe that the distinction between rural and urban is becoming less relevant (Cohen 2003) and that the boundary definitions are inevitably somewhat arbitrary.

Cut-off points for identifying urban areas or populations vary within the different criteria. Minimum population density criteria commonly range between 400 and 1,000 persons per square kilometer; minimum size criteria typically range between 1,000 and 5,000 residents; and maximum agricultural employment is usually in the vicinity of 50–75%. In each case, however, cut-off points outside these ranges can easily be found.

According to a recent report on world urbanization prospects (United Nations 2002), 109 of the 228 countries covered use an administrative criterion to distinguish urban from rural localities, and 89 of these use it as the sole criterion. Population size or density was used as a criterion in 96 countries, and as the sole criterion in 46. The administrative and population-based criteria are themselves different in different countries: for example, the lower limit above which a settlement was considered urban ranged between 200 and 50,000 persons.

There are also differences in the manner in which localities are identified and settlement populations calculated. Some countries report city populations on the basis of the boundaries of the city proper; others in terms of a metropolitan area; and still others in terms of a (usually larger) urban agglomeration. These differences have persisted for many years. In the 2001 revision of the U.N. report, about half the countries in the world used estimates based on "city proper," with most of the remaining claiming to be applying the concept of urban agglomeration.

Although country-specific definitions will remain central to defining and assessing urban centers for many years to come, the basis for a more uniform definition is emerging from work using remote sensing and geographical information systems. This chapter relies on two different delineations of urban to examine urban conditions and trends: one based on the country-specific definitions used by the United Nations, and the other based on a preliminary urban-rural split developed as part of a broader mapping and indicator exercise being undertaken by the Center for International Earth Science Information Network (Balk et al. 2004).

The country-specific definitions provide the basis for the statistics on historic urban populations and short-term projections, as well as a number of the descriptive statistics on urban population, such as the share with access to improved water sources. The geospatial estimates are used for the map in Figure 27.1 and for the Tables situating urban populations in relation to coastal zones, dryland, mountains, and other MA system categories. Although the geospatial estimates remain provisional and are unlikely to be adopted by national governments in the foreseeable future, they have a number of potential advantages, including better international comparability and local verifiability, as well as the ability to portray, for example, how sets of urban centers themselves are concentrated spatially.

Many economic and social characteristics once considered quintessentially urban are increasingly found among residents of what must demographically be classified as rural areas. Alternatively, many people living in large cities do not have access to what is sometimes considered defining "urban" infrastructure, such as piped water and sewerage. Such phenomena are important to recognize, but for the purposes of this chapter people are identified as urban or rural depending on their primary residence rather than their economic or sociocultural characteristics. Thus, for example, a Kansas farmer living in a rural area but with "a university degree, hooked up to the Internet and a fax machine, with a barn full of expensive machinery, who keeps strict accounts and sells his grain on the Chicago Mart" (Friedmann 2002) would be identified as a rural person with the accoutrements of an urban lifestyle rather than an urban person living in a rural location.

volved profound changes in human ecology, and urban land area is a very poor indicator of the ecological significance of urban systems.

As illustrated in Figure 27.1 (in Appendix A) (see also Table 27.6, later in this chapter), urban settlements are themselves concentrated regionally. Africa and Oceania have the lowest shares of area in urban systems, whereas Asia has the largest. Within regions, there is also a high degree of variation. The global map also indicates that urban areas tend to be on or near the coasts.

Human systems within urban boundaries are not functionally complete ecosystems. Urban areas have been described as the human equivalent of the livestock feedlot: a spatially limited area characterized by a large population of humans living at a high density and supported by biophysical processes mostly occurring somewhere else (Rees 2003). Large urban agglomerations, or cities, are intense nodes of energy and material transformation and consumption. However, the biologically productive part of the human ecosystem, which sustains both the human and the industrial metabolism of the city, is located primarily in rural areas, as well as in oceans and other uninhabited locations. Urban dwellers still rely on rural residents to transform and tap these rural ecosystems, and much human activity in rural areas responds to urban demands. Historically, the development of urban centers has been tightly bound up with changes in the surrounding ecosystems (Cronon 1992). Increasingly, urban systems are also linked to more distant ecosystems scattered across the globe.

Although it is the concentration of humans that makes an area urban, urban areas are also home to many nonhuman species. Many studies of urban ecosystems have focused on these species and their relations with each other and with nonliving components of the urban environment. (See Box 27.2.) These may include, for example, forest, wetland, or grassland ecosystems that exist in and around cities and towns. These ecosystems provide services to humans, such as recreation in urban parks and fresh

BOX 27.2

Chapter Topic: Ecosystems in Urban Systems, Urban Systems as Ecosystems, or Ecosystems and Urban Systems?

There is a significant literature on ecosystems within urban areas and an emerging literature on the ecology of urban areas, treating urban systems as ecosystems (Hejný et al. 1990; Platt et al. 1994; Pickett et al. 1997; Brennan 1999; Grimm et al. 2000; Pickett et al. 2001). Whereas the former is consistent with traditional ecosystems analysis, which has treated human activity as disturbing rather than constituting ecosystem dynamics, the latter is more consistent with the MA, which clearly situates humans within ecosystems (MA 2003).

This chapter does not restrict itself to examining the conditions and trends of ecosystem remnants in and around urban centers, nor does it rely on treating urban systems as ecosystems or treat all urban services as ecosystems services. Related to this, although it is accepted that urban systems have social as well as biophysical dimensions, ecosystems are understood to be biophysical systems, and the value of ecosystem services is assumed to be distinct from the value intentionally added through the application of human labor. Thus the urban conditions and trends of primary concern in this chapter are biophysical; social conditions and trends that do not have clear relation to these biophysical conditions and trends are not examined in any detail, even when they have important implications for human well-being.

As the result, this chapter only covers some of the ways in which urban development affects human well-being. There is no mention of urban violence, for example, and urban inequality is only considered to the extent that it affects access to or pressures on ecosystem services. Similarly, there is no systematic treatment of the benefits that derive from urban manufacturing or commercial services, except to the extent that they rely upon ecosystem services, as defined in the glossary of this report.

water from nearby watersheds, some of which are difficult to appropriate from ecosystems that are farther away.

Understanding these ecosystems in urban areas can not only help with ecosystem management within urban areas, it can also help us understand how urban systems function more broadly (Berkowitz et al. 2003). From this perspective, not only are urban systems characterized by a varied landscape, consisting of a range of ecosystems and habitats, but the shift from rural to urban can be conceived of in terms of a series of gradients rather than a single threshold or boundary. Typical rural-urban gradients include not only increasing human population density and increasing shares of impermeable land cover, but also decreasing population density for many nonhuman species (McDonnell and Pickett 1991, 1997; Blair 1996; Natuhara and Imai 1996; Rolando et al. 1997; Denys and Schmidt 1998; Luck and Wu 2002) as well as changes in species diversity. The dynamics of ecosystem change in and around urban centers are also influenced by a number of features characteristic of how urban landscapes change, such as a high rate of introduction of alien species, high habitat diversity and fragmentation, and a high rate of (human-induced) habitat disturbance (Rebelee 1994; Niemela 1999).

Humans themselves are host to many microorganisms; changing urban settlement patterns influence the relations between humans and these microorganisms, some of which cause human diseases. Just as early shifts from hunting and gathering changed the infectious disease profile of early agriculturalists, changing patterns of human movement and settlement are still influencing infectious as well as noninfectious diseases (Anderson and May 1991; McNeill 1993). (See also Chapters 13 and 14.)

Shifts in the drivers of change in urban systems at very different scales often combine to create new challenges for humans. Urban development and trade, for example, enabled the epidemics that devastated Europe in the Middle Ages and introduced people in large parts of the world to infectious diseases they had never encountered and to which they were particularly susceptible (McNeill 1989). The affluent cities of the nineteenth century spearheaded industrialization and economic "modernization," but on average the people living in these cities lived shorter lives than did their rural contemporaries (Bairoch 1988; Woods 2003). The emergence and spread of HIV/AIDS toward the end of the twentieth century has itself been an urban-centered phenomenon, with large urban populations one of the conditions resulting in its emergence as a significant human disease and with a higher urban than rural prevalence in sub-Saharan Africa, where there are indications that it is beginning to affect urbanization levels (Dyson 2003). Despite all these challenges and setbacks and the significant number of countries where life expectancies have declined in recent years (McMichael et al. 2004), on average people living in urban centers today live longer and healthier lives than ever before.

Urban areas are more spatially scattered than most other systems assessed in the MA. On the other hand, urban centers are closely interlinked. Indeed, geographers have long viewed urban systems not as individual settlements but as networks of urban centers connected by flows of capital, people, information, and commodities regionally (Armstrong and McGee 1985).

27.1.1 Classifying Urban Settlements: Size, Economic Status, and Location

Of the many ways of classifying urban settlements, three of the most common are population size, economic condition, and location. All three are used in this chapter, with the particular emphases as described in this section.

27.1.1.1 Urban Population Size

Table 27.1 summarizes the distribution of the world's population by the population class of urban settlement in the year 2000, according to both the 2001 revision of *World Urbanization Prospects* from the Population Division of the United Nations (United Nations 2002) and the urban-rural mapping undertaken by the Center for International Earth Science Information Network in support of the MA (Balk et al. 2004). As indicated, and contrary to some of the more inflated rhetoric about "exploding cities," more than half of the world's urban population lives in settlements of less than half a million inhabitants, and well under 10% live in cities of more than 10 million. Because of the higher densities of the latter, the share of urban land area accounted for by these large cities is considerably less than this. As described in later sections, however, even these figures reflect a continuing demographic shift toward urban living, and toward large cities in particular, that is having a profound effect on both the socioeconomic organization of the human world and the biophysical organization of the world as a whole.

Although settlement size is clearly related to the ability of an urban center to play certain roles, the size distributions of urban settlements show little evidence of clustering around certain sizes.

Table 27.1. Distribution of World Population by Size Class of Settlement, 2000 (CIESIN et al. 2004a, 2004b; United Nations 2002)

Size Class of Urban Settlement	UN Total Population (million)	GRUMP[a] Total Population (million)	GRUMP[a] Settlements (number)	GRUMP[a] Population Density (persons per sq. km.)	UN Share of Total Population (percent)	GRUMP[a] Share of Total Population (percent)
Urban area	2,862	2,828	24,176	770	47.3	46.7
10 million or more	225	426	23	2,192	3.7	7.0
5 to 10 million	169	265	39	1,571	2.8	4.4
1 to 5 million	675	729	353	1,223	11.1	12.0
500,000 to 1million	290	280	395	821	4.8	4.6
under 500,000	1,503	1,128	23,366		24.8	18.6
100,000 to 500,000		568	2,792	706		9.4
50,000 to 100,000		223	3,199	517		3.7
20,000 to 50,000		229	7,297	419		3.8
5,000 to 20,000		108	10,078	183		1.8
Rural area	3,195	3,224		25	52.7	53.3
Total	**6,057**	**6,052**		**46**		

[a] Global Rural-Urban Mapping Project.

Instead, in many countries there is an approximately log-linear relationship between a ranking of the sizes of urban settlements and their actual populations. This has come to be known as the rank-size distribution. When the slope is exactly negative one, this implies that the largest city is twice the size of the second largest, three times the size of the third largest, and so on. The claim that the slope does tend to be exactly one is sometimes referred to as Zipf's Law and appears to hold for some countries, such as the United States. More generally, although the slopes may vary over time and between countries, given comparable definitions and criteria for including urban centers, rank size distributions do generally conform to a log-linear relation (Brakman et al. 2001).

27.1.1.2 Urban Economic Conditions

Economic conditions are not quite such obvious features of an urban center as its population size and are less easy to define and measure.

Table 27.2 summarizes the distribution of urban population based on the World Bank's classification of low-, lower middle-, upper middle-, and high-income countries. In principle, national income accounts can be adapted to urban centers and used to calculate the urban equivalent of GNP and GDP per capita. Because the required statistics are often not available at the appropriate level, however, it is more common to refer to the per capita income of the country where the urban centers are located. This will tend to be lower than the average income of the urban population, because in most countries average incomes are higher in urban centers than in rural areas, and in some countries the disparities are very significant (Eastwood and Lipton 2000).

As indicated, urbanization levels are higher in higher-income countries, although even in low-income countries almost one third of the population lives in urban areas, and about 60% of the world's urban population lives in low- or lower middle-income countries, implying a national income of less than $3,000 per capita in 2001.

Table 27.2. Population in Urban Areas and Percentage of Total Population That Is Urban, 2000. Economies are divided according to 2001 GNI per capita, calculated using the World Bank Atlas method. The groups are low-income, $745 or less; lower-middle-income, $746–2,975; upper-middle-income, $2,976–9,205; and high-income, $9,206 or more. (Based on figures from www.world bank.org/data/countryclass/countryclass.html in May 2003; data on percentage urban based on United Nations 2002)

Economy Group	Urban Population (million)	Share Urban (percent)
Low-income countries	718	31.2
Lower-middle-income countries	949	44.6
Upper-middle-income countries	365	77.0
Upper-income countries	731	79.2
Undesignated	99	41.7
World	**2,862**	**47.2**

27.1.1.3 Urban Location

In international statistics, urban location is conventionally summarized in terms of countries or regions. This typically means that coastal-zone settlements are combined with inland settlements, mountain with lowland settlements, and so on. Following a brief overview of the regional distribution, this section uses a newly constructed urban-rural database (Balk et al. 2004) to examine the distribution of urban populations in relation to the principal nonurban systems used in the MA. The bases for the system boundaries are summarized in Chapter 1. These systems are not mutually exclusive.

Table 27.3 provides a summary of urban population by continent, based on the regions used by the United Nations Population Division. The two lowest-income continents (Africa and Asia)

Table 27.3. Population in Urban Areas, and Share Urban, for World and Major Areas, 2000, Comparison of U.N. and GRUMP Statistics (CIESIN et al. 2004a, 2004b; United Nations 2002)

	UN		GRUMP[a]	
Region	**Urban Population**	**Share Urban**	**Urban Population**	**Share Urban**
	(million)	*(percent)*	*(million)*	*(percent)*
Africa	295	37.2	304	38.4
Asia	1,376	37.5	1,378	37.5
Latin America and Caribbean	391	75.4	352	67.9
Northern America	243	77.4	256	81.5
Europe	534	73.4	514	70.9
Oceania	23	74.1	22	70.8
World	**2,862**	**47.2**	**2,828**	**46.7**

[a] Global Rural-Urban Mapping Project.

are also the least urbanized. Whereas Latin America has conventionally been combined with Asia and Africa in discussions of ''developing countries,'' its level of urbanization is comparable to that of Europe and North America. Furthermore, the overall and urban population densities in Latin America are comparable (26 and 656 persons per square kilometer, respectively) to those found in Europe (32 and 588) and North America (17 and 289). In contrast, sparsely populated Africa (27 persons per square kilometer overall) has urban areas as dense as those found in densely populated Asia (120 overall): both over 1,250 persons per square kilometer. Rural densities tend to be fairly consistent by continent with the exception of Asia, where population densities are more than four times greater than that of any other continent.

The coastal system is disproportionately more urban than other systems assessed in the MA. (See Table 27.4.) Population densities in both urban and rural areas are especially high in coastal areas because of the services available from coastal systems and the access to transportation. The population density of urban areas in the coastal zones is about 45% greater than the average density of urban areas globally.

The coastal zone is also the system with the greatest share of urban land area (10.2% globally), as indicated in the far-right columns in Table 27.4. Cultivated agricultural systems and inland water zones also have urban land areas that are higher than average. It is noteworthy that in addition these systems are more densely populated than average. Coastal, cultivated, and inland water zones tend to support the world's largest cities, as shown in Table 27.5. Conversely, mountain, forest, and dryland systems tend to support smaller settlements than the other systems. However, as Table 27.4 also shows, coastal and inland water systems are less populated than cultivated zones and thus do not contain such large shares of urban dwellers.

Many of the differences between the MA systems globally are also evident within individual continents. (See Table 27.6.) In every continent except North America, for example, the highest shares of urban population and land are in the coastal zones; even in North America the figures for the coastal zone are well above the continent average. The differences are more accentuated in some continents than others, however. Thus, whereas populations of the coastal zones of Europe and North America are only slightly more urbanized than their continental averages (84% and 90% in the coastal zones, compared with 71% and 81% on average), in Asia and even more in Africa the differences are far more striking (56% and 72% in the coastal zones, compared with 37% and 38% on average). The net result, when combined with other factors, is that the two continents with the lowest shares of population living in urban areas have the greatest number of coastal urban dwellers per square kilometer of coastal zone.

Total urban population distribution also tends to reflect a region's underlying system characteristics. For example, more than

Table 27.4. Population Estimates, Densities, and Land Areas for MA Systems, by Urban and Rural (CIESIN et al. 2004a, 2004b)

	Population				Population Density			Land Area			
System	**Total**	**Urban**	**Rural**	**Share Urban**	**Overall**	**Urban**	**Rural**	**Total**	**Urban**	**Rural**	**Share Urban**
	(million)			*(percent)*	*(persons per sq. km.)*			*(square kilometers)*			*(percent)*
Coastal zone	1,147	744	403	64.9	175	1,119	69	6,538,097	664,816	5,873,281	10.2
Cultivated	4,233	1,914	2,309	45.3	119	793	70	35,475,983	2,412,618	33,063,350	6.8
Dryland	2,149	963	1,185	44.8	36	749	20	59,990,129	1,286,421	58,703,698	2.1
Forest	1,126	401	725	35.6	27	478	18	42,092,529	839,094	41,253,435	2.0
Inland Water	1,505	780	726	51.8	51	826	25	29,439,286	943,518	28,495,767	3.2
Mountain	1,154	349	805	30.3	36	636	26	32,083,873	548,559	31,535,242	1.7
World	**6,052**	**2,828**	**3,224**	**46.7**	**46**	**770**	**25**	**130,669,507**	**3,673,155**	**126,996,316**	**2.8**

Note: Population numbers for each ecosystem will not add to total as systems are not mutually exclusive. Island systems are excluded.

Table 27.5. Population and Share of Various Population Sizes in Urban Areas within Selected MA Systems, 2000 (CIESIN et al. 2004a, 2004b)

		Urban Population by Settlement Size							
System	Urban Population	5,000–20,000	20,000–50,000	50,000–100,000	100,000–500,000	500,000–1 million	1 million–5 million	5 million–10 million	10 million or more
					(thousand)				
Coastal zone	744,000	13,000 (1.7%)	28,000 (3.7%)	33,000 (4.4%)	112,000 (15.0%)	69,000 (9.2%)	196,000 (26.4%)	119,000 (16.0%)	175,000 (23.5%)
Cultivated	1,914,000	75,000 (3.9%)	175,000 (9.1%)	166,000 (8.6%)	411,000 (21.5%)	183,000 (9.5%)	484,000 (25.3%)	172,000 (9.0%)	249,000 (13.0%)
Dryland	963,000	39,000 (4.1%)	84,000 (8.7%)	88,000 (9.2%)	224,000 (23.3%)	111,000 (11.5%)	260,000 (27.0%)	71,000 (7.4%)	85,000 (8.9%)
Forest	401,000	22,000 (5.5%)	43,000 (10.7%)	37,000 (9.2%)	83,000 (20.8%)	41,000 (10.1%)	98,000 (24.3%)	26,000 (6.4%)	52,000 (12.9%)
Inland water	780,000	24,000 (3.1%)	49,000 (6.2%)	48,000 (6.1%)	151,000 (19.4%)	81,000 (10.4%)	193,000 (24.8%)	79,000 (10.2%)	154,000 (19.8%)
Mountain	349,000	21,000 (6.1%)	47,000 (13.3%)	35,000 (10.1%)	77,000 (22.1%)	34,000 (9.7%)	85,000 (24.4%)	25,000 (7.2%)	24,000 (7.0%)

Note: Urban population figures have been rounded to nearest million, therefore total population does not equal the sum of populations in all settlement sizes. Percent columns do not sum to 100. Island systems are excluded.

half of Africa's urban population lives in dryland or cultivated systems because these systems predominate in Africa, even though the total population of these systems is only about 20% urban. Similar patterns are observed globally. Further, predominating ecosystems—drylands in Africa, for example—may be home to Africa's largest cities, even though they tend to be less urban overall than other systems, simply by virtue of the size of the system (and the constraints imposed by political borders).

Although it is beyond the scope of this chapter to examine the differential impact of cities across the ecosystems they inhabit, which depends heavily on local conditions, monitoring urban locations in relation to ecosystems is a potentially important contribution to policy debate and decision-making. More attention needs to be paid to preventing or restricting urban growth where this threatens ecosystem services, such as in watersheds or ecologically fragile areas. It may also be possible to identify locations where cities can benefit more from ecosystem services. It should be kept in mind, however, that urban growth in a liberal market economy occurs where investors decide to locate job-creating enterprises rather than where planners decide that growth ought to occur. Political processes can influence urban development, but urban location is not itself a policy decision.

27.1.2 Urbanization Trends

During the twentieth century, the world's urban population increased almost fifteenfold, rising from less than 15% to close to half the total population. In most middle- and high-income nations, the majority of the population to live in and work in urban areas. Many aspects of urban change during the twentieth century were unprecedented, including the size of each region's urban population, the number of nations having predominantly urban populations and economies, and the size and number of very large cities. For Europe, North America, and parts of Latin America, the most rapid urban change was mostly in the first half of the century; for most of the rest of the world, it was in the second half. During the past 50 years, most nations in Africa, Asia, and Latin America experienced rapid urban change, including cities whose population grew more than tenfold, and a growing share of the world's urban population and its largest cities have been in Africa, Asia, and Latin America. (See Table 27.7.) By 2000, most of the world's largest cities were, once again, found in Asia, not in Europe and North America. (See Table 27.8.)

Although there have been numerous cities with over 1 million inhabitants during the past 2,000 years, until recently they were rare (at most only one or two within the world at any one time), and they still existed within predominantly rural societies, except for a few city-states. Only in the late nineteenth century did London emerge as the first city with several million inhabitants; the megacities with 10 million or more inhabitants only emerged in the second half of the twentieth century. By 2001, there were 17 of these (United Nations 2002). Only with the industrial revolution did the increasing concentration of population (and production) in urban areas become commonplace.

Changes in urbanization levels were underpinned by large economic, social, political, and demographic changes. The main driver of urbanization (understood as an increase in the proportion of a population living in urban areas) is economic growth; in general, the most urbanized nations are those with the highest per capita incomes, and the nations with the largest increases in their levels of urbanization are those with the largest economic growth. Decolonization and the development of independent nation-states had large influences on urbanization levels for all of Africa and much of Asia, in part as controls on the rights of the inhabitants to live in or move to urban centers were dismantled, and in part because the building of the institutions for independent governments increased urban employment. In some countries, such as Australia, colonizing populations concentrated in urban settlements from the start, resulting in somewhat different patterns

Table 27.6. Urban Population and Land Percentages and Densities by Selected MA Systems and Continent (CIESIN et al. 2004a, 2004b)

System	Africa	Asia	Latin America	Oceania	Europe	North America	World
Share of population that resides in urban areas							
				(percent)			
Coastal	71.5	55.7	82.1	89.2	83.7	90.4	64.9
Cultivated	40.5	36.6	68.8	71.1	71.6	97.5	45.3
Dryland	43.5	37.7	67.0	54.2	67.4	88.2	44.8
Forest	22.7	23.2	58.9	47.0	56.2	69.3	35.6
Inland water	51.2	41.3	74.6	80.5	79.1	85.3	51.8
Mountain	21.7	23.0	57.8	12.4	47.9	66.1	30.3
Overall	38.4	37.5	67.9	70.8	70.9	81.5	46.7
Urban land as share of total land							
				(percent)			
Coastal	5.4	13.0	8.8	3.3	11.6	11.6	10.2
Cultivated	1.8	6.9	4.6	1.9	9.7	13.0	6.8
Dryland	0.6	3.0	2.7	0.1	5.0	4.1	2.1
Forest	0.5	2.6	1.2	1.0	1.9	4.2	2.0
Inland water	1.2	5.0	2.8	1.0	3.2	3.8	3.2
Mountain	1.1	1.6	2.7	0.4	1.7	1.8	1.7
Overall	0.8	3.5	2.6	0.6	3.9	4.7	2.8
Urban population density							
				(persons per square kilometer)			
Coastal	2,123	1,934	789	610	640	497	1,119
Cultivated	1,279	1,352	548	300	630	258	793
Dryland	1,200	1,034	541	159	522	265	749
Forest	997	956	685	300	387	206	478
Inland water	1,647	1,536	655	451	604	302	826
Mountain	810	879	746	191	387	154	636
Overall	1,278	1,272	656	427	588	289	770
Average population density							
				(persons per square kilometer)			
Coastal	160	451	83	23	89	64	175
Cultivated	56	255	36	8	85	34	119
Dryland	18	82	21	0	39	12	36
Forest	23	105	14	6	13	12	27
Inland water	37	185	25	6	25	13	51
Mountain	42	60	34	6	14	4	36
Overall	27	120	26	4	32	17	46
Share of urban dwellers in cities over 1 million							
				(percent)			
Coastal	56.1	69.6	54.9	67.7	50.9	79.0	65.3
Cultivated	49.8	47.5	40.6	37.0	44.0	55.5	47.0
Dryland	50.3	41.6	39.4	27.2	38.4	59.6	43.3
Forest	25.9	39.9	53.7	39.9	36.7	54.8	42.9
Inland water	54.6	56.7	45.9	56.0	46.1	61.3	54.4
Mountain	19.8	34.1	59.8	0.7	23.3	46.5	38.5
Overall	45.9	50.6	49.3	57.4	44.5	61.5	49.8

Table 27.7. Distribution of World's Urban Population by Region, 1950–2010 (Satterthwaite 2002, with statistics from United Nations 2002)

Region	1950	1970	1990	2000	Projection for 2010
Urban population			*(million)*		
Africa	32	82	197	295	426
Asia	244	501	1,023	1,376	1,784
Europe	287	424	521	534	536
Latin America and the Caribbean	70	164	313	391	470
Northern America	110	171	213	243	273
Oceania	8	14	19	23	26
World	751	1,357	2,286	2,862	3,514
Share of population living in urban areas			*(percent)*		
Africa	14.7	23.1	31.8	37.2	42.7
Asia	17.4	23.4	32.2	37.5	43.0
Europe	52.4	64.6	72.1	73.4	75.1
Latin America and the Caribbean	41.9	57.6	71.1	75.4	79.0
Northern America	63.9	73.8	75.4	77.4	79.8
Oceania	61.6	71.2	70.8	74.1	75.7
World	29.8	36.8	43.5	47.2	51.5
Share of world's urban population			*(percent)*		
Africa	4.3	6.1	8.6	10.3	12.1
Asia	32.5	37.0	44.8	48.1	50.8
Europe	38.3	31.3	22.8	18.7	15.3
Latin America and the Caribbean	9.3	12.1	13.7	13.7	13.4
Northern America	14.6	12.6	9.3	8.5	7.8
Oceania	1.0	1.0	0.8	0.8	0.8

of urban growth. In general, rapid demographic growth influenced growth rates for urban populations but had little influence on urbanization levels.

Although the general trend worldwide is toward increasingly urbanized societies, the aggregate statistics in Tables 27.7 and 27.8 obscure the great diversity in urban trends between nations (and how these change over time) and within nations, especially the large-population nations. Nations may have been urbanizing more slowly than anticipated in the past two decades because of poor economic performance, but this may not register in the official estimates of countries that have not had recent population censuses. Many of the world's largest cities have had significant decelerations in their population growth rates and have much smaller populations in 2000 than had been anticipated. In 1978, for example, the United Nations Population Division projected Mexico City's population in 2000 to be 31 million and that of São Paulo to be 26 million, whereas the population of both these cities in 2000 was estimated at 18 million (Satterthwaite 2002).

Most of the world's largest cities either have key global roles (the command-and-control centers for global or regional economies) or are centers linking large national economies with the global economy. The exceptions tend to be national capitals or former national capitals in large-population nations (such as Cairo, Lagos, and Delhi), and there are also locations that have major roles in the global economy without very large cities, as shown by Zurich and Silicon Valley. However, the world's large cities will increasingly be those that are successful in concentrating enterprises able to compete in the global economy, and the low- and middle-income nations that urbanize most will be those with more successful economies (Satterthwaite 2002).

The low-income nations in Africa, Asia, and Latin America that do not have successful economies are unlikely to urbanize much unless civil conflict or famine drives people to urban centers. However, recent trends in Africa may appear to contradict this assessment. In the most recent U.N. Population Division figures for urban trends, it appears that most of sub-Saharan Africa continued urbanizing rapidly during the 1990s, despite very poor economic performance. However, a lack of reliable census data means that most urban population statistics for the region from 1990 onwards are based on projections from older census data. In many sub-Saharan African nations, there is only one census available between 1959 and the present; for many more, there are only two. In the most recent U.N. Population Division compendium of urban statistics (United Nations 2004), very few sub-Saharan African nations had new census data from the past 10 years. Thus it is likely that many sub-Saharan African nations urbanized much more slowly during the 1990s than the U.N. figures (based on projections) suggest.

Although most urbanization will take place in the nations with growing economies, this is likely to be less concentrated in very large cities than in the past, or at least less concentrated in what are today the world's largest cities. In successful economies with good transport and communications systems and increasingly competent local authorities outside the larger cities, new investment is often targeted outside the largest cities, and most large cities are also becoming more dispersed (McGee and Robinson

Table 27.8. Distribution of World's Largest Cities by Region over Time. The statistics for 2000 in this Table are an aggregation of national statistics, many of which draw on national censuses held in 1999, 2000, or 2001, but some are based on estimates or projections from statistics drawn from censuses held around 1990. There is also a group of countries (mostly in Africa) for which there are no census data since the 1970s or early 1980s, so all figures for their urban populations are based on estimates and projections. (Satterthwaite 2002; data for 1950 and 2000 from United Nations 2002; data for 1800 and 1900 from IIED database, drawn from various sources, including Chandler et al. 1974, Chandler 1987, and Showers 1979)

Region	1800	1900	1950	2000
Number of "million cities"				
Africa	0	0	2	35
Asia	1	4	31	195
Europe	1	9	29	61
Latin America and the Caribbean	0	0	7	50
Northern America	0	4	14	41
Oceania	0	0	2	6
World	2	17	85	388
Regional distribution of the world's largest 100 cities				
Africa	4	2	3	8
Asia	65	22	36	45
Europe	28	53	35	15
Latin America and the Caribbean	3	5	8	17
Northern America	0	16	16	13
Oceania	0	2	2	2
Average size of the world's 100 largest cities	187,000	725,000	2.1 million	6.2 million

1995). Within wealthier nations, urbanization has become obscured as increasing numbers of rural dwellers do not work in typical ''rural'' occupations such as forestry and farming, including those who commute to urban areas, those who are retired and live supported by pensions, and those able to work in rural areas because of advanced telecommunications systems (such as industrial or service enterprises located in greenfield sites in what are officially classified as ''rural'' areas or those who telecommute) (Pahl 1965).

27.1.3 Urban Systems and Ecosystem Services

The net flow of ecosystem services is invariably into rather than out of urban systems. These flows have increased even more rapidly than has urban population growth in recent centuries, and the average distance of these flows has increased substantially as well.

In the fourteenth century, Ibn Khaldûn could advise the planners of his day to locate new towns in well-protected locations with wholesome air, ample freshwater resources, and easy access to pastures for livestock, arable fields for grain, and forests for fuel (Khaldûn 1981). Few modern urban populations can still rely on local ecosystem services to meet their fuel, food, or water needs. The scale of the relationship between urban centers and ecosystem services has expanded, and while the global linkages may be especially evident for the more affluent cities, this expansion has been experienced by virtually all urban areas.

In light of these changing spatial relations, it is useful to distinguish among the linkages between urban systems and ecosystem services that exist within urban areas, between urban centers adjoining nonurban ecosystems, and between urban centers and distant ecosystems. Moreover, to appreciate the importance of relations between urban systems and ecosystem services, it is important to consider the negative as well as the positive effects that urban systems can have on ecosystem services. Even if urban systems are not major producers of ecosystem services, urban activities can alter the supply of ecosystem services at every scale, from within to far beyond the bounds of the urban area itself.

Within urban areas, the primary issue from the perspective of human well-being is whether the urban settlements provide a healthy and satisfying living environment for residents. Urban development can easily threaten the quality of the air, the quality and availability of water, the waste processing and recycling systems, and many other qualities of the ambient environment that contribute to human well-being. Certain groups (such as low-income residents) are particularly vulnerable, and certain services (such as those not easily traded or brought in from outside—the recreational services provided through urban parks, for instance) are of concern to all urban dwellers. Moreover, even for easily traded products, local ecosystems can be important, especially for households that lack the monetary income to purchase imports. Agriculture practiced within urban boundaries, for example, contributes significantly to food security in urban Sub-Saharan Africa (Bakker et al. 2000).

The urban area and its surrounding region is a better scale at which to understand the relations between urban development and local ecosystems. People in urban areas have historically been heavily dependent on adjoining systems for food, clean water, waste disposal, and a range of other services. The intensity of interaction between an urban system and its surroundings tends to fall off with increasing distance. Interaction also tends to be more intense along certain corridors (such as rivers and roads) and within environmentally bounded areas, such as watersheds. Because most urban centers are growing in population and extent, the peri-urban areas where the systems adjoining urban systems are located are also undergoing a twofold transformation, with arable land coming under increasingly intense cultivation and both arable and nonarable land being increasingly built over to provide space for commercial, industrial, and residential establishments and for roads and parking facilities. The more populated an urban area is, the greater its influence is likely to be on surrounding areas, although other characteristics, such as industrial production levels and per capita incomes, can also be important (Hardoy et al. 2001). (Peri-urban is used in this chapter to refer to land around the edges of an urban area, either just within or beyond urban boundaries, where land use patterns are often in the process of changing from more rural (agriculture) to more urban (buildings).)

In order to capture all the ecosystem service flows into urban areas, it is also necessary to consider the global scale, as many of the ecosystem services contributing to urban well-being do not depend upon the condition of local environments and ecosystems. Many products and amenities used in urban areas, including food, are traded extensively, and their availability depends primarily on the purchasing power of local residents. By importing goods, urban consumers are effectively drawing on ecosystem services from other parts of the planet. The institutions and practices controlling the ecosystems of origin remain outside the political reach of urban consumers (although emerging exceptions include certification systems (Bass et al. 2001)). Affluent consumers (and producers) are also increasingly likely to be contributing to pollutants whose impacts are themselves spread out across increasingly large areas (Wackernagel and Rees 1996; McGranahan et al. 2001).

Table 27.9 presents problems relating to urban systems and ecosystem services that are potentially of critical importance to human well-being at each of these three scales. Superficially, these problems can seem to represent a temporal sequence from past problems (such as bad urban water and sanitation) toward modern and even future problems (such as climate change). However, there are many urban centers today that still have bad urban water and sanitation, and the more obvious description of the current state of affairs is that all sets of problems coexist, but with different severity in different parts of the world. Similarly, although superficially there can seem to be a shift from issues involving the provisioning of private goods (such as water for home consumption) to those involving the provision of public goods (such as global climate stability), at their own scales all these issues involve externalities and public goods.

All these problems also involve issues of human well-being and social justice, with distinct spatial dimensions. Unhealthy and unpleasant living conditions involve the most vulnerable groups living in urban areas and the risks they face when local ecosystem services are lacking and alternatives are inaccessible. At the second scale, when urban development harms ecosystems in the surrounding region, there are more extensive issues of spatial injustice, although most of those affected are likely to be of the same nationality. The third scale involves burdens that urban activities impose on distant people and future generations by reducing their access to ecosystem services, either because these services are diverted to urban uses or because the ecosystems themselves are degraded: this raises international issues of spatial justice as well as issues of temporal justice.

As described in Box 27.3, the patterns described in Table 27.9 can also be represented in terms of stylized urban environmental transitions, displaying a historical tendency for more economically successful urban settlements to create more extensive and delayed environmental burdens. There is also a great deal of variation between urban centers of similar economic status, and no reason to assume that this stylized transition represents current or future urban development patterns. Currently, however, it is rare to find a very poor urban community that does not face serious environmental health hazards or a very affluent urban community that does not impose a large ecological footprint (as described later in this chapter).

27.2 Condition and Trends of Urban Systems and Ecosystems

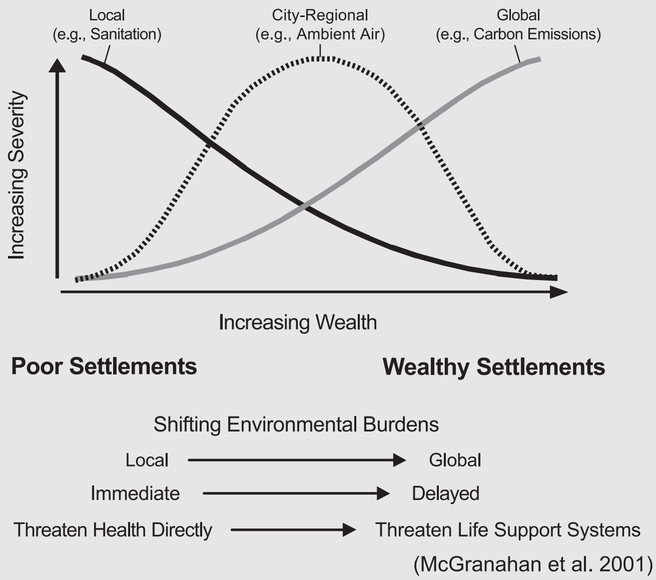
This description of condition and trends builds on the spatial classifications presented earlier. The first section examines the condi-

Table 27.9. Priority Problems in Urban Systems and Ecosystem Services at Three Different Spatial Scales

Problem and Characteristics	Intra-Urban (Urban Systems as Human Habitats)	Urban-Region (Urban Systems and Their Biospheres)	Urban-Globe (Urban Systems and Global Ecosystems)
Priority problem identified	unhealthy and unpleasant living environments	deteriorating relations with adjoining ecosystems	excessive "ecological footprints"
Urban areas most closely associated with problems	low-income cities and neighborhoods	large, middle-income, industrial cities	affluent cities and suburbs
Indirect driving forces	demographic change, inequality; trade and development that ignores ecology of infectious diseases and urban ecosystem services	industrialization, motorization; trade and development that ignores impacts on adjoining ecosystems	material affluence, waste generation; trade and development that ignores global ecosystem impacts
Direct driving forces	inadequate household access to safe water, sanitation, clean fuels, land for housing	ambient air pollution, groundwater degradation, river pollution, resource plundering, land use pressures	greenhouse gas emissions, import of resource and waste intensive goods (linear vs. circular flows)
Negative impacts associated with problem	spread of infectious diseases, loss of human welfare and dignity	loss of natural ecosystem services, "modern" diseases, declining agroecosystem productivity	global climate change, loss of biodiversity, depletion of globally scarce natural resources
Temporal characterization of key processes	rapid	varied	slow
Example of historically relevant response	sanitary reform	pollution controls	sustainable cities?

BOX 27.3

The Relationship between Economic Conditions and Urban Environmental Burdens



This stylized diagram portrays local environmental health burdens declining with increasing urban affluence, global burdens increasing, and city-regional burdens first increasing and then declining (McGranahan et al. 2001). As with many ecological systems, the "big" processes are "slow" whereas the "small" processes are "fast" (MA 2003, pp. 114–17), with the result that the burdens associated with low-income settlements affect poor people in the present, whereas those associated with affluent settlements affect a more extensive public after a considerable delay.

A number of similar diagrams have been generated to describe urban "transitions". Smith and Lee (1993) presented an urban environmental risk transition in terms of two curves—one representing declining traditional risks (such as fecally contaminated water and food, or indoor air pollution due to smoky cooking fuels) and the other increasing modern risks (such as exposure to industrial pollution). Holdren and Smith (2000) more recently adapted the Figure reproduced here to present a risk transition that incorporates the risks arising from global threats such as climate change.

Bai and Imura (2000) and Bai (2003) presented similar curves to provide a conceptual illustration of a staged evolutionary trajectory of environmental problems in cities as they become more affluent and as their environmental burdens shift from poverty-related to production-related and finally to consumption-related challenges. Marcotullio (2004) and Marcotullio and Lee (2003) used the Figure as a basis for exploring the differences between western and rapidly developing Asian urban environmental transition histories, hypothesizing that transitions in rapidly developing countries are occurring sooner (at lower incomes), faster (increasing more rapidly over time), and more simultaneously (with greater overlaps among sets of environmental burdens) than those experienced by what are now industrial-world cities.

tion and dynamics of ecosystems in and around urban settlements. The second focuses on the condition and trends in the suitability of urban areas as habitats for humans. The third section examines how urban systems relate to adjoining ecosystems and their ecosystem services. The fourth and last section focuses on the global pressures that urban systems exert on ecosystems.

27.2.1 Condition and Dynamics of Ecosystems within Urban and Peri-urban Areas

Ecosystems in urban and peri-urban areas often display distinctive characteristics and dynamics that are neither of human design nor a hold-over from some rural past. Historically, urban planners have been inclined to focus on the purposefully designed and built components of urban systems and to ignore all but the most glaring changes in local ecosystems. Their environmental critics, on the other hand, have been inclined to focus on the loss of rural ecosystems and services. The combined effect has been the neglect of new opportunities that urban development creates for nonhuman species and ecosystems (not all of which benefit humans, of course).

27.2.1.1 Nonhuman Species and Ecosystems in Urban Areas

Although a concentration of humans is a defining feature of them, urban areas typically contain numerous opportunities for the persistence of native nonhuman species as well as the invasion or introduction of exotic species. Similarly, although a high share of built-over land is often used to identify areas as urban, urban land is far from impervious and often includes a range of different land use types, including gardens, grassland, wooded land, and agricultural land.

Urban and peri-urban ecosystems are heavily influenced by environmental change driven by people, but they also reflect the ability of plants, animals, and microorganisms to survive and exploit these changes. Urban construction and production typically conflict with wildlife and habitat conservation (Thompson 2003). They frequently result in the loss of critical wetland habitats, forest environments, and coastal sites and threaten many aspects of biodiversity. Urban development does not eliminate natural processes, however. It creates different opportunities and allows for new combinations of species through both introductions of exotic species to parks and gardens and the migration of invasive species. Many new opportunities are provided by the habitat shifts created by modification of biogeochemical cycles and the adjustment of micro- and local climates to make human life more comfortable, and some species are more able than others to exploit urban opportunities (see Rydell 1992 and Shapiro 2002 for examples relating to bats and butterflies).

Urban structures themselves provide opportunities for organisms—from the rats in the sewers to the birds nesting under the eaves of buildings. Spillages in factories, retail outlets, transport depots, and homes can create abundant food sources. Important mineral nutrients, such as calcium and magnesium, are common in building materials and find their way into urban soils (Bradshaw 2003). Parks, gardens, and zoos provide sites for a variety of plants and animals, including introduced and exotic species. Vacant and derelict sites are also colonized, and urban areas often include disused sites at various stages of succession. (See Table 27.10.)

The thermal properties of built-over land surfaces result in more solar energy being stored and converted to sensible heat (the heat energy stored in a substance as a result of an increase in its temperature), and the removal of shrubs and trees reduces the natural cooling effects of shading and evapotranspiration. The average ambient temperature in urban systems is generally 2–3 degrees higher than in nonurban systems, which can cause discomfort and even health risks in locations that are already warm

Table 27.10. Essential Steps in the Process of Natural Succession in Urban Areas (Bradshaw 2003)

Ecosystem Attribute	Processes Involved
Colonization by species	immigration of plant species establishment of those plant species adapted to the local condition
Growth and accumulation of resources	surface stabilization and accumulation of fine mineral materials accumulation of nutrients, particularly nitrogen
Development of the physical environment	accumulation of organic matter immigration of soil flora and fauna causing changes in soil structure and function
Development of recycling process	development of soil microflora and fauna possible difficulties in urban areas
Occurrence of replacement process	negative interactions between species by competition positive interaction by facilitation
Full development of the ecosystem	further growth new immigration, including aliens
Arrested succession	effect of external factors reduction of development
Final diversification	the city as a mosaic of environments high biodiversity as a result

or can lead to greater use of air-conditioning and attendant energy consumption. It can also exacerbate urban air pollution, alter rainfall patterns in and around urban centers, and change the composition of urban wildlife (see, e.g., Nowak et al. 2002). On the other hand, the heat island effect can attract warmth-seeking species to urban areas, and for people, too, more warmth is not always a disadvantage.

Within built-up areas, complex mosaics of land use emerge. The inner areas of many older North American cities, for example, have abandoned areas that may be totally neglected or derelict but that provide opportunities to create urban gardens that can be beneficial to local residents' well-being and health (Dinno 2000). In addition to abandoned spaces, there are numerous areas of vegetation that are planted or managed to some degree, ranging from roadside verges and canal and railway corridors to formal gardens, parks, urban woodlands, ponds, and lakes.

There is a trend to develop areas of more natural vegetation in cities, establishing urban nature reserves, such as the 1-hectare Camley Street Reserve adjacent to Kings Cross Station in London and the 1,215-hectare Rock Creek Park in Washington, D.C., which is 86% wooded. Preserved natural areas can become symbolic for cities, such as the 164-hectare Bukit Timah Reserve in Singapore and the 11-hectare Bukit Nanas Reserve in Kuala Lumpur. Other areas are totally ephemeral, being invaded by vegetation while awaiting development. The value of these ephemeral patches of vegetation depends on how long they are left undisturbed and on the character of their substrates. Many derelict chemical works sites can offer unusually acid or alkaline sites that provide niches for plants associated with acid peat bogs or highly saline marshes not normally found in urban areas.

Collins et al. (2000) suggest a number of reasons why new human-imposed scales for ecological processes are found within urban areas. First, compared with ecosystems in rural areas, urban ecosystems are highly patchy and the spatial patch structure is characterized by a high point-to-point variation and degree of isolation between patches. Second, disturbances such as fire and flooding are suppressed in urban areas, and human-induced disturbances are more prevalent. Third, because of the higher temperatures in urban systems, in temperate climates there are longer vegetation growth periods. Fourth, ecological successions are altered, suppressed, or truncated in urban green areas, and the diversity and structure of communities of plants and animals may show fundamental differences from those of nonurban areas (Niemela 1999; Pickett et al. 2001).

The patchwork nature of urban ecosystems is accentuated by the variety of agencies, landowners, individuals, and businesses responsible for parcels of urban land, ranging from municipal parks and gardens departments, to public hospitals and educational institutions, to private individuals and corporations. Their differing goals and practices create diversity among these managed spaces. The urban environment is thus full of ecological discontinuities. Many species overcome these, simply surmounting obstacles—for example, the way urban foxes dash across main roads to get at other food sources. For some, however, migration corridors are important, and many planning strategies incorporate green corridors along streams or public utility easements. Preliminary results of investigations in Birmingham, England, suggest that the River Cole "wildlife corridor" does not enhance the number of wetland specialist species but it may act to increase and stabilize the number of habitat generalist species (Small 2000).

Compared with relatively simple temperate forest ecosystems, temperate industrialized agroecosystems, or tropical plantations, urban areas tend to be high in species richness as a result of the high habitat diversity of urban areas (Rebele 1994). However, some of the species richness is due to introduced species and is not always conducive to high levels of biodiversity at larger scales. An imported species that initially increases the species diversity within an urban area can, in certain circumstances, become an invasive species that reduces biodiversity in the surrounding areas. For example, on March 6, 1890, 40 pairs of the European Starling (*Sturnus vulgaris*) were released in New York's Central Park. Within a few years the starlings had spread from coast to coast, and they are now one of the most common birds in the United States, competing with native species (Kieran 1995; Mittelback and Crewdson 1997).

27.2.1.2 Contrasting Urban and Peri-urban Areas

In several studies, species diversity along an urban-rural gradient has tentatively been found to be hump-shaped in distribution, with the highest diversity in areas between rural areas and the urban core (Blair 1996; Blair and Launer 1997). The generality of this pattern across taxa has not been thoroughly investigated, nor have the mechanisms leading to such a pattern. It is, however, consistent with a more general observation that peri-urban areas are more varied and changing than are central urban or more distant rural locations.

In the heart of built-up areas, there is often a large share of fixed or long-term land uses. Although one building may replace another, comparatively few green spaces are built on, few new roads are created, and few new plants are introduced. It is in the peripheries and suburbs that the most rapid land use changes typically occur, usually with a loss of gardens and other open spaces and with increases in paved and roofed impermeable areas, as apartments or compound housing units replace single family dwellings and as retail land office buildings get larger. Sometimes new green spaces are created in such redevelopment projects, although these are often landscaped and maintained.

At the edge of the built-up area, large tracts of land are affected by transient uses. These peri-urban areas (except for many protected areas, which often include river valley and transportation corridors) undergo a change from rural to increasingly urban uses. In many North American and Australian peri-urban areas, the transition typically begins with the building of isolated houses for comparatively affluent townspeople. In much of Africa, Asia, and South America, on the other hand, migrants and a mix of longstanding residents frequently occupy peri-urban areas. Extremely poor people build temporary dwellings on any land from which they are not immediately evicted, provided there are employment opportunities. They may also cultivate food for themselves, hoping to sell the surplus at the roadside or in urban markets. (See Box 27.4.) Such land cover changes introduce not only plants but also a variety of waste and other materials to the local environment, which is likely to alter both the character and the dynamics of local ecosystems.

Alternatively, land-market economics can lead to agricultural land around the city being taken out of production while the owner waits for the price for urban uses to rise. In urbanizing rice-growing areas of Asia, this process can result in a patchwork of developed former rice fields, abandoned rice fields, and rice fields that are still being cultivated. Settlements and even regions may combine characteristically urban and rural features (McGee 1991).

With tight greenbelt planning regulations around many European cities (Hall 2002), the pace of peri-urban land cover change is often not as obvious as elsewhere in the world, such as in the United States, where it has been estimated that urban area has doubled since 1960 (Heimlich and Anderson 2001). In many rapidly growing cities in low- and middle-income countries, areas that were totally rural 10 years ago may be part of suburbia today. The peri-urban transition zone migrates out from the city almost relentlessly unless tight regulations are enforced or transport costs are high, as they were when many of the more compact cities developed (Bairoch 1988; Newman and Kenworthy 1999).

Rapid urban development also creates peri-urban demands for earth resources, especially aggregates and brick-making clays, and for land for disposal of wastes. Frequently, industries with high levels of pollution or hazardous wastes are also located in peri-urban zones, so that there is a high risk of contamination from industrial chemicals and toxic substances. Thus peri-urban zones may accommodate potentially conflicting activities. The juxtaposition of emissions of chemicals, disposal of waste, and peri-urban agriculture can lead to many health hazards. Vermin from waste dumps can be a threat to crops, domestic animals, and human beings.

Where urban settlements are themselves combining into large conurbations, the distinction between urban and peri-urban areas often ceases to be meaningful. In a multicentered agglomeration, for example, an area near the middle of the agglomeration may be peripheral to several sub-centers and retain at least some features characteristic of peri-urban areas. Green areas often remain between the original major towns, particularly where there is a history of greenbelt designation. At the same time, the inner areas of the city show successive waves of building, demolition, and rebuilding as needs change and as industry and business activity grows and declines.

27.2.1.3 Ecosystem Services in Urban and Peri-urban Areas

Whereas urban development is driven by deliberate human activity, most of the ecosystem changes that occur in and around cities are unintentional. These changes affect the supply of ecosystem services, including the regulation and ecology of human diseases.

By the time a given area is urbanized, most pre-existing ecosystems are likely to be severely disrupted, if not entirely transformed. Even the ecosystems associated with lands that remain comparatively undisturbed are likely to be altered by the habitat fragmentation and pollution that typically accompany urbanization (Bradshaw 2003). New opportunities for native species may arise, but in a different context and with potentially important implications for local ecosystem dynamics. Newly introduced species find opportunities beyond their area of introduction and compete with native species.

In urban areas and their margins, ecosystems can provide an especially wide range of services. The most widely recognized services are associated with green spaces and are recreational and cultural. Parks have become a central part of the identity of many urban centers, and greenbelts are an increasingly accepted means of providing outdoor recreation facilities for urban dwellers. In the MA sub-global assessment for Stockholm, 10 potential urban ecosystem services in National City Park have so far been examined, including not only recreational and cultural values but also air filtration, regulation of microclimate, noise reduction, surface-water drainage, nutrient retention, genetic library, pollination, seed dispersal, and insect pest regulation (Bolund and Hunhammar 1999). The sustainable supply of these ecosystem services depends not only on the presence of the parkland but also on the resilience of the ecosystems that provide them. This resilience could be undermined by insufficient conservation of parkland and by increased fragmentation. Alternatively, many of these services are also provided to at least some degree by non-park land, even if a park is one of the urban sites where the scope for managing and enhancing the value of these services is greatest (Elmqvist et al. 2004).

Just as not all ecosystem services arising from urban ecosystems are from green spaces, not all green spaces are ecologically beneficial. Urban and suburban lawns, for example, provide recreational services to their homeowners, aesthetic value to the neighborhood, and a number of other ecosystem services. However, large quantities of water, fertilizer, and pesticides are applied to maintain the aesthetics of the green lawns, especially in affluent countries, with numerous adverse consequences (Robbins et al. 2001). Indeed, fertilizers and pesticides are applied more intensively to lawns in the United States than to arable lands in large parts of the world (Robbins et al. 2001).

The lack of some ecosystem services in urban systems makes them more valuable. For example, the at-field value of urban agricultural produce is greater than that produced elsewhere because it does not need to be transported so far to reach the consumer. Some ecosystem services in urban areas can become so degraded through overuse that changes that would otherwise increase service delivery are of no avail. For example, once groundwater is no longer used for drinking purposes due to low quality, a further loss in the capacity of local ecosystems to filter and clean the water is less directly relevant. The result is the importation of the service from other ecosystems (in this case, through piped or bottled water), often at higher overall cost. Moreover, high population densities and the fact that some of these services provide spatially

BOX 27.4

Urban Agriculture, Vulnerability, and Recycling

For many of today's urban dwellers, urban agriculture provides an important source of food and supplementary income, especially in times of economic crisis. Although urban agriculture is associated with environmental health risks, it also has many environmental advantages and can help to provide a range of ecosystem services within urban areas.

There are no reliable estimates of the land used, the labor applied, or the outputs produced by urban agriculture. This is not surprising. The extent of urban agriculture is particularly sensitive to where urban boundaries are drawn, because a large share is located on the margins of urban areas. More centrally located agriculture is often spatially scattered and involves a large number of small plots (or even pots and pools) and animals (domestic fowl, for instance) that are difficult to identify, let alone monitor. In many cities, agriculture is officially banned, further complicating any attempt to collect reliable statistics.

There is, however, a growing body of research detailing the importance of urban agriculture in particular locations and for particular groups (United Nations Development Programme 1996; ETC—Urban Agriculture Programme 2001). This research suggests that urban agriculture can provide a number of major benefits: income and food security for producers; employment for under- or unemployed residents; lower prices for urban consumers; environmental improvements such as reduced runoff; and avoided costs of wastewater treatment and solid waste disposal. Urban farming takes place not only in peri-urban fields but also on rooftops, in backyards, in community vegetable and fruit gardens, and on unused or public spaces. It produces high-value products like fruit, vegetables, and fish, staples such as cassava, maize, and beans, and supplementary products such as berries, nuts, herbs, and spices. Urban agricultural enterprises range from highly commercialized operations to small informal and occasional enterprises. These latter operations are typically managed by long-term urban residents, by the moderately poor, and often by women.

From the perspective of current human well-being, the most significant contribution of urban agriculture probably does not lie in the share of overall agriculture production for which it accounts, but in the food security and supplementary income it can provide to cash-strapped urban residents, and to women in particular. In response to the economic deprivations of recent decades, urban agriculture in sub-Saharan Africa provided an important safety net for those who could find the land (Maxwell 1999).

Urban agriculture reportedly grew rapidly in many African cities (Howorth et al. 2001; Page 2002; Bryld 2003), largely as an informal activity involving either on-plot cultivation in more densely settled areas or off-plot cultivation on urban peripheries and marginal lands (Rogerson 1995). The urban farmers are often not from the poorest groups (Flynn 2001), and indeed in some cities the very poor find it difficult to gain access to land. Regardless, urban agriculture has helped many urban Africans weather the continuing crisis, and where the data have been examined there is at least some evidence that urban agriculture is contributing to food security (Maxwell et al. 1998). Urban agriculture has often played a similar role in other parts of the world. For example, it emerged in Cuba in response to the decline of Soviet aid and trade and the persistence of the American trade embargo (Altieri et al. 1999; Moskow 1999).

Increasingly, proponents of urban agriculture also emphasize its ecological benefits (Smit and Nasr 1992). One of the ecological disadvantages of urban development is that it tends to replace circular flows with linear ones: ecological cycles are disrupted; materials previously returned to the soil as nutrients become urban waste; substances that are hazardous at high concentrations accumulate. Urban agriculture provides the opportunity to recycle the nutrients in urban organic waste (Eaton and Hilhorst 2003) and can be combined with "ecological sanitation" to improve public health (Esrey 2002). The cultivation of plants in urban areas can also provide other ecosystem services of particular value to urban dwellers, such as cooling and pollution reduction.

Urban agriculture does pose various problems. It can create environmental health problems including food contamination, water pollution, and the increased prevalence of disease vectors such as malarial mosquitoes (Birley and Lock 1998). When combined with ecological sanitation, there is the potential for improving public health if the systems are well managed, but there are also severe risks if management is poor. Moreover, theft can be an especially serious problem for urban agriculture. The fact that it remains illegal in a great many cities where it is practiced constrains its potential (Allen 1999). On the other hand, when agriculture is formally allowed, it often has difficulty competing against alternative urban land uses (Midmore and Jansen 2003); in some contexts, making urban agriculture legal could make it even harder for the poorest residents to gain access to the land.

In affluent cities, urban agriculture now tends to be associated with the production of high-value products supplied fresh to discerning local consumers. Because arable land is scarce and costly, farm sizes tend to be small and yields tend to be high. In the United States, for example, farming in metropolitan areas accounts for less than one fifth of the cropland but for about one third of farms and one third of the value of agricultural production (Heimlich and Anderson 2001). Even in the United States, however, urban agriculture is sometimes promoted as a means of improving food security for some of the more deprived urban communities (Allen 1999).

delimited public benefits (that is, one person's use does not detract from use by others) also help make ecosystem services more valuable in urban areas.

Some ecosystem services in urban locations are especially important to vulnerable groups. As described in Box 27.4, urban agriculture can enhance food security and supplement the livelihoods of the urban poor. In many urban areas, although the more affluent residents no longer use it, local groundwater continues to be used by those living in poverty despite being heavily contaminated. In Jakarta, for example, bottled water has become popular for those who can afford it, and piped water is available at a price in many parts of the city, but a large share of low-income households still rely on shallow groundwater and are very aware of differences in quality even among different wells in the neighborhood (McGranahan et al. 1998). Local ecosystem filtration clearly affects the quality of water, even if it often cannot make it truly potable. More generally, those who cannot afford to purchase alternatives are more dependent on local ecosystem services. This does not mean that protecting ecosystems and ecosystem services in urban areas will necessarily benefit vulnerable groups: vulnerable people are sometimes evicted from their homes in the name of environmental protection. It does mean, however, that there is the potential in many cities for policies that would both enhance ecosystem services and benefit vulnerable groups.

Among planners and decision-makers, there has historically been a strong tendency to neglect ecosystem services and other relations between ecosystems and human well-being, at least until a local or international crisis has forced such concerns onto the policy agenda. In many urban settlements, the quality of the urban groundwater and of the ambient air, for example, has been allowed to deteriorate considerably before any action has been taken (Melosi 2000; Tarr 1996). The policy debates are often very poorly informed, partly because of underlying ignorance about the processes involved, and partly because they are driven by vested interests rather than by sincere attempts to understand the nature of the problem (see, e.g., Davis 2002).

27.2.2 Urban Systems as Habitats for Humans

As long as people continue to live in urban areas, it is important for their well-being that the urban air be healthy to breathe, that there be sufficient water of adequate quality to meet domestic needs, that the urban landscape be pleasing to the eye, that the urban climate be comfortable, and generally that the urban environment be healthy and pleasant for people to live in. With urbanization, the ability of local ecosystems to provide these services tends to decline, even as the number of people per unit of area, and hence the need for these services, increases.

Many of the services once provided by local ecosystems are now provided by some combination of more-distant ecosystem services (such as water diverted to the city through constructed waterways) and manufactured services (such as water treatment plants). Even if the health benefits of the economic growth that has accompanied urbanization in most countries has outweighed the local loss of ecosystem services, these losses have been extremely important historically and remain important to this day, as described later in this section.

Urban development can bring major investments in public health infrastructure and measures to reduce exposure to environmental hazards. Without such investments and measures, urban areas would still be far less healthy than rural areas. With them, however, urban habitats are on average healthier (Montgomery et al. 2003, Chapter 7). Yet the benefits from urban investments in public health infrastructure are very unevenly distributed (Hardoy et al. 2001).

Although urban living is often associated in people's minds with industrial and motor vehicle pollution, the role of cities in facilitating the spread of infectious diseases has probably been more important to human health, and it remains important today. Humans are exceptional among animals in the high proportion of their deaths due to disease (see, e.g., McKeown 1988). Changes in human densities and travel patterns are implicated in the emergence of many of the most devastating infectious diseases.

Without sufficiently large urban settlements, a number of diseases, including measles and smallpox, could not be maintained in human populations (the measles virus, for example, can only persist in one person for a couple of weeks, and so at least 26 times a year it must move to a person who has not been previously infected) (Mascie-Taylor 1993). Trade and urban conditions helped spread the vectors and eventually the plagues that beset Europe during its early urbanization, and in the more extreme cases killed upward of 25% of the population (McNeill 1989). Urban settlements are still important to the spread of epidemics and pandemics, including, for example, HIV/AIDS (Dyson 2003; see also Chapter 14).

The water, sanitation, and hygiene problems described in the next section provide an example of urban conditions that historically created some of the most serious health problems and that remain significant to this day. In a recent World Health Organization ranking of leading risk factors in terms of attributable disease burdens, unsafe water, sanitation, and hygiene ranked sixth (WHO 2002). Water and sanitation deficiencies tend to be a particular risk in economically deprived areas, both rural and urban.

Urban exposure to chemical pollution is also important to human health and well-being. Urban development often leads to unintentional threats to health and well-being by increasing waste generation or by bringing people into closer contact with waste products, some of which contain harmful chemicals (as well as pathogens). These waste products may be in the urban air, water, or land, in public or private spaces, and in relatively more or less frequented locations. Exposure to health-threatening ambient urban air pollution is highest in large industrialized and motorized cities (McGranahan and Murray 2003), whereas health-threatening indoor air pollution is particularly severe in homes where smoky fuels are used without adequate ventilation (Saxena and Smith 2003). Neither surface nor groundwater is potable in most urban settlements, with chemical water pollution a particularly serious problem in industrial centers. Solid waste can contribute to urban air pollution (through burning, for instance) or water pollution (such as through leaching) or can result in direct exposure.

The ambient air pollution problems described in more detail later provide an example of an environmental health problem often considered quintessentially urban. The burden of disease attributable to urban air pollution is estimated to be less than one quarter of the burden from water and sanitation problems (WHO 2002). The burden of illness due to indoor air pollution, by contrast, is nearly the same as that due to water and sanitation problems (WHO 2002).

The later sections on air pollution and on water, sanitation, and health attempt to provide simplified accounts of how urban conditions affect ecosystem services (such as clean air and water) and hence human health. It is also important to recognize, however, that complex environmental interactions and enormous inter- and intraurban variation in environmental health conditions are themselves characteristic of the challenges encountered in urban habitats.

First, in the evolution of an epidemic or of an individual's health, there are discontinuities and thresholds in relations between environmental conditions and health outcomes. Thus, for example, declining sanitary conditions may initially increase the burden of endemic diarrheal diseases, and then, after crossing some threshold, allow a cholera epidemic to break out. An urban settlement's role in epidemics also depends on its size, with larger cities acting as reservoirs of disease and providing a source for outbreaks in smaller settlements below the threshold necessary to maintain the infection in the human population (Cliff et al. 1998). Alternatively, whereas the conditions in the United States and Europe were such that relatively small shifts in the ecology of malaria could lead to its disappearance, in the parts of sub-Saharan Africa where malaria is holoendemic (that is, in an equilibrium where the disease is endemic at a high level among children and adults show less evidence of the disease), the disease can persist in the face of far larger shifts (Bradley 1991).

Second, in service-deprived low-income neighborhoods the conventional boundaries between environmental health problems do not apply (McGranahan et al. 2001). As the result of home industries, occupational health hazards are often encountered in people's homes. When fecal material is not separated off and contained or flushed away, it can contaminate water supplies, become mixed with the solid waste, and attract flies and other pests. Where water is not piped into people's homes, it is more easily contaminated with fecal material and less likely to provide for good hygiene within the home, and there is a risk that water storage containers will become a breeding site for vectors of diseases such as dengue and dengue hemorrhagic fever. When solid waste is not contained and carried away, there is a significant likelihood that it will create unsightly, malodorous, and inconvenient accumulations of refuse and become a breeding ground for pests. And it will also cause air pollution when it is burned or flooding when it is washed into the drains. Combined with crowded housing, smoky fuels, the use of pesticides, and food storage problems, these multiple hazards often create extremely unhealthy living environments, especially for infants and children who have not yet built up resistance to infectious diseases (see, e.g., Cairncross and Feachem 1993; McGranahan et al. 2001; McGranahan and Murray 2003).

Third, many of the environmental conditions that facilitate the transmission of infectious diseases in deprived urban areas lie in the public domain, such as those associated with poor sanitation and solid waste removal, and create local public health risks that private actions cannot address effectively (Pickering et al. 1987; Bateman et al. 1993; McGranahan et al. 2001). Others, on the other hand, involve transmission within households. The relative importance of public and domestic routes of transmission varies, depending on the disease (Cairncross et al. 1995). Much the same applies to exposure to chemical pollutants; it is noteworthy that whereas indoor air pollution was identified as one of major risks to health in the most recent burden of disease estimates (WHO 2002), it was not even included in previous estimates (Murray and Lopez 1996).

The very nature of these interconnections makes the resulting hazards difficult to address, either through the privately negotiated trades that have historically underpinned the success of market economies or through public agency. Those who are most affected tend to have very little income or assets with which to trade and comparatively little political power with which to influence government agencies or political processes. In any case, pathogens, pests, and toxins respect neither the boundaries of private property nor those of organized communities, administrative areas, or ministerial responsibilities. These difficulties are important factors when considering both the history of urban environmental health and the contemporary situation with regard to urban water, sanitation, and air pollution.

27.2.2.1 Urban Water, Sanitation, and Hygiene and Human Health

In most parts of the world, there have been enormous improvements in urban water and sanitation since the mid-nineteenth century, when urban water and sanitation problems first gained international prominence. Nevertheless, according to the most recent global burden of disease assessment, unsafe water, sanitation, and hygiene still account for almost 6% of the burden of disease in ''high-mortality developing regions,'' exceeding all but two other risk factors (Ezzati et al. 2002). Although the ''urban penalty''—the increase in mortality rates associated with living in urban areas (see, e.g., Dobson 1997; Woods 2003)—that helped to motivate reform in the nineteenth century is no longer evident, eliminating unhealthy conditions in African, Asian, and Latin American urban areas remains a major challenge.

Urban poverty, particularly when combined with rapid urban population growth, is still closely associated with unsafe water and sanitation. Reducing the share of the population without adequate water and sanitation services is still central to the development goals and targets that have been adopted internationally, including most notably the Millennium Development Goals. (See MA *Policy Responses,* Chapter 20.)

In Table 27.11, the left-hand columns summarize the water and sanitation statistics that were used in developing exposure estimates for the burden of disease just mentioned and also used in starting to monitor progress toward the water and sanitation targets associated with the MDGs. These statistics might seem to suggest that only a small minority of urban dwellers lack provision of clean water and sanitation. Even in Africa, 85% of the urban population had ''improved'' provision for water and 84% had ''improved'' provision for sanitation by 2000. Problems are probably much more serious in rural areas, where most of the 1.1 billion people without access to improved drinking water and most of the 2.4 billion people without access to improved sanitation live (WHO and UNICEF 2000).

Unfortunately, these statistics are based on a definition of ''improved'' provision for water and sanitation that includes conditions where the risk of human contamination from fecal-oral pathogens remains high (Prüss et al. 2002). The Global Assessment from which the statistics are taken acknowledges that, because of the lack of internationally comparable data, it was not able to calculate the proportion of people with ''adequate'' provision or with ''safe'' water (WHO and UNICEF 2000).

For water supply, access to ''improved'' supplies was defined as being able to obtain at least 20 liters of water per person per day from a household connection, public standpipe, borehole, protected dug well, protected spring, or rainwater collector within 1 kilometer of the user's dwelling (WHO and UNICEF 2000). In many low-income urban settings, however, standpipes or other publicly available water sources available within a kilometer may be shared with hundreds and occasionally thousands of people, and there are often serious deficiencies in the quality of the water and the regularity of the supply (Hardoy et al. 2001; UN-Habitat 2003a).

For sanitation, ''improved'' provision was defined as access to a private or shared toilet with connection to a public sewer or a septic tank or access to a private or shared pour-flush latrine, simple pit latrine, or ventilated improved pit latrine (WHO and UNICEF 2000). In many urban settings, however, dozens of households share each latrine, making access difficult and maintenance inadequate, sometimes causing people and especially children to avoid using the latrines (UN-Habitat 2003a).

Moreover, detailed case studies often indicate levels of provision that are difficult to reconcile with the national estimates used in calculating the figures on ''improved'' provision in Table 27.11, even accepting the definitions of ''improved'' supply. For instance, the national estimates for Bangladesh show that 99% of its urban population had access to ''improved'' water supplies in 2000 (WHO and UNICEF 2000), whereas detailed studies in its two largest cities (Dhaka and Chittagong) show large sections of their populations having to rely on poor-quality water that was difficult to obtain (UN-Habitat 2003a). Similarly, the national estimates for Tanzania and Kenya show that virtually all their urban populations had ''improved sanitation,'' but detailed studies in their major cities and smaller urban centers showed otherwise, especially in the large informal areas within urban settlements where a high proportion of the population of Dar es Salaam and Nairobi live (UN-Habitat 2003a). The numbers in the right-hand columns of Table 27.11 are very crude estimates, but they suggest a far higher level of water and sanitation deprivation (UN-Habitat 2003a).

Such statistics, even if they are rigorously defined and measured, can misleadingly imply that the underlying problem is a lack of infrastructure. In effect, health risks arising from the local ecology of waterborne or water-related diseases are ascribed to the absence of the presumed solution: more extensive piped water and sanitation systems (or other ''improved'' technologies). As part of this more general tendency to oversimplify, in policy discussions it is often presumed that ''waterborne'' diseases, which

Table 27.11. Different Estimates of Number of Urban Dwellers Lacking Provision for Water and Sanitation, 2000 (WHO and UNICEF 2000; UN-Habitat 2003b)

Region	Number (and Share) of Urban Dwellers without "Improved" Provision for:		Indicative Estimates for the Number (and Share) of Urban Dwellers without "Adequate" Provision for:	
	Water	Sanitation	Water	Sanitation
Africa	44 million (15%)	46 million (16%)	100–150 million (c. 35–50%)	150–80 million (c. 50–60%)
Asia	98 million (7%)	297 million (22%)	500–700 million (c. 35–50%)	600–800 million (c. 45–60%)
Latin America and the Caribbean	29 million (7%)	51 million (13%)	80–120 million (c. 20–30%)	100–150 million (c. 25–40%)

include most diarrheal diseases, are contracted by people drinking water contaminated with fecal material.

In fact, although waterborne diseases can be spread via drinking water, they can also spread through person-to-person contact, and often by other means (Cairncross and Feachem 1993). Many waterborne diseases can be transmitted mechanically by insects, and there is some evidence that the presence of flies can make a large difference to their prevalence (Cohen et al 1991; Levine and Levine 1991; Crosskey and Lane 1993). Contaminated food is quite possibly an even greater problem than contaminated water. Insufficient water for washing is probably more important to health than poor-quality drinking water. Better sanitation facilities are unlikely to achieve their potential health improvements unless they are accompanied by changes in hygiene behavior; in some circumstances, changes in behavior are the most significant factor in reducing the prevalence of fecal-oral diseases (Curtis et al. 2000; Curtis and Cairncross 2003).

27.2.2.2 Urban Air Pollution and Human Health

Serious exposure to air pollution began with the advent of burning fuels for cooking and heat within unventilated abodes. Air pollution was a major nuisance for many and a serious concern for some in the industrializing cities of the nineteenth century (Mosley 2001), but concerted efforts to address ambient air pollution only began in the twentieth century. In particular, it was the urban air pollution episodes between the late 1940s and mid-1960s in Donora (in the state of Pennsylvania), London, Osaka, and New York City, among other locations, when many died or were hospitalized, that prompted public concern and responses including clean air legislation, regulations, and other actions.

Table 27.12 provides the sources of indoor and outdoor air pollution associated with some of the principal pollutants. The distribution, magnitude, and trends of many of these pollutants within ecosystems are addressed in Chapter 13. This section focuses on their generation and health impacts within urban systems.

Recent estimates of the global burden of disease suggest that approximately 5% of trachea, bronchus, and lung cancer, 2% of cardiorespiratory mortality, and about 1% of respiratory infections are attributed to urban outdoor air pollution (WHO 2002, and see also Ezzati et al. 2002). This amounts to about 800,000 deaths (1.4% of the total) and about 0.8% of the total global burden of disease. This burden falls predominantly on low- and middle-income countries, with 42% occurring in parts of the WHO Western Pacific Region and 19% occurring in parts of the WHO Southeast Asian Region.

Although these figures suggest that outdoor urban air pollution is an important health concern, the burden of indoor air pollution is estimated to be considerably higher (Smith and Akbar 2003; WHO 2002). Indoor air pollution concentrations tend to be highest in low-income settings, and more specifically where smoky fuels are used in homes with poor ventilation (Saxena and Smith 2003). Nearly half the world cooks with biofuels, including more than 75% of those living in India, China, and nearby countries, and 50–75% of those living in parts of South America and Africa (WHO 2002). Exposure to pollutants from burning these fuels is particularly intense for women and young children, who spend much of their time indoors, and is in aggregate substantially greater than exposure to outdoor air pollution in cities with severe air pollution problems (Smith and Akbar 2003). Although ambient air pollution is usually worse in urban centers, overall exposure to air pollution (both indoor and ambient) is higher in rural areas because most of these biofuel users are rural (Saxena and Smith 2003).

There is also considerable variation in exposure to air pollution between and within urban centers, depending on geographical factors as well as the types of activities undertaken in and around the urban centers and the fuels used to power them. Ambient air pollution has reached excessively high levels in many large cities in Asia, Africa, and Latin America (Krzyzanowski and Schwela 1999), where concentrations of ambient air pollution often rival and exceed those experienced in industrial countries in the first half of the twentieth century. Pollution from industries and power plants can account for a large share of urban emissions, and it also tends to be the target of initial pollution control measures. Vehicular pollution is also a chief contributor to overall local and regional ambient air pollution (NO_x, O_3, CO, volatile organic compounds, and suspended particles).

In general, low- and middle-income countries account for only 10% of the world's vehicles, including 20% of the buses (Elsom 1996). Growth rates for vehicle ownership, however, are two to three times higher in these countries than in high-income countries. For example, during the 1980s Pakistan experienced an annual average vehicle growth rate of 9%, Brazil's was 11%, China 14%, Kenya 26%, and both the Republic of Korea and Thailand 30%, compared with 2–3% growth in the United Kingdom and the United States (Elsom 1996). In 1990, there were 700,000 private cars in China and 5 million other motor vehicles. By 2001, this had risen to more than 5 million private cars and some 13 million other vehicles. For the next 20 years, East and Southeast Asia are expected to have the fastest-growing car markets in the world (Walsh 2003). The number of motor vehicles

Table 27.12. Sources of Outdoor and Indoor Emissions and Principal Pollutants (Murray and McGranahan 2003)

Sources	Principal Pollutants
Predominantly outdoor	
Fuel combustion, smelters	sulfur dioxide and particles
Photochemical reactions	ozone
Trees, grass, weeds, plants	pollens
Automobiles	lead, manganese
Industrial emissions	lead, cadmium
Petrochemical solvents, vaporization of unburned fuels	volatile organic compounds, polycyclic aromatic hydrocarbons
Both indoor and outdoor	
Fuel burning	nitrogen oxides and carbon monoxide
Fuel burning, metabolic activity	carbon oxides
Environmental tobacco smoke, re-suspension, condensation of vapors and combustion products	particles
Biologic activity, combustion, evaporation	water vapor
Volatilization, fuel burning, paint, metabolic action, pesticides, insecticides, fungicides	volatile organic compounds
Fungi, moulds	spores
Predominantly indoor	
Soil, building construction materials, water	radon
Insulation, furnishing, environmental tobacco smoke	formaldehyde
Fire-retardant, insulation	asbestos
Cleaning products, metabolic activity	ammonia
Environmental tobacco smoke	polycyclic aromatic hydrocarbons, arsenic, nicotine, acrolein
Adhesives, solvents, cooking, cosmetics	volatile organic compounds
Fungicides, paints, spills, or breakages of mercury-containing products	mercury
Consumer products, house dust	aerosols
House dust, animal dander	allergens
Infections	viable organisms

worldwide is expected to increase from around 660 million in 1990 to 1 billion by 2030 (Faiz et al. 1990).

Besides absolute numbers, the quality and fuel efficiency of motor vehicles also affects emissions and hence ambient air quality. High emissions per vehicle are associated with outdated technologies, older vehicles, poorly surfaced or badly maintained roads, weaker environmental legislation or weak enforcement of the regulations, poor vehicle maintenance (as vehicle emission inspections are less rigorous or nonexistent), and the dominance of low-quality fuels (such as diesel with high sulfur content) (Elsom 1996). These circumstances tend to be more common in low- and middle-income cities than in high-income cities. Leaded fuels are also more common in low-income cities and account for most atmospheric lead in countries where they are still in use.

27.2.3 Urban Systems Interrelating with Surrounding Regions

Partly because of the demands that urban systems place on ecosystems in the surrounding region, cities and towns are often presented as environmentally damaging. This is misleading, particularly if human well-being is a central concern. If urban activities and residents moved to rural areas, the demands placed on ecosystems would be more dispersed, but not reduced. Yet even if, from an ecosystems perspective, urbanization is preferable to most rural alternatives involving similar economic production levels, urban pressures are increasing rapidly as the result of population growth, economic growth, and urbanization. Moreover, for adjoining ecosystems, the concentration of people and activities in urban areas can be a particular burden. Urban centers in the vicinity of fragile ecosystems are especially problematic. Cities associated with highly polluting industries typically have a greater impact on nearby ecosystems than those dominated by service industries. Poorly managed urban development can be especially destructive to nearby ecosystems.

27.2.3.1 Urban Systems and Rural Lands

In peri-urban areas, the influence of urban development is visible and often involves the conversion of land to urban uses, as described earlier, but the less direct urban influence on somewhat more distant rural lands can be just as great and extends from demand-driven land use changes to the effects of urban remittances on rural development patterns.

In an ecological history of Chicago and the ''Great West,'' Cronon (1992) describes how innovations in grain markets were linked to the loss of species diversity in the grasslands, how developments in meat handling and marketing affected animal stocks and living conditions on the farms, and how the urban lumber industry led to the decline of the White Pine forests on which it depended. When such changes occur, it is not just the increasing size of urban demands that influences the surrounding ecosystems, but the changing qualities of urban demands, including, for example, the tendency of many urban markets to demand standardized produce, thereby favoring monoculture and reducing biological diversity.

Although most contemporary cities do not have as great an influence on their hinterlands as Chicago once did, urban development remains a major influence on agricultural systems. A recent study of peri-urban agriculture in Hanoi documents a process that is likely to be present in the peripheries of most developing urban centers: the shift by farmers to producing higher-value goods in response to consumer demand in the urban areas (van den Berg et al. 2003). Such goods include vegetables, milk, and other perishable commodities (including from fish farming, shrimp farming, and flower production). Here, as in and around many other cities, agriculture is also disrupted by land speculation or the conversion of land to urban uses (including farmers who sub-divide and sell their land for housing, sometimes illegally). However, cities often provide surprising new opportunities for farmers: for instance, the demand for ''turf'' (sod) and ornamental plants for middle-class gardens in Mexico City and the demand by international tourists for authentic ''pre-Columbian'' food produce new opportunities for farmers around Mexico City (Losada et al. 1998; Losada et al. 2000).

While increasing urban demand for agricultural produce can be expected to lead to a larger expanse of agricultural land, urban demands for marketable wood products are often assumed to reduce tree cover. In the 1980s and 1990s, for example, urban demands for fuelwood and charcoal were often presented as leading to ''rings of deforestation'' around African and Asian cities where charcoal is a major cooking fuel (Cleaver and Schreiber 1994). However, as described in Chapter 21, such outcomes depend on the institutions guiding the resource use. Increasing urban demand can contribute to institutional conflicts over forest use. On the other hand, it can also motivate efforts to protect and plant forests. Although the slow growth of most woody products may inhibit private investment, trees can be planted, and in some circumstances an increasing demand for wood will result in an expansion of forest area.

From the perspective of human well-being, many of the more destructive relations between urban and adjoining systems involve interrelations that are neither valued within the market economy nor given priority by government agencies. Urban water demands often conflict with agricultural demands, and in many circumstances the institutions for reconciling such conflicts are neither equitable nor efficient (Baumann et al. 1998). Urban water pollution can damage downstream agriculture; conversely, the use of agricultural fertilizers and pesticides pollutes urban water sources. Cultivated systems can also lead to erosion, siltation, and more flooding in downstream urban areas, as well as damage to water storage facilities and water conveyance services. (See Chapter 26.) Urban air pollution contributes to acid precipitation, affecting forests and croplands with low buffering capacity; forest fires contribute to urban pollution concentrations as well as to urban fire risks.

Although some of these negative relationships have little to do with urban settlement patterns per se, others are directly related to the spatial concentration of urban consumption and production. Urban centers rely on adjacent ecosystem services to break down their biodegradable wastes, but when the capacities of these local ecosystems are overwhelmed, people living in downstream settlements are put at risk. These same biodegradable wastes may represent the loss of nutrients from agricultural and forestry systems. Urban consumption and production can also result in the accumulation of nondegradable and sometimes toxic substances (such as heavy metals) at waste sites, where they may leach into the groundwater or result in human exposure through some other means. Even relatively small urban centers face such problems, but they are magnified in large cities, and particularly in large industrial cities.

Again, it is important to distinguish between the often negative impacts that urban development has on ecosystems services and the often positive comparisons that can be made between well-managed urban development and alternative, less urban, development options. It has been suggested, for example, that urban development in drylands should lead to a reduced risk of desertification when compared with agricultural development (Portnov and Safriel 2004). In some circumstances, urban development can also provide the justification for expensive investments in water infrastructure, providing the basis for other developments.

27.2.3.2 Urban Development and Regional Water Systems

Historically, urban centers have often been founded near water sources and waterways, both to provide for urban water demands and to take advantage of water transport. As described earlier, the coastal zone is not only the most urbanized of all of the major systems identified for the MA, it is also the most densely populated with rural dwellers. A disproportionate number of urban centers, including especially large urban centers (over 500,000 people), are located at or near river mouths, which are also ecologically critical sites, particularly for some migratory aquatic and bird species. (See Chapter 20.)

Water is also a resource with a strong regional dimension. Freshwater resources from surrounding regions are still the major source of water for urban consumption, unlike many other resources that can more easily be imported great distances. Intraregional water flows provide critical connections between urban systems and the surrounding regions; as indicated earlier, unintentional changes to these water flows can create serious problems. Even groundwater aquifers can have a regional dimension. The flow of water represents the largest material flow in and out of urban areas, and it has been estimated that water represents about 90% of all material entering megacities (Decker et al. 2000).

In assessing the water relations between urban centers and their surrounding regions, it is important to consider:

- Urban→Upstream: how measures designed to meet urban demands for water and hydropower have changed the upstream water flows, affecting, for example, the availability of water for urban and nonurban users upstream.
- Upstream→Urban: how upstream water and land use changes not specifically designed to change urban water conditions have affected the qualities and quantities of water available to or flowing through urban centers.
- Urban→Downstream: how urban water and land use changes have affected the qualities and quantities of water available downstream (including coastal waters).

There are some changes that are not captured by these three categories. Thus, for example, dams and water diversions created to serve urban demands affect not just upstream users, but also those downstream, in all the river basins affected. While competition for good-quality water is often central to these relations, changes in urban water regimes can also influence flood risks, biodiversity, wetland and delta ecosystems, fisheries, migratory aquatic species, and a range of other less obvious water-related issues. Moreover, groundwater depletion often leads to land subsidence, which can have severe consequences in urban areas.

During the nineteenth and twentieth centuries, rapidly growing and economically successful urban centers relied on bringing in water from increasingly distant sources (Tarr 1996). Conflicts between urban and nonurban users have been common. Urban water use requires a higher-quality and more stable supply than that in most rural uses (for irrigation, for example), and the social, economic, and political importance of cities often ensures that their demands are given priority. The manner in which the water demands of Los Angeles were allowed to dominate over those of Owens Valley provides a well-documented example (Kahrl 1982; Reisner 2001).

When water is diverted from agriculture to urban areas, agricultural productivity can be severely affected. For example, in the Hai river basin in China, most of the freshwater resources captured by large reservoirs are directed to meet the increasing water demands from Beijing and Tianjin, and access to water has become the limiting factor in the region's agricultural productivity (Bai and Imura 2001). On the other hand, with decreases in water availability, farmers have traded off grain production for other more economically productive uses for their land and their time, not all of which are so dependent on water, and despite declining water resources, incomes have been increasing (Nickum 2002).

In most parts of the world, the spatial range of urban water withdrawals is expanding. In countries with capital-intensive water infrastructure, some of the regional water systems have become so closely integrated that it is no longer meaningful to link urban centers with spatially delimited supply networks: as with electricity systems, they are simply ''attached to the network'' (Baumann et al. 1998). Even where there is less water infrastructure, cities are reaching further upstream for more and fresher water resources, sometimes even from other river basins. In Africa, where inadequate infrastructure is often cited as a major problem, in the early 1970s many urban centers still used groundwater supplies as their primary water sources, but by the 1990s the primary water sources were more likely to be rivers, and increasingly these river sources were more than 25 kilometers away (Showers 2002).

Investment in tapping water supplies that are further away is often undertaken when less costly alternatives have not been explored. Moreover, when cities and surrounding rural areas compete for water resources, ecological water requirements (the water needed to maintain ecosystem function and local hydrological cycles) are often neglected. In many situations, demand-side management is an inexpensive means of freeing up water supplies and could be used to avoid tapping distant water supplies or undermining ecological functions (Baumann et al. 1998). Alternatively, economic analysis of other measures to improve water supplies in New York City found that in many cases it would be cheaper for the city's residents to pay upstream individuals and enterprises operating in the city's upper watershed to adopt less damaging practices than to invest in more water supply and treatment facilities. Investing in water filtration in New York is estimated to cost approximately $6 billion for design and construction and $300 million in annual operating expenses (NRC 2000; Pires 2004).

Urban centers themselves can cause a wide range of problems for people and ecosystems downstream, including those in other urban locations. Urban areas usually have a high percentage of paved areas, which concentrates rainwater rather than dissipating it. This tends to intensify flooding and can cause flash floods. Changes in the water flows can also affect downstream fish stocks, recreational opportunities, and biodiversity. (See Chapter 20.) Sewers convey human waste out of urban locations, often releasing it untreated in local waterways or coastal waters. Human waste not only poses a health risk for people who might come to ingest the contaminated water, it causes eutrophication and damages aquatic ecosystems downstream. (See Chapter 12.) Chemical water pollution is also a major problem, particularly around large industrial centers.

Coastal zones are among the worst affected by urban development, and they combine many of the most critical land and water issues. As indicated earlier, the share of land in coastal zones that is urban is particularly high, and land conversion and habitat losses of coastal wetlands, dune systems, and coral reefs are often irreversible. (See Chapter 19.) Urban areas at river mouths often constitute bottlenecks for aquatic migratory species. Other important situations related to urban areas in coastal systems are the development of ports out of natural harbors, the dredging of shipping channels, and the development of industrial centers in the coastal fringe. Port development also creates the risks of species invasion, with large ships in harbors acting as vectors for species introduced via ballast-water transfer and hull fouling.

Although high levels of urbanization are not in and of themselves a problem, urban development undertaken with little regard for its ecological implications can be extremely destructive. Dispersed rural settlements can bring about more vegetation fragmentation than population concentration in urban areas, with a strong negative impact on the health of inland water systems. The concentration of population in urban areas makes it easier to treat wastewater and avoid pollution, as point pollution sources are more likely to be controlled or eliminated. There are also many opportunities in urban areas for reusing wastewater and for engaging in demand-side management for conservation and for improving well-being. There are indications that water-management systems are slowly changing, with more attention being given to improving water use efficiency and productivity and less of a tendency to assume that water shortages must be met by more water infrastructure (Gleick 2003). On the other hand, concentrating settlement concentrates the burdens, and where urban development is poorly managed, concentration will make local disturbances even worse.

27.2.4 Urban Systems Creating Global Ecosystem Pressures

If the environmental shortcomings of the affluent city in the nineteenth century were unsanitary slums and environmental health problems within the city, and those of the affluent city in the twentieth century were urban pollution and environmental degradation in and around the city, then the major environmental burden of the affluent city in the twenty-first century is likely to be the global burden it imposes, often on ecosystems far removed from the city itself.

The importance of global trade and of global environmental burdens has grown considerably over the past two centuries, and especially in the last few decades. (See Chapter 3.) Urban development has been an integral part of this process; all urban centers are engaged to some degree in the production and consumption of internationally traded goods and in contributing to globally burdensome wastes such as greenhouse gases, persistent organic pollutants, and ozone-depleting substances. In general, however, global ecosystem pressures derive from the consumption and wastage undertaken to support the lifestyles of the world's more affluent residents, most of whom live in the urban centers of high-income countries. As much as two thirds of total consumption and pollution can be traced to cities in rich countries alone (Rees 1997).

Increasing long-distance trade spreads the ecological burden of consumption, but it also increases the likelihood that consumers will neglect the costs of ecological pressures and damage. If a population depends on local ecosystems and degrades these through excessive growth or overexploitation, the negative consequences (declining productivity) are more likely to inhibit further growth. Trade serves to short-circuit such negative feedback and may even lead to positive feedback. Urbanites who live mainly on imported goods lose their incentive to conserve remaining local or regional stocks of natural capital (biophysical resources). Thus, a city interested in promoting economic growth may sacrifice prime cropland on the urban fringe to ''highest and best (economic) use,'' permanently destroying the land's agricultural potential. Second, people living on imports are less likely to be aware of the negative ecological or social consequences of unsustainable production processes in the distant regions that are supplying them. The most successful traders are those who seek out and find the least-cost supplies, whether the low costs are based on a real comparative advantage or on the fact that the loss of ecosystem services is not being costed into the supply chain.

Urban systems are also vulnerable to global environmental shifts, including climate change and its consequences. In addition to the direct effects of warming on the habitability of urban centers, many cities are vulnerable to flooding from sea level rise or to damage from tropical storms. Nevertheless, most assessments of the global pressures of urban development focus first and foremost on impacts outside urban boundaries, recognizing that in the long run these impacts too will affect the well-being of urban residents.

27.2.4.1 Ecological Footprint Analysis

Ecological footprint (or eco-footprint) analysis is a quantitative tool that estimates the load imposed on the ecosphere by any specified human population in terms of the land and water (ecosystem) area dedicated to supporting that population (Rees 1992; Rees and Wackernagel 1994; Wackernagel and Rees 1996). It does not capture the dynamics of either ecosystems or markets, nor does it provide the basis for assessing whether any given ecological burden involves economic externalities or can be justified in terms of human well-being. Summing up ecological footprints is inevitably complicated by the diversity of services that any given ecological area can provide. Ecological footprint estimates are revealing, however, not only in demonstrating how much more extensive urban footprints are than the urban areas themselves, but also in allowing the ecological pressures of different urban centers or different population groups to be compared, at least roughly.

An eco-footprint analysis begins with the quantification of the material and energy resources required to support the consumption demands of the study population at its present material standard of living. The method is based on the fact that many of these resource and waste flows can then be converted into a corresponding productive land and water area. Thus, the ecological footprint of a specified population can be formally defined as "the area of land and water ecosystems required, on a continuous basis, to produce the resources that the population consumes, and to assimilate the wastes that the population produces, wherever on Earth the relevant land/water is located" (Rees 2001). A complete eco-footprint analysis would therefore include the ecosystem area that the population effectively appropriates to supply its needs through all forms of economic activity, including trade, plus the area it needs to provide its share of certain (usually free) land- and water-based services of nature, such as the carbon sink function.

The size of the eco-footprint depends on four factors: population, the average material standard of living, the productivity of the land/water base (whether local or "imported" in trade goods), and the efficiency of resource harvesting, processing, and use. Regardless of the relative importance of these factors and how they interact, every population has an ecological footprint. (For full details of the methodology, see Wackernagel et al. 1999; Rees 2001, 2003; World Wide Fund for Nature 2002; Monfreda et al. 2004.)

Eco-footprint analysis reveals that the residents of the more urban high-income countries impose a vastly larger load on Earth than do the residents of low-income countries. The citizens of high-income countries such as the United States and Canada have average ecological footprints of 8–10 hectares, or up to 20 times larger than the eco-footprints of the citizens of the world's poorest countries such as Bangladesh or Mozambique (see, e.g., World Wide Fund for Nature 2002).

Because consumption, production, and trade data are generally compiled at the national level by domestic statistical offices and international agencies, it is easiest to estimate national eco-footprints. Data specific to lower-level political entities such as states, provinces, or cities are generally much harder to come by. Nevertheless, a rough estimate of the eco-footprint of any given city can be made by multiplying the city's human population by the national per capita ecological footprint, and methods do exist for developing estimates at sub-national levels (see method applied in Wackernagel 1998).

Various researchers have estimated urban eco-footprints by using different assumptions and levels of detail. Despite methodological differences, such studies invariably show that the eco-footprints of typical modern cities are two to three orders of magnitude larger than those of the geographic or political areas they occupy (see, e.g., Rees 2003).

A city may represent as little as 0.1% of the area of the host ecosystems that sustain it. Such fractions emphasize that even in a stable world, no city or urban region as presently configured could be sustainable on its own. Moreover, the combined requirements of urban systems are increasingly unsustainable in the long run; in a politically unstable world, dependence on extensive and often distant ecosystems raises issues of shorter-term sustainability.

27.2.4.2 The Urban Sustainability Multiplier

Although cities, particularly high-income cities, have large eco-footprints, they also provide many opportunities to lighten the human load on Earth's ecosystems. To begin with, cities are concentrations of buildings and associated infrastructure, and the "built environment" is a key consumer of materials and energy, with considerable scope for savings. To a first approximation, the construction, operation, and maintenance of the built environment accounts for 40% of the materials used by the world economy and for about one third of energy consumption. Studies indicate that buildings in the United States account for between 15% and 45% of the total environmental burden in each of eight major categories of impact used for life-cycle assessment (an integrated "cradle to grave" approach to assessing the environmental performance of products and services) (Levin et al. 1995; Levin 1997). However, given equivalent levels of consumption, increased human density is associated with lower eco-footprints.

Many other attributes of urban life provide leverage in dealing with the energy and material dimensions of sustainability. Together these factors contribute to what might be called the "urban sustainability multiplier" and include the following (Rees 2003):

- high population densities, which reduce the per capita demand for occupied land;
- lower costs per capita of providing piped treated water, sewer systems, waste collection, and most other forms of infrastructure and public amenities;
- a high proportion of condominiums, apartment buildings, and other multiple-family dwelling units, which reduces per capita consumption of building materials and service infrastructure;
- increasing interest in eco-neighborhoods and forms of cooperative housing, which reduces demand for appliances and personal automobiles;
- easy access to the necessities for life and to urban amenities by walking, cycling, and public transit. This further reduces the demand for private automobiles, thereby lowering fossil energy consumption and air pollution (some residents even adopt an auto-free lifestyle);
- a high density and diversity of communication infrastructure, reducing the need for energy-intensive travel to face-to-face meetings;
- greater possibilities and a greater range of options for material recycling, reuse, remanufacturing and a concentration of the specialized skills and enterprises needed to make these things happen;
- economies of scale and agglomeration economies that make electrical co-generation possible and facilitate the use of waste

process-heat from industry or power plants for local (neighborhood) water and space heating, thus reducing demand for energy; and

- the opportunity to implement the principles of low-throughput "industrial ecology" (that is, the creation of closed-circuit industrial parks in which the waste energy or materials of some firms are the essential feed-stocks for others).

Walker and Rees (1997) provide a graphic illustration of the economies associated with housing type and attendant urban form. They show that the increased density and consequent energy and material savings associated with high-rise apartments, compared with single-family houses, reduce the part of the per capita urban ecological footprint associated with housing type and related transportation needs by about 40%. Such gains are independent of building materials used. Similarly, Kenworthy and Laube (1996) detail how personal energy consumption associated with transportation needs is dramatically inversely related to urban density. The sprawling cities of Australia and the United States feature vastly less energy-efficient transportation systems than can be found in wealthy, compact Asian cities. European cities generally fall somewhere in between.

27.3 Important Processes Driving Change

This section explores some of the important drivers of urban system change and their impact on urban systems and, at least indirectly, ecosystem services. Drivers can have either direct or indirect impacts on urban development. (See Chapter 1.) Among indirect drivers being considered in this assessment, those associated with globalization, technological change, political shifts (including institutional and legal framework changes), and demographic shifts are of particular importance for urban systems. Direct drivers for urban centers include, among other things, changes in land use (the expansion of cities and urban areas) and user rights and structures.

Contemporary urban development around the world also reflects the fossil fuel economy; energy use and availability are primary urban drivers. Without petroleum-based fuels and the transportation systems they underpin, existing urban systems would be inconceivable, not just because they would be unsustainable but because they would be dysfunctional (Droege 2004). More generally, energy underpins economic growth, globalization flows, and technological advances, all of which operate through urban centers. Globally, urban activities, including intra- and interurban transport, consume approximately 75 percent of the world's fossil fuel production (Droege 2004). Urban activities in high-income countries account for a disproportionate share of this consumption, but even urban centers in very low-income countries have levels of energy consumption that are higher than the historical norm.

Globalization and other drivers are experienced differently in different parts of the world. The urbanization and feminization of poverty (United Nations Centre for Human Settlements 2001; Chant 2003), the aging of populations (Lutz et al. 2004), and the adoption of telecommunication technologies are all examples of trends that are common to many different types of cities but that take different forms (see, e.g., United Nations Centre for Human Settlements 1996, 2001).

The following sections examine drivers and urban development in low-, middle- and high-income cities. This division has been selected because of its political significance as much as its empirical relevance.

27.3.1 Low-income Cities and Middle-income Cities with Economic Difficulties

Not all nations and their cities have benefited economically from globalization. Many nations have not benefited from contemporary trade and foreign direct investments flows, which underpin globalization, and therefore their urban centers are not considered "world cities" (see, e.g., Friedmann 1986, 1995). These include, for example, cities in the lowest-income economies of Africa, Asia, and Latin America (Lo 1994; Gilbert 1996; Rakodi 1997). Macroeconomic conditions and national debt burdens have played an important role in the recent development of some of these cities, and the predominance of agricultural and mineral trade and the lack of manufacturing have made them more dependent on rural than on urban economic activity and more susceptible to changes in commodity market prices. When global primary commodity prices fell in the early 1980s and interest rates increased, many of these countries experienced recessions combined with high inflation and increased debt. Foreign and domestic investment typically slowed, housing finance became less available, and infrastructure deteriorated. Without foreign investment, the application of new technologies slowed, particularly digital information and communication technologies, which further exacerbated the "digital divide" (United Nations Centre for Human Settlements 2001).

Regulatory frameworks, including policy documents, laws, traditions, regulations, standards, and procedures, influence urban development, although often not in a straightforward manner. The lack of provision of adequate shelter and the generation of slums themselves are often due in part to inappropriate regulatory frameworks (Payne and Majale 2004). The lack of appropriate institutional structures helps drive ecological and environmental trends within and around cities in this category. Ability to finance infrastructure and provide public services depends heavily on intragovernmental institutional arrangements, because capital markets rarely provide an adequate source of finance in low-income countries and because users, or potential users, in these cities are typically unable to pay the large costs associated with construction (United Nations Centre for Human Settlements 1996). Lack of access to land, because of its high cost or inadequate property rights and land tenure arrangements, has facilitated the development and expansion of slum and squatter areas within urban settlements (Hardoy et al. 2001).

These direct and indirect pressures have combined to affect cities in this category in a number of ways. One important outcome has been a reshaping of urban structure through the expansion of urban slums and squatter (sub-) settlements. The UN Habitat suggests, for example, that squatter settlements house 40–50% of the people living in Calcutta; 50–60% of those living in Bombay, Delhi, Lagos, and Lusaka; and 60% or more of those living in Dar es Salaam, Kinshasa, Addis Ababa, Cairo, Casablanca, and Luanda (see "Global Trends" from the Global Urban Observatory, at www.unchs.org/habrdd/global.html). Informal areas within urban settlements are not aberrations; rather, they are the dominant means through which cities in this category are growing. Moreover, many of these are expanding in ecologically sensitive areas, such as on steep hillsides, riverbanks, and wetlands (Hardoy et al. 2001).

The results of these pressures on human ecology have been just as stark as changes in urban form. The increase in size of cities without adequate infrastructure has put pressure on the basic ecosystem services necessary for healthy life. Inadequate and unsafe piped water supply, a lack of proper sewerage and stormwater drainage, lack of provision for garbage collection and disposal, and indoor air pollution that results from burning biomass have all affected human health and well-being (Bartone et al. 1994; McGranahan et al. 1996). The shift of population to urban areas, the lack of access to safe drinking water, the lack of the simplest latrines, the spread of preventable diseases and health risks, inadequate secure and healthy shelter, and hunger have combined to move considerable poverty and poverty-related problems from rural to urban settings (United Nations Centre for Human Settlements 2001).

Flooding and a general proneness to other natural disasters affect these communities more than more-wealthy settlements. Natural disasters act as both a driver and a consequence of current development patterns. Without adequate governance, regulation, and public spending, increasing numbers of the urban population are locating on floodplains, within swamps, and in other ecologically sensitive areas. This development pattern is making parts of a large number of cities vulnerable to natural disasters. Among the total reported deaths from disasters between 1993 and 2002, more than 53% were in countries at low levels on the Human Development Index, compared with just 4% of deaths in countries with high levels and 42% in countries with medium levels of human development (International Federation of Red Cross and Red Crescent Societies 2001).

Although most of the ecological challenges remain localized and associated with health and safety issues, activities within cities in this category have generated city-wide ecological impacts. Natural resources in and directly around these cities are being depleted as urban populations search for space to live, biofuels for cooking, and water for daily needs (World Commission on Environment and Development 1987; Hardoy et al. 2001). The pressures inherent in consumption patterns of citizens in cities of this category are far less than those created by more affluent urban residents, but the context can mean that these pressures have serious consequences both locally and throughout the metropolitan region.

In some cities in this category there are promising signs of economic growth. For example, since the 1980s many if not most Latin American countries have experienced positive growth, notwithstanding fluctuations (Tulchin 1994). Recently, some of the cities in Asia that were previously disconnected from the world economic system of trade and foreign direct investment have become connected to it, and cities such as Phnom Penh and Hanoi are on the brink of rapid economic growth. This growth, however, does not ensure either improved well-being for all or decreased ecosystem impact. Indeed, citizens in rapidly developing cities may be experiencing intensive local ecological deterioration while increasing their burdens on hinterlands and ecosystems at larger scales and farther away.

27.3.2 Rapidly Growing Middle-income Cities

Cities in this category are undergoing rapid development and are sometimes included as ''second-tier'' world cities (Taylor 2004). They are the locations of the world's new industrial production systems, and many of them are in Asia. The most obvious impacts of indirect drivers are increasingly rapid economic development. For example, during the mid-1990s Jakarta's economy was growing at 8.2% annually (Soegijoko and Kusbiantoro 2001) and Shanghai's at 14.2% annually (Ning 2001). This growth has been facilitated by the transnational connections between these cities and international investment capital. Many of the cities in this category are linked to the global economy and have experienced the world city formation process—the process by which the world's capital accumulates in cities through global trade and investments (Friedmann and Wolff, 1982), as they become manufacturing production centers (Lo and Yeung 1996; Lo and Marcotullio 2001).

Rapid economic growth has been driven, in some cases, by the emergence of clusters of private-sector organizations applying new technologies to production processes in and around cities (Hall 1995). For example, new industrial regions have sprung up in and around some cities within this category: Guangzhou, Kuala Lumpur, Seoul, Singapore, and Taipei, which are among the leaders of the high-technology and computer industries.

Rapid growth has been associated with rapid urbanization, rapid urban growth rates, and large urban sizes. The trend, particularly within the rapidly developing world, has been toward very large urban agglomerations, or megacities and megaurban regions (Fuchs et al. 1994; McGee and Robinson 1995; Gilbert 1996).

Although cities in this category have been able to compete successfully within the global economy, they have paid the price in terms of disruption to local ecosystems (Lo and Marcotullio 2001). The growth of the largest cities has slowed over the past few decades, but at the same time their internal ecosystem service conditions have worsened, suggesting that rapid demographic growth is not the primary source increasing urban environmental burdens (Brennan 1999). For example, the larger, slower-growing Asian megacities are among the world's most severely environmentally distressed (Asian Development Bank 1997).

In contrast to the experiences of cities in industrial countries, where the emergence of ecological challenges appeared over longer periods of technological and socioeconomic change and in a more sequential order, rapidly developing cities may experience a new mix of environmental challenges at lower levels of income that increasingly appear concurrently (Marcotullio 2004). Within a single city there are often pressing challenges associated with basic sewage and sanitation, industrial water and air pollution, greenhouse gas emissions, and green space.

In Bangkok, for example, transport accounts for 70% of urban energy consumption. The level of the city's GDP is three times the national average, and 70–80% of the city's population has been described as ''middle class'' (Plumb 1999), with the associated increased consumption levels that wealth brings. At the same time, Bangkok, like many of these cities in this category, has substantial numbers of people without water supply and sanitation services. Further, Bangkok is a major source of pollution, both industrial and residential, for the Chao Phraya River and a growing source of consumption, with related wider ecological impacts. Hence, Bangkok is experiencing several different sets of burdens simultaneously (Marcotullio 2003).

Given the forecasts for urbanization and industrialization in the Asian region, the overlapping burdens experienced within cities in this category are not likely to disappear in the medium term. The same may be said for rapidly developing cities in other parts of the world. From the policy perspective, this phenomenon has produced important questions concerning how to manage this mix of environmental problems in order to ensure the well-being of the urban population, the ecological integrity of urban region, and the long-term viability of economic growth.

27.3.3 High-income Cities

Cities that are at the top of the global networked hierarchy are also rapidly growing as producers of business services for global capital and finance (Sassen 1991; Honjo 1998). During the recent past, those in North America have been undergoing restructuring, as some have moved from industrial to service-dominated economies and others have grown as rapidly as cities in the developing world. Other than the influence of globalization flows, particularly important drivers of urban system change in this category include demographic shifts, technological advances, and institutional and policy changes.

Important demographic shifts include the reduced birth rate, the increase in the older population, and the decrease in household size. Most of the OECD nations have stopped growing in size and are experiencing increases in the proportion of aged populations (Lutz et al. 2004). This has substantially affected urban population structures. For instance, while the proportion of the elderly is greater in the nonmetropolitan regions of the United States than in the metropolitan regions, more than 74% of the older population resides in metropolitan areas, and the number and share of the elderly are increasing in both (Glasgow 2000). In 1990, the U.S. population over 65 years of age living in metropolitan areas reached 23.1 million. This has social and economic consequences: increasing numbers and proportions of the elderly translate into both proportionately fewer middle-aged care providers and proportionately fewer contributors of social security funding.

Accompanying the low or even negative overall natural increase in urban populations in the United States and Europe, average household size has shrunk to fewer than three, and the number of single-person households has increased to 25% in Europe and 20% in the United States. In Europe, the increased demand for new households is expected to account for 12.5 million new dwelling units in 2000–05 and for 11.5 million units in 2005–10. Despite the stabilization of the size of the urban population, the increasing number of households is still driving the demands for construction materials, space for building, energy, transport, and natural resources. Satisfying these demands can have an adverse impact on biodiversity (Keilman 2003; Liu et al. 2003).

Another important driver for urban system change is technological advance. Advances in transportation and communications have allowed the decentralization of industry and the loss of manufacturing jobs from urban centers. At the same time, the increasing application of information and communication technologies has facilitated both an expansion of markets and control over national and international economic space (globalization) and the rise of the service sector dominated by advanced business services (Sassen 1991). Moreover, within the OECD, new industrial regions based upon these technologies have sprung up around the older industrial areas (such as the Western Crescent around London, the southwest sector of Paris, the south of France, the Munich region, Silicon Valley, and Los Angeles) and some older cities (such as Munich and Tokyo) have transformed themselves into high-tech centers. Contrary to former predictions that these technologies would make cities unnecessary, dense human concentrations within the new global economy are increasingly important (see, e.g., Sassen 1991; Taylor 2004).

Environment-related policies within cities of this category have played an important role in providing cleaner and more habitable internal urban environments and have therefore become important ecosystem drivers. User charges, including utility charges for water and wastewater and pollution charges for solid waste, affect the use of these services. (See Chapter 7.) Air quality is protected in many urban areas by user charges such as road tolls (used as a traffic regulator) and pollution charges used to control and reduce emissions. Land use is regulated through user charges such as betterment charges and access fees to parks and beaches, which are widely used, in part to protect landscapes. Zoning and transferable development policies have been extensively used to conciliate environmental and development aims, including conservation of greenbelts, wetlands, cultural heritage sites, and coastal areas, and for the preservation of open space, green space, and farmland in urban hinterlands (World Resources Institute 1996).

On the other hand, decreasing household sizes, increasing vehicle ownership and usage, highway development, air-conditioning, mall construction, and new building technologies combine to facilitate land use change at urban fringes (Rusk 2001) and hence directly affect hinterland ecosystems. U.S. cities are consuming land at rates faster than that of population growth. For example, the Washington, D.C., area lost 85,000 hectares of farmland, forest, wetlands, and other open spaces during the 1980s, and California continues to lose wetlands at a rate of almost 2,000 hectares per year. Environmentally related impacts of sprawl are increasingly evident, as urbanization in these economies is associated with the degradation of water resources and water quality, changes in hydrology, increased inputs of water pollution and nutrients, and increased acidity and higher water temperatures of lakes, ponds, and streams (US Environmental Protection Agency 2001). There are also growing concerns about the health implications of this urban sprawl (Frumkin et al. 2004).

Moreover, increased transportation has also had significant global ecosystem impacts through greenhouse gas emissions. In 1997, the U.S. transportation sector accounted for 32% of national carbon emissions from fossil fuels, or 473.1 million tons of carbon. From 1984 to 1997, carbon emissions from transportation increased by 25% (rising from 379 million tons). In addition, vehicle use contributes to emissions of two other greenhouse gases, methane and nitrous oxide. Total emissions of these gases for the United States in 1997 were 213 tons of methane and 205 tons of nitrous oxide (US Environmental Protection Agency 2001).

27.4 Responding to the Environmental and Ecological Burdens of Urban Systems

Many of the reasons why ecosystem services and environmental problems in general have tended to be neglected in urban systems are similar to the reasons they have been neglected elsewhere.

- *Ecosystem services are provided through complex and poorly understood processes, taking place mostly beyond urban boundaries.* It is often difficult to understand how ecosystem changes affect human well-being, and hence which ecosystems are of particular value and which changes will result in the greatest losses (MA 2003). In urban areas, people are also likely to be even less aware than rural dwellers of how dependent they are on ecosystem services and how their actions affect distant ecosystems.
- *Ecosystems services (and environmental burdens that affect ecosystems) are difficult for private agencies to own and trade.* Only a small share of ecosystem services accrue to the owner of property where the ecosystem is located, and it is rarely feasible for the owner to charge beneficiaries for the services that they receive. It is equally difficult for those affected by ecosystem change to negotiate with those who are causing the changes to take place. Thus property owners rarely have the incentive to take account of how they are altering the availability of ecosystem services. Attempts have been made to develop markets for ecological or environmental services, but these remain rudimentary.
- *Ecosystem services are difficult for public agencies to manage or regulate.* Ecosystems located on private land are difficult for government agencies to regulate in the best of circumstances. Even where public land is involved, the benefits of ecosystem

services typically cross administrative and sectoral boundaries, and often no agency has the responsibility and capacity to care for the relevant ecosystems.

- *The groups most vulnerable physically and socially tend to be the least influential economically and politically.* The urban dwellers most dependent on local environmental services and conditions are the urban poor in low-income countries. Alternatively, among those most likely to be affected by global ecological degradation and resource depletion are future generations, who do not even have a political or economic presence.

There have been some notable successes despite these difficulties. This applies at all scales, from the intraurban environmental health issues so common in low-income areas to the global pressures associated with affluent urban lifestyles. The enormous variation in and among urban centers makes it difficult to generalize about the relevance of these successes. Moreover, even if they reflect the potential for addressing urban environmental and ecological challenges, the relevance of past successes to future responses is limited.

The concerted responses to sanitary threats that emerged in a number of cities in the nineteenth century are testimony to the potential for changing urban environmental management when the need arises. They included elements addressing each of the four challenges just noted and combined them in what came to be known as the sanitary movement (Melosi 2000).

Enormous progress was made in the study of urban public health issues: the nineteenth century saw eventual ascendance of the bacterial theory of disease over alternatives such as miasma theory, which held the diseases were contracted from the vapors emitted by, for example, urban filth (Rosen 1993). Municipal and national governments were put under pressure to organize sanitary improvements, and although there was successful resistance to demands to control air pollution (Mosley 2001), water and sewerage improvements received widespread support (Melosi 2000). There was public debate over the appropriate organization form for local water and sanitation networks (Jacobson 2000), and in many cities private enterprises helped undertake major public infrastructure projects. The increasing efforts to address water and sanitation were linked to changes that had given more political influence to the urban residents at risk (Szreter 1998, 2002).

Despite these successes, the problems that motivated the nineteenth-century sanitary reforms remain some of the major challenges for twenty-first-century urban areas. It has been estimated that more than 900 million people live in urban slums, characterized as having inadequate housing and basic services (UN-Habitat 2003b, 2003c). As indicated, a poorly documented but appreciable share of urban and rural dwellers do not have access to adequate water and sanitation, and this remains one of the major causes of preventable illness and death globally. The ecology of disease in low-income urban settlements remains poorly understood, debate over the appropriate roles of the public and private sectors continues, and the political influence of slum dwellers is still not sufficient to secure needed improvements. Moreover, conventional infrastructure projects, involving water-borne sewage systems and long-distance water conveyance, can have large environmental as well as economic costs.

The urban environmental problems that helped motivate the environmental movement in industrial countries in the twentieth century also remain a major challenge. There is a considerable body of work on sustainable cities (Haughton and Hunter 1994; Satterthwaite 1999; Beatley 2004), and the agenda for action agreed on at the United Nations Conference on Environment and Development in 1992 (*Agenda 21*) explicitly attempted to ground global aspirations in local initiatives (*Local Agenda 21*s).

Moreover, numerous technologies have been developed that, if adopted on a large scale, would radically reduce the ecological footprint of urban settlements. For example, industrial parks that promote the use of wastes from one production process as inputs into another are emerging in Canada, Denmark, the United States, and many countries in Asia, following the model set by Kalundborg in Denmark (Cohen-Rosenthal and Musnikow 2003). Rapid bus transit systems in Latin American cities such as Bogotá, Quito, and Curitiba provide successful alternative examples to the previous solutions of heavy and light rail (Fjellstrom 2003). Fuel-efficient cars and cleaner fuels are becoming increasingly available, creating a potentially significant influence on reducing local and global burdens of urban transport systems. Indeed, some have argued that the technological bases for reducing environmental pressures manyfold, without sacrificing human well-being, have been available for some time now (Weizsäcker et al. 1997).

There is no evidence, however, that the tendency toward increasing ecological footprints per capita has been reversed, even in upper-income countries where footprints are the largest and least sustainable. In part this is due to the large use of materials to produce the tools necessary for high-technology products. For example, manufacturing one desktop computer and a 17-inch cathode ray tube monitor requires at least 240 kilograms of fossil fuels, 22 kilograms of chemicals, and 1,500 liters of water. In terms of mass, the total amount of materials used is about equal to that of a midsize car (Williams 2003). The large energy and material inputs for these products, without recycling, does not suggest a dematerialization of the "knowledge society" in the near future.

In summary, although past trends demonstrate considerable potential for addressing urban environmental and ecological burdens, they do not indicate whether this potential will be realized. Historically, concerted responses have been a reaction to crises rather than the result of forward thinking. Sanitary reform, for example, emerged at a time when epidemics flourished as the result of unsanitary urban conditions, and it has proved far more difficult to maintain in the face of less dramatic diseases. It is possible to interpret the history of some of the world's affluent cities as a series of victories over ecological and environmental challenges: first a sanitary revolution (nineteenth century), then a pollution revolution (twentieth century), and now an anticipated sustainability revolution. It is also possible, however, to interpret this same sequence as a process of displacement that has left most contemporary cities in a very difficult situation.

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