

Chapter in Understanding Urban Ecosystems, Alan Berkowitz *et al.* (eds) New York: Springer-Verlag (2003).

(Second Draft)

William E. Rees, University of British Columbia

Understanding Urban Ecosystems: An Ecological Economics Perspective

Framing the Analysis

Is an anthill an ecosystem? Is a cattle feedlot? These might seem like strange questions to begin a discussion of so-called ‘urban ecosystems’, but if we think about it for a moment there is more than mere metaphor in comparing cities to anthills and feedlots.

Anthills, feedlots, and cities share important systemic characteristics. Each of these entities is associated mainly with a single species – anthills with ants, feedlots with cattle, and cities with humans. All three are characterized by large populations and extraordinary densities of their keystone inhabitants. And, most importantly from the perspective of their defining species, none is ecologically self-contained nor self-sufficient – anthills, feedlots, and cities are all sustained by biophysical processes that occur mainly outside the boundaries of the named entities themselves. What, then, are the relevant ecosystems for ants, cattle, and people? This chapter addresses this question for people, particularly urban dwellers, from the perspective of human ecology and ‘ecological economics’.

What do We Mean by ‘Urban Ecosystems’?

We increasingly hear the term ‘urban ecosystem’ and there is now even a scientific journal called *Urban Ecosystems*. Nevertheless, the very idea remains ambiguous as illustrated by virtually any copy of the journal itself. Despite the fact that human beings are clearly the dominant species in the urban environment often a majority of the papers focus on non-human plants and animals or on remnant ‘natural’ ecosystems within the city. These studies analyze such things as changes in earthworm species composition with soil contamination, the pattern of vegetation across the urban density gradient, the habitat characteristics of urban scorpions or coyotes, or the fate of urban wetlands.

Clearly, such studies cast the city as a somewhat unnatural habitat for non-human organisms. Indeed, it is the presumptive unnaturalness that makes the urban habitat interesting. To many ecologists, the ‘urban ecosystem’ consists of the assemblage of non-human species *in the city* and the purpose of inquiry is to determine how these species have adapted to the structural and chemical vagaries characteristic of the ‘built environment.’ People are implicitly involved but merely as the external causative agents, the doers of the damage or the creators of the habitat to

which the other species are adapting. In this sense, many of the papers are variations on ‘impact ecology’ – the scientific issue is: how do the qualities of the ‘built environment’ affect the structure and function of the (non-human) ecosystems it contains?

Other articles reverse the orientation and study the impacts of non-human ecosystems (e.g., urban forests and green open space) on the quality of the urban environment or on urban micro-climates as they affect people. Still others examine the human economic or aesthetic values ascribable to nature in the city. These are all valid research perspectives and the questions they raise are clearly important, but they by no means tell the full story. Most significantly, they do not examine humans integral components of urban ecosystems nor the role of ‘the city’ in human ecology.

In this chapter, therefore, I adopt an explicitly human-centred ecological perspective in an exploration of so-called ‘urban ecosystems’. After all, cities are among the most spectacular of human creations and many people see cities as *the* principal habitat of sophisticated, modern ‘man’. Almost half of humanity will live in cities by the year 2000 and the world’s (human) urban population is expected to swell by an additional 2.1 billion people by 2025 (UN 1995, UNDP 1998). The urban expansion anticipated in the first quarter of the new century is the equivalent of the entire human population attained by the early 1930s. The scientific questions here are: what is the role of the city in human ecology, how should this be reflected in ‘urban’ land use planning, and what are the implications of urbanization – local and global – for ecological security and socioeconomic sustainability?

Defining Ecosystems

Understanding *urban* ecosystems requires some exploration of the ecosystems concept itself and this leads immediately into difficult territory. Ecosystems are not discrete entities like an apples or oranges. To some extent, they are a product of the human mind constructed for purposes of analytic convenience. For example, boundaries between ecosystems are often indistinct and seemingly arbitrary. While anyone can distinguish the deep forest from the open prairie, the line of demarcation between them (the ‘ecotone’) may be diffuse, especially if there are no marked changes in topography. Ecosystems are also constantly in flux. Their species composition and structure changes over time in a natural ‘succession’ of plant and animal communities, particularly after being perturbed by fire or human action such as clear-cutting. Where we draw the line between ecosystem types in space and time is therefore often more determined by human purpose than by any abrupt discontinuities in nature.

All this serves to emphasize that ecosystems should be understood more in terms of characteristic structural properties and functional relationships than by gross morphology. All ecosystems comprise living organisms existing in obligatory relationship with each other and with certain non-living components of their physical environment. Any biotic community interacting with its environment such that the flow and dissipation of energy results in a defined trophic (feeding) structure, the emergence of biodiversity, and characteristic material cycles between the living and non-living components may be considered an ecosystem (Odum 1971).

The living component of an ecosystem includes both producer and consumer organisms. The ‘producer’ or autotrophic (self-feeding) organisms, mainly green plants, are able to ‘fix’ solar energy and use it to ‘manufacture’ complex chemicals (food) from simple inorganic chemicals (e.g., carbon dioxide and water) and a few nutrients (e.g., nitrate, phosphate). By contrast, ‘consumer’ or heterotrophic (other-feeding) organisms obtain their energy and material requirements by feeding on other organisms or on organic detritus (i.e., by rearranging and degrading the complex chemicals originally photosynthesized by the autotrophs). The heterotrophs can be further divided into macro-consumers, mainly animals that eat other plants or animals; and micro-consumers, mainly bacteria and fungi. The latter break down the complex compounds of dead (sometimes living) organisms, extracting some of the energy and material for their own growth and reproduction, and releasing organic nutrients back into the systems for reuse by the autotrophs.

The major non-living components of most ecosystems include simple organic and inorganic substances, solar energy, a physical substrate, and the climatic regime (temperature and other physical factors).

The various components of ecosystems typically interact in a manner that results in the emergence consistent and predictable functional relationships. The key relationships can be analyzed in terms of energy flows, food chains or food webs, and material (nutrient) cycles. Ecosystems relationships also produce discernable developmental and evolutionary patterns in time and space.

Two points from the above are particularly critical to interpreting ecosystem structure and function. First, a universal feature of ecosystems is the continuous recycling of nutrients between the autotrophic and heterotrophic organisms. Second is the generally high degree of interdependence, particularly causal linkages and obligatory relationships, among ecosystems components. Thus, while there is often minor spatial or structural separation between systems components in natural ecosystems (e.g., the vertical stratification between producers and consumers in forests and lakes), in functional terms, critical components are operationally inseparable from each other and the whole (Odum 1971).

What makes these latter qualities critical is that they characterize complete ecosystems as ‘autopoietic’ or self-producing systems. “Living systems... [are] organized in a closed causal circular process that allows for evolutionary change in the way the circularity is maintained, but *not for the loss of the circularity itself*” (Maturana 1970, emphasis added). Thus, autopoiesis results from a network of production processes in which each component participates in the production of other components of the network through the relationships that specify the system (Maturana and Varela 1980, 1987).

Thinking Ecologically: Beyond Cartesian Dualism

With these concepts in mind, contemplate the following simple experiment designed to determine how typical urban residents conceive of the city. Ask a random sample of adults on the street to define ‘city’. Hypothesis: virtually no one will characterize the city as an ecosystem or even as part of the total ecosystem complex of which humans – and their cities – are a part.

Almost invariably, people describe cities as places characterized by great (human) population densities or as spaces dominated by buildings, streets, and other human-made artifacts (this is the architects' 'built environment'). Some may think first of the city as a political unit with a defined boundary over which the municipal government has jurisdiction; the artistically inclined might see the city as a concentration of cultural, social, and educational facilities that would simply not be possible in a town or village; and the economically-minded will describe the city as a place of intense exchange among individuals and firms, as the engine of national economic production and growth. (Indeed, Jane Jacobs [1984] famously described cities the basis for the "wealth of nations.") However, only rarely does anyone characterize the city in terms of its ecological structure or function, as an ecosystem, and certainly not as part of the human ecosystem. While these qualities are as real and arguably as important to the human condition as the demographic, social, or economic dimensions of cities they go unremarked by the average citizen today. Modern humans are unaccustomed to thinking of themselves as ecological or even biological entities.

This observation illustrates is the inordinate power of 'Cartesian dualism' in maintaining the psycho-separation of humans from their natural roots. The legacy of the enlightenment in western culture is a reductionist mindset that sees the human enterprise as somehow separate from and above the natural world (Hayward 1994). Such humanity-nature apartheid is even evident in most of our academic disciplines. For example, as previously noted, ecologists studying urban ecosystems tend to focus on non-human species as if people, the major inhabitants of the city, were not part of nature. Similarly, neoliberal or neoclassical economists tend to treat the economy and 'the environment' as separate systems, with the former functioning more or less independently of the latter (Daly 1991a) (Figure 1a).

So it is that our scientific-industrial culture sees urbanization in the 20th Century mainly as a demographic transition driven by economics abetted by modern technology. We virtually ignore its ecological implications even though the mass 'migration' of humans from all over the countryside into cities may well be the most ecologically significant phenomena since the emergence of *Homo sapiens* on the evolutionary scene.

This explains why I adopt an explicitly ecological perspective – more precisely, an 'ecological economics' perspective – in this chapter. Ecological economics was conceived, in part, to reconcile humankind with the rest of the natural world. It treats human beings not as outside nature, but rather as integral components of, and active participants in, the ecosystems that support them, i.e., as macro-consumers. From this point of view, much economic activity is really the material expression of human ecological relationships (Figure 1b). Ecological economics thus sees the human economy not as a separate system, but rather as an open, fully contained and dependent growing sub-system of the materially closed, non-growing ecosphere (Daly 1992, Rees 1995).¹ This framework better equips us to and analyze cities – the economic engines of national economies – as ecological entities.

¹ A full comparison of the differing precepts and implications of ecological and neo-liberal economics is provided in Appendix 1. [Alternately, insert Table 1 near here.]

- figure 1 (a,b) near here -

Ecological Economics and the 'Second Law'

The second law of thermodynamics governs the unidirectional flow of energy through ecosystems. If we accept humans as ecological entities then we must also accept that human economic activity is governed by the second law (Georgescu-Roegen 1971, Daly 1991). This most fundamental of physical laws is central to ecological economics, but is virtually ignored by conventional economic models.

In its simplest form, the second law states that any isolated system will tend toward equilibrium; alternately, the 'entropy' of any isolated system always increases. Available energy spontaneously dissipates, concentrations disperse, gradients disappear (Rees 1997a). An isolated system thus becomes increasingly unstructured in an inexorable slide toward thermodynamic equilibrium. This is a state of maximum entropy in which there is no structure and nothing can happen (Ayres 1994).

The second law was originally formulated for simple isolated systems close to equilibrium. We now recognize, however, that even open, far-from-equilibrium, self-organizing (autopoietic) systems are subject to the forces of entropic decay. Clearly, however, not all such systems dissipate as expected. On the contrary, many biophysical systems, from individual fetuses to entire ecosystems actually gain in organizational complexity and mass over time (i.e., they *increase* their distance from equilibrium).

How can we reconcile this seemingly paradoxical behavior with the second law? The explanation lies in the functional relationships that develop among complex autopoietic systems in nature. Biophysical systems exist in loose, nested hierarchies, each component subsystem being contained by the next level up and itself comprising a chain of linked subsystems at lower levels. (Kay *et al.* 1999) define such complex hierarchic structures as 'self-organizing holarchic open' [SOHO] systems.) This arrangement enables each subsystem to maintain itself and to grow by importing available energy and material (essergy) from its host environment. Subsystems also export their degraded energy and material waste (entropy) back into their hosts. In effect, contemporary interpretations of the second law posit that all highly-ordered self-producing systems develop and grow (increase their internal order) "at the [potential] expense of increasing disorder at higher levels in the systems hierarchy" (Schneider and Kay 1994). Because such systems maintain themselves by continuously degrading and dissipating available energy and matter, they are called 'dissipative structures' (Prigogine 1997).

Economic 'Production' as Consumption

The second law explains an important difference between ecological and economic perceptions of the economic process. Mainstream economists, who ignore thermodynamics, are preoccupied with increasing *output*, and see the economy mainly as a productive process. (Historically, they have considered pollution impacts as 'external' to the market or pricing system.) By contrast, ecologists who regard thermodynamics as fundamental, focus on resource *inputs* and waste outputs (potential pollution), and see the economy also as a consumptive process.

Indeed, ecologists would classify humans (along with all other mammals) as consumer organisms – macro-consumers to be precise. As noted, macro-consumers are large organisms, mainly animals, that consume other organisms (plants or animals) to satisfy their metabolic requirements (Odum 1971). There can be no dispute about this classification. Through population growth and technology, humans have inserted themselves as the dominant consumer organism in all the world's major ecosystem types, from grasslands and forests to rivers and the sea. (How many people conceive of humans as the most ecologically significant marine mammal?)

However, humans differ from other consumer organisms in important ways. Not only do we have a biological metabolism, we also have an industrial metabolism (Ayres and Simonis 1994). Like our bodies, all our toys and tools, factories and physical infrastructure, require continuous flows of energy and material from and to 'the environment' for their production, operation, and maintenance. Thus, any complete material accounting for the human enterprise must factor in the 'metabolic' demands and waste output of all our cultural artifacts. Many of these artefacts constitute what conventional economists refer to as 'manufactured capital' or 'the built means of production'.

Of course, humans are also producers but there are significant differences between production in the economy and from production in ecosystems. In nature, green plants are the 'factories.' They use an *extra-terrestrial* source of relatively low-grade energy (light from the sun) and use it to assemble simple, dissipated chemicals (mainly water, carbon dioxide, and a few mineral nutrients) into the high-grade fats, carbohydrates, proteins, and nucleic acids upon which most other life forms depend. The assimilated solar energy is further degraded and dissipated in the process. Because they are 'self-feeding' and use only dispersed (high entropy) substances for their growth and maintenance, green plants are called *primary* producers.

By contrast, humans are strictly *secondary* producers. To produce our bodies and all manner of economic goods and services, humans must extract large quantities of high-grade energy and material resources from ecosystems and other sources within the ecosphere. In short, all production by humans, from population growth to manufactured goods, services, and capital itself, requires the consumption of a larger quantity of energy and material *first produced by nature*. Thus, while the ecosphere develops and produces itself by dissipating solar energy, the economy grows by dissipating the ecosphere.

Are Cities Ecosystems?

We now have a framework from which to address the questions posed at the beginning of the chapter. Do anthills, feedlots – and cities – qualify as ecosystems? As previously noted, a universal structural feature of ecosystems is the coexistence of autotrophs and heterotrophs. Producer and consumer organisms (particularly micro-consumers) coexist in a mutually interdependent obligatory relationship which ensures a cascade of energy and the continuous recycling of essential chemical nutrients through the ecosystem. Continuous energy and nutrient flows are essential if the system is to persist as a self-sustaining assemblage of components and relationships within a particular physical environment. In functional terms, autotrophs and heterotrophs are operationally inseparable from each other

From this classical perspective, it is clear that neither anthills nor feedlots qualify as ecosystems. They may be systems at some level (e.g., as an economic unit in the case of the feedlot), but they are not ecosystems. Some of the defining parts (primary producers) are missing altogether and, certainly in the case of the feedlot, others (micro-consumers) are insufficiently abundant for conditions in the artificial environment.

Let's stay with the feedlot for a moment. This system is dominated entirely by a single macro-consumer species, cattle destined for human consumption. The autotrophs that produce the feed for feedlot cattle (or pigs, or chickens, which are raised using even more constrained industrial methods) are located at great distance from the feedlot itself. Having separated the 'operationally inseparable', industrial feedlotting usually short-circuits even the possibility of within-ecosystem organic decomposition or nutrient recycling. As a result, feedlots often accumulate vast quantities of manure much of which is disposed of inappropriately, contaminating soils, surface, and subsurface waters. Such obvious ecological dysfunction is no small matter. In Canada, more nitrates are lost in manure that, because of distance, cannot be reapplied economically to crop and grazing land than is applied to crops in the form of artificial fertilizers (Canada 1971). Clearly, while industrial livestock operations may be economically viable for their operators, the unaccounted real economic and ecological costs born by society are considerable.

Cities, of course, are much more ecologically complex than feedlots. Certainly they contain various ecosystems that, while greatly modified by human activity or inputs, include all the essential parts and function more or less normally. As already noted, such 'urban ecosystems' are worthy objects of study because of adaptations their constituent species have made to the urban environment or because of their impacts on the quality of the urban environment for humans.

However, while humans create cities, are the largest macro-consumer in the urban environment, and many consider cities to be the principal habitat for humankind for the foreseeable future, urban dwellers have an ambiguous relationship to most of the urban ecosystems referred to above. Certainly in-city ecosystems serve as an aesthetic backdrop to human affairs and they may affect the quality of the urban physical environment either positively or negatively. However, people are arguably not a functional component of most urban ecosystems (backyard and community gardens excepted). In the main, modern cities to people are analogous to anthills for ants and feedlots for cattle. Humans may be the most obvious urban species, but the producer organisms that feed them, and the bulk of the micro-consumers needed to complete the nutrient cycles of which they are a part, are located in other ecosystems at distance from the city. We can only conclude that while urban ecology must consider humans, cities *per se* constitute only a small part of the ecosystem complex needed to support urban human populations.

Ecological Footprint Analysis

How small a part can be shown using ecological footprint analysis. Eco-footprinting is an analytic tool designed to estimate the 'load' imposed on the ecosphere by any specified human population. The metric used is the total area of productive land- and waterscape required to support that population (Rees 1996, Wackernagel and Rees 1996). Eco-footprinting is solidly

based on the premises of ecological economics. For example, it: 1) recognizes that despite our technological wizardry, humans remain a part of nature and that the economic production/consumption process invariably appropriates the biophysical output of a finite area of terrestrial and aquatic ecosystems; 2) emphasizes biophysical (rather than monetary) measures of humankind-ecosystems relationships.

Eco-footprint analysis has helped to reopen the controversial issue of human ‘carrying capacity.’ For non-human species such as deer or cattle, carrying capacity (indicated by ‘K’ in the logistic equation) is typically defined as the maximum population that can be supported indefinitely in a defined habitat without permanently damaging the habitat (Gever *et al.* 1991, Meadows *et al.* 1992). However, because the physical environment is in constant flux, carrying capacity is often more theoretically than practically useful even for other animals and economists have long rejected the concept as irrelevant to humans.

The economists’ argue that trade can usually relieve local resource shortages and, if that fails, technology can increase resource productivity or provide functional substitutes for specific goods and services of nature. Theoretically, these factors should remove any practical constraints on the growth of local populations or economic activity. According to some authors, human ingenuity has been so successful historically in pushing back the limits to growth that “the term ‘carrying capacity’ has by now no useful meaning” (Simon and Kahn 1984).

Eco-footprint analysis gets around the economists’ argument simply by inverting the standard carrying capacity ratio: rather than asking how large population can live in a given area, eco-footprinting estimates how much area is needed to support a given population, wherever the relevant land is located. This approach recognizes that while trade enables increases in local populations, those populations are now dependent, in part, on the productivity of *distant* ecosystems. Thus, by shuffling resources around, trade increases total human load but *does not increase total carrying capacity*. Similarly, increasing technological sophistication has not decoupled the economy from the land. On the contrary, as we shall see, modern humans are arguably more land-dependent than ever. Carrying capacity is therefore still a valid concept and potentially limiting.

Methodological Premises

Eco-footprinting builds on traditional trophic ecology. We construct what is, in effect, an elaborate ‘food-web’ for the study population by quantifying the material and energy flows supporting that population and identifying corresponding significant sources of resources and sinks for wastes. As previously noted, in compiling a human ‘food’-web we must account for the energy and material demands of not only our biological metabolism but also our industrial metabolism.

Eco-footprinting is further based on the fact that many material and energy flows (resource consumption and waste production) can be converted into land- and water-area equivalents. Thus, *the ecological footprint of a specified population is 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. A complete eco-footprint analysis would therefore include both the area the population ‘appropriates’ through commodity trade and the area it needs to provide its share of certain free land- and water-based services of nature (e.g., the carbon sink function). Note that eco-footprint estimates are generally trade-corrected. For example, a population’s consumption of wheat can be represented as follows: $\text{consumption}_{\text{wheat}} = \text{production}_{\text{wheat}} + \text{imports}_{\text{wheat}} - \text{exports}_{\text{wheat}}$.

Generally speaking, the ecological footprint in hectares (ha) for a specific consumption item is estimated by dividing total consumption of that item by the study population (kg) by the average yield of producing lands/waters ($\text{kg} \times \text{ha}^{-1}$). In the case of selected wastes, total output of a given waste is divided by average assimilation rates per hectare. The population’s total eco-footprint is obtained by summing the footprints of all calculable consumption and waste items. We avoid double counting whenever it is recognized (e.g., leather is a by-product of beef production so is not separately estimated). Note that it is not generally possible to determine the actual locations of various ecosystems providing resources and services to a given study population. (Many wastes, for example, are generally spewed into the global commons. Carbon dioxide from Chicago is transported by the atmosphere and partially assimilated all over the world.) However, this affects neither the size of the eco-footprint estimate nor the reality that an equivalent aggregate area of real land/water is being used by that population, however widely it may be distributed across the planet.

A population’s ecological footprint can be interpreted in ‘second law’ terms. As noted, from the ecological perspective, humans and their economies are primary consumers. However, for sustainability, consumption by humans cannot persistently exceed production by the corresponding supportive ecosystems. Since biophysical production is essentially driven by photosynthesis (solar energy), a population’s ecological footprint represents the area required continuously to generate photosynthetically the free energy and material (essergy) dissipated by that population’s consumptive activities. In effect, it is the solar collector required to power the population’s creative, maintenance, and growth-related activities.

Many factors bear on the ultimate area of a given population’s eco-footprint, including the size of the population, the average material standard of living, the productivity of the land/water base, and the (technological) efficiency of resource harvesting, processing, and use. For practical reasons, only major categories of consumption (132 categories in recent calculations) and waste can be included in the analyses. Thus, most published eco-footprint calculations tend to be under- rather than over-estimates. Fuller details of the method with examples can be found in Rees (1996), Rees and Wackernagel (1994), Wackernagel and Rees (1996) and Wackernagel *et al.* (1999).

Urban Ecological Footprints

Recent eco-footprint analyses show that average citizens of North America, Europe, Japan, and Australia – the worlds most intensely urban regions – require the biophysical output of five to ten hectares (12-25 acres) of biophysically productive land and water *per capita* to support their consumer lifestyles (Wackernagel *et al.* 1999). These findings should alter our perceptions about cities, urban ecosystems, and urban economies.

For example, in 1995 the author's home city of Vancouver, Canada, had about 472,000 residents living on a political footprint of 114 km² (11,400 ha). Assuming Vancouverites enjoy the average Canadian eco-footprint of 7.7 hectares *per capita* (Wackernagel, *et al.* 1990), we estimate that the aggregate eco-footprint of Vancouver is 3,634,400 ha, or 319 times its nominal area. Similarly, in 1996 Canada's largest city, the newly amalgamated Metro Toronto, had a population of approximately 2,385,000 and an area of 630 km². With a *per capita* footprint of about 7.6 hectares, the total ecological footprint of Toronto was about 181,260 km², or nearly 290 times larger than its political area Onisto *et al.* (1998). Finally, in an unusually comprehensive analysis, Folke *et al.* (1997) estimated that the 29 largest cities of Baltic Europe appropriate for resource consumption and waste assimilation, an area of forest, agricultural, marine, and wetland ecosystems 565 to 1130 times larger than the areas of the cities themselves (depending on assumptions about waste assimilation). These studies show that the ecosystems *in* high-income cities constitute less than one percent, and as little as .1%, of the total ecosystem area required to support their human populations.

We have noted that traditional economics sees cities as the engines of the national economy – certainly the manufactured financial capital that produces most of the nation's money income is located in and around cities. However, ecological economics underscores the dependence of the urban economic machine on the 99+ percent of the supportive ecosystems that lie outside the city. While cities produce the goods and services from which we earn our money incomes, stocks of natural capital in the countryside and the global commons produce the natural income – flows of resources and ecosystems services – upon which urban populations and the entire economic process feeds. (see Box 1 for a fuller explanation of the natural capital/income concept).

- Box 1 near here -

The sheer scale of high-income eco-footprints produces some potentially troubling comparisons. A limited analysis for the International Institute for Economy and Development in London shows that the biophysical demands of London alone appropriate a productive area equivalent to all the ecologically productive land in Britain (IIED 1995). This result presages another key finding of ecological footprint analysis – most high-income countries have an ecological footprint several times larger than their national territories. In effect, they are running massive *ecological deficits* with the rest of the world (Rees 1996).

In fact, several studies suggest that urban industrial society is now running a *global* ecological deficit of 30 percent or more and are accumulating a non-repayable ecological debt (Carley and Spapens 1998, Folke *et al.* 1997, Wackernagel and Rees 1996, Wackernagel *et al.* 1999). Even at current average levels of economic production and consumption, the human load exceeds the long-term carrying capacity of the Earth. Fisheries collapses, ozone depletion, greenhouse gas accumulation, and falling water tables are some of the better-known empirical trends showing that much of today's economic activity is derived from the unsustainable liquidation of natural capital.

As noted, many experts and ordinary people alike interpret the material abundance of the industrial world as evidence of humanity's growing *independence* of nature. According to well-

known growth advocate, the late Professor Julian Simon: “Technology exists now to produce in virtually inexhaustible quantities just about all the products made by nature...” (Simon, cited in Bartlett 1996). Sometimes urbanization itself is taken as proof that people are throwing off the shackles of the land. These beliefs are illusion. Sustainability is unattainable from within the expansionist paradigm. The ecological reality is that productive croplands, pasture-lands, and forests everywhere are being used more intensely than ever to sustain the world’s burgeoning urban populations. In fact, the average *per capita* and total loads imposed by people on the land have increased steadily with rising incomes since the beginning of the industrial revolution.

Reconsidering Urban Ecosystems: A Human Ecological Perspective

Great cities are planned and grow without any regard for the fact that they are parasites on the countryside which must somehow supply food, water, air, and degrade huge quantities of wastes.

- Eugene P. Odum (1971).

This chapter set out to explore the human element of ‘urban ecosystems’ from an ecological economics perspective. What, then, have we learned? Several points flow from the preceding analysis. To summarize:

- While people create ‘urban ecosystems’, and these systems provide the entire habitat for many non-human populations, urban ecosystems comprise only a tiny fraction (typically much less than one percent) of the total area of productive ecosystem required to support urban human populations.
- Urban dwellers play only a minor functional role within many ‘in city’ urban ecosystems, but they are virtually the sole macro-consumers in vast areas of cropland, pasture, and forest outside the city scattered all over the world. Similarly, many wastes generated by people in the city are injected into the global commons – the atmosphere, rivers, and ultimately the oceans – for processing and possible recycling.
- This means that the ecosystems providing most of the biophysical life support for urban human populations are actually rural and other extra-urban ecosystems. Major cities (and many entire countries) are sustained largely on ‘carrying capacity’ imported from the countryside and the global commons all over the world. Thus people who live in cities are no less dependent on, and may be more demanding of, the productivity of rural landscapes than they would be if they were still living ‘on the land.’
- As is the case with livestock feedlots, cities lack key ecosystems components. The migration of people from the land to cities effectively disrupts human-dominated ecosystems by separating the ‘operationally inseparable’ (primary production is spatially removed from consumption, and consumption from most subsequent decomposition). Most importantly, urbanization significantly alters natural biogeochemical cycles of vital nutrients and other chemical resources. It changes local, cyclically integrated ecological production systems into global, horizontally disintegrated, throughput systems (Rees and Wackernagel 1996). Thus, from the perspective of their main inhabitants, cities *per se* are not functional ecosystems.
- Cities are nodes of intense energy/material consumption and waste production embedded within a vastly larger global tapestry of productive land and water. In this singular sense (as Odum [1971]) remarked, cities do resemble parasites in their relationship to the countryside. A parasite is an organism that gains its vitality at the expense of the vitality of its host. In

thermodynamic terms cities are ‘dissipative structures’ that grow and maintain their internal order using low-entropy and matter extracted from their host environments. They also discharge (dissipate) the resultant low-entropy waste back into their hosts. Because of their enormous energy and material throughput, cities generate most of the world’s waste and their populations suffer the most heavily polluted environs on the planet.

Some critics might object to the emphasis here on cities’ dependence (parasitism) on rural areas. One can argue, quite rightly, that the relationship is actually a two-way, mutualistic one. Certainly rural residents benefit from such things as urban markets, the products of urban factories, urban-based services, and technology transfers from urban areas; indeed, they freely trade the products of forest and field to obtain these benefits. However, it is also true that while rural populations have always survived with or without cities, the ecological dependence of urbanites on rural environments is absolute. There can be no urban sustainability without rural sustainability.

More generally, the above conclusions should not be construed as an argument against either cities or urbanization. Rather, the intent is to clarify the ecological role of cities in an increasingly human-dominated world. For example, knowing the extent to which cities currently undermine the very ecosystems that sustain them is essential to developing any strategy to reconcile cities with the rest of nature. Indeed, such knowledge is critical not only to the sustainable planning and development of cities *per se*, but also to developing overall strategies to reduce the human load on the ecosphere.

For example, the construction, operation, and maintenance of buildings presently accounts for 40 percent of the materials used by the world economy and for about a third of energy consumption (Worldwatch Institute 1995). This suggests that improvements in building technology, design, and maintenance alone could make a significant contribution to reducing the ecological footprints of cities (Rees 1999). Moreover, the sheer concentration of population and consumption in cities gives them enormous leverage in dealing with the material dimensions of global sustainability. I call this the ‘urban sustainability multiplier’ (Rees 1995). Some of the major advantages of cities include:

- lower costs *per capita* of providing piped treated water, sewer systems, waste collection, and most other forms of infrastructure and public amenities;
- greater possibilities for, and a greater range of options for, material recycling, re-use, re-manufacturing, and the specialized skills and enterprises needed to make these things happen;
- high population density which reduces the *per capita* demand for occupied land;
- great potential through economies of scale, co-generation, and the use of waste process heat from industry or power plants, to reduce the *per capita* use of fossil fuel for space-heating;
- great potential for reducing (mostly fossil) energy consumption by motor vehicles through walking, cycling, and public transit.

(Mitlan and Satterthwaite 1994, Rees and Wackernagel 1996, UNCHS 1996)

It is also important to recognize that ecological impacts that can be traced *to* cities are not necessarily the impacts *of* cities *per se*. Much of a city’s ecological footprint is attributable to the consumption patterns of urban residents. What and how much we consume reflects prevailing

social values as well as personal preferences and activities, and to a large extent these things are independent of where we live. Certainly if the fixed elements of an individual's footprint require the continuous output of two hectares of ecosystems scattered about the globe it doesn't much matter where that individual resides (Rees and Wackernagel 1976). This means that while the ecological dysfunction caused by rural-urban spatial separation, and the sheer volume of waste production in cities are particular urban ecosystem problems that must be dealt with, modern industrial society itself may be inherently unsustainable.

This leaves unanswered the question of whether there is an ecologically optimal population distribution or settlement pattern. This is a complicated issue. For example, people often move to cities because of greater economic opportunities. To the extent that the higher average incomes result in increased average personal consumption (*net* of any savings resulting from urban agglomeration economies), the average urbanite's ecological footprint may well be greater than those of a typical rural resident in the same country. This would be true even though many categories of elevated urban consumption – higher clothing bills, cleaning costs, increased expenditures on security – do not contribute to a net improvements in urbanites' welfare. These things nevertheless add to the individual's and therefore the city's total eco-footprint. Are today's cities inherently more or less sustainable than more dispersed settlement patterns? We cannot say with certainty on the basis of the mixed evidence to date.

We can argue, however, that urban economies should be much more efficient in their use of resources. Despite the absence of short-term market signals, there are two immediately compelling reasons for cities to strive to do more with less: the increasing probability of global climate change and a possibility of serious petroleum shortages in coming decades (Duncan and Youngquist 1999). Climate change may undermine agriculture and geopolitical stability, and therefore threatens the ecological and political security of urban populations dependent on reliable flows of resources from afar. Abundant cheap energy is a critical resource in itself and is the means by which humans obtain most other resources. Industrial society in general, and cities in particular, are the product of petroleum and may implode without it (Price 1995). Some energy analysts argue that given the continuing lack of suitable substitutes for myriad uses of petroleum as fuel and feedstock, the life-expectancy of our western techno-industrial society "is less than 100 years" counting from the 1930s! (Duncan 1993). Enhanced efficiency would both reduce carbon dioxide emissions (thus slowing climate change) and conserve oil supplies.

The prospect of global change and the needed efficiency revolution also argues for enhancing the self-reliance of urban regions (Rees 1997). With urbanization and an increasingly global market, many commodities and manufactured goods travel thousands of kilometers between the point of production and point of consumption. This involves a considerable and often unnecessary expenditure of energy and material on transportation and related infrastructure alone, and contributes significantly to urban ecological footprints. Increased regional self-reliance would produce immediate economic and ecological savings in the form of reduced transportation costs, lower carbon dioxide emissions, and fewer processing and storage facilities.

There are additional ecological advantages to local production for local consumption. The juxtaposition of production and consumption has the potential to restore, at least partially, the integrity of the total human-dominated ecosystem complex. For example, depositing urban

organic compost on nearby farm- and forest-land would close the nutrient cycles broken by the spatial separation of rural ecosystem and urban populations today. This would make cities less destructive of their sustaining ecosystems and the money costs might be recovered by savings from lower artificial fertilizer bills and reduced pollution damage from both fertilizer and urban wastes.

All this suggests that we should even begin rethinking the city in a 'whole-systems' framework. For completeness, should not the urban ecosystem as much as possible comprise both the consumption-based urban core and a production-oriented rural periphery? At the very least there is an argument for rationalizing land uses within major urban regions to satisfy intra-regional urban demand. In this context, the bioregional philosophy of learning to live as much as possible 'in place' has considerable appeal (Berg 1990, Sale 1985). The central idea of urban ecosystem planning would then be to reintegrate the geography of living and employment, of production and consumption, of city and hinterland. Such a transformed "homeplace, ... rather than being merely the site of consumption, might, through its very design, produce some of its own food and energy, as well as become the locus of work for its residents" (Van der Ryn and Calthorpe 1986, xiii). In short, the urban ecosystem would finally become a complete ecosystem. Regrettably, the notion of regional self-reliance is anathema to those committed to the growth-based values of globalization and liberalized trade.

A Final Reflection: The Material Reality of Sustainability

As radical as such thinking may appear to today's liberal free-trading growth-bound mindset it may be seen as excessively conservative in the near future. Up to one-half of the land on Earth has already been directly transformed by human action; more than half of the planet's accessible fresh water is being used by people; atmospheric carbon-dioxide has increased by 30% in the industrial era; more atmospheric nitrogen is fixed and injected into terrestrial ecosystems by humans than by all natural terrestrial processes combined; two-thirds of the world's major fisheries are fully- or over-exploited; and biodiversity losses are accelerating (Lubchenco 1998, Vitousek *et al.* 1997). The sheer scale of the human enterprise suggests the global economy is consuming the ecosphere from within. Contrary to the assumptions of expansionist thinking, so-called 'First World' material lifestyles are not sustainably extendible to the entire world population in the foreseeable future.

Meanwhile, the present analysis has shown that human populations, however urbanized they may become, are increasingly in competition for the available load-bearing capacity of the planet.

Meanwhile, the present analysis has shown that human populations, however urbanized they may become, are increasingly in competition for the available load-bearing capacity of the planet.

The wealthy fifth of the human family appropriates the goods and life support services of five to ten hectares of productive land and water *per capita* to support their consumer lifestyles using prevailing technology. However, there are only about two hectares of such ecosystems for each person on Earth (with no heed to the independent requirements of other consumer species).

Carrying capacity studies by the Sustainable Europe Campaign suggest that to achieve sustainability, the world must lower its energy and material demands by approximately 50 percent in coming decades. However, to clear sufficient 'environmental space' to enable developing countries to grow, high-income countries must reduce their consumption of various non-renewable resources by between 88 and 94% (Carley and Spapens 1998). This seemingly extraordinary challenge is supported by several other studies. For example, the United Nations Environment Program's recent 'Global Environment Outlook 2000' report argues the need for a tenfold reduction in resource consumption by high-income countries (UNEP 1999). Even the Geneva-based world Business Council for Sustainable Development concurs that the industrial world must reduce material throughput and pollution by 90% by 2040 "to meet the needs of a growing world population fairly within the planet's ecological means" (BCSD 1993).

The goal of sustainable economic growth in the Third World, accompanied by rapidly declining material throughput in the First World is theoretically achievable through a massive increase in resource productivity (doing more with less) in combination with population control and an absolute reduction in material demand (i.e., the shift to simpler lifestyles). It is here that the ecological advantages of cities (the 'sustainability multiplier) can really come to the fore. However, to achieve these sub-objectives, unprecedented advances in technological efficiency, population policy, consumer values, material expectations, and governance are required. This in turn will require an unprecedented degree of moral courage, political leadership, and international cooperation. Powerful forces are raised in opposition to this endeavor but success in achieving ecologically sustainable equitable development would herald the final triumph of reason over technological hubris.

It would also provide much needed evidence that there is actually intelligent life on Earth.

References

Ayres, R. U and U. Simonis. 1994. *Industrial Metabolism: Restructuring for Sustainable Development*. United Nations University Press, New York.

Ayres, R.U. 1994. *Information, Entropy and Progress: A New Evolutionary Paradigm*. AIP Press, Woodbury, NY.

Bartlett, A. 1996. The exponential function XI: The new flat Earth society. *The Physics Teacher*, **34**, 342-343.

Berg, P. 1990. Growing a life-place politics. *In Home! A Bioregional Reader*, V. Andrus *et al.* eds. New Society Publishers, Philadelphia, pp. 137-44.

Canada. 1991. *The State of Canada's Environment*. Government of Canada (Supply and Services Canada), Ottawa

Daly, H. E. 1991a. The circular flow of exchange value and the linear throughput of matter-energy: A case of misplaced concreteness. *In* H.E. Daly, *Steady-State Economics*. Island Press, Washington, pp. 195-210.

Daly, H. E. 1991b. *Steady-State Economics*. Island Press, Washington.

Daly, H. E. 1992. Steady-state economics: concepts, questions, policies. *Gaia* **6**, 333-338.

Duncan, R.C. 1993. The life-expectancy of industrial civilization: The decline to global equilibrium. *Population and Environment* **14**, 325-357.

Duncan, R.C. and W. Youngquist. 1999. Encircling the peak of world oil production. *Natural Resources Research* **8**, 3: 219-232.

Georgescu-Roegen, N. 1971. *The Entropy Law and the Economic Process*. Harvard University Press, Cambridge, MS.

Gever, J., R Kaufmann, D. Skloe and C Vörösmarty. 1991. *Beyond Oil: The Threat to Food and Fuel in the Coming Decades*. (3rd ed.). Niwot, The University Press of Colorado.

Hayward, T., 1994. *Ecological Thought*. Polity Press, Cambridge, UK.

IIED. 1995. *Citizen Action to Lighten Britain's Ecological Footprint*. (Report prepared for the UK Department of the Environment). International Institute for Environment and Development, London.

Jacobs, J. 1984. *Cities and the Wealth of Nations*. Vintage Books, New York.

Kay, J.J., H.A. Regier, M. Boyle, G. Francis. 1999. An ecosystem approach for sustainability: Addressing the challenge of complexity. *Futures* (in press).

Lubchenco, J. 1998. Entering the Century of the Environment: A New Social Contract for Science. *Science* **297**, 491-497.

Maturana, H. 1970. *Biology of cognition*. *Reprinted in* H. Maturana and F. Varela. 1980. *Autopoiesis and Cognition*. D. Reidel, Dordrecht, Netherlands.

Maturana, H. and F. Varela. 1980. *Autopoiesis and Cognition*. D. Reidel, Dordrecht, Netherlands.

Maturana, H. and F. Varela. 1987. *The Tree of Knowledge*. Shambala, Boston.

Meadows, D. H., D. L. Meadows, and J. Randers. 1992. *Beyond the Limits: Global Collapse or a Sustainable Future*. Earthscan Publications, London.

Mitlin, D. and D. Satterthwaite. 1994. *Cities and Sustainable Development*, Background Paper prepared for “Global forum ’94”, Manchester, 24-28 June 1994. International Institute for Environment and Development, London.

Odum, E.P. 1971. *Fundamentals of Ecology* (3rd ed). Saunders, Philadelphia.

Onisto, L.K., E. Krause and M. Wackernagel. 1998. *How Big Is Toronto’s Ecological Footprint?* Centre for Sustainability Studies and the City of Toronto, Toronto.

Price, D. 1995. Energy and human evolution. *Population and Environment* **16**, 301-319.

Prigogine, I. 1997. *The End of Certainty: Time, Chaos, and the New Laws of Nature*. The Free Press, New York.

Rees, W. E. 1992. Ecological footprints and appropriated carrying capacity: what urban economics leaves out. *Environment and Urbanization* **4**, 2, 120-130.

Rees, W. E. 1995. Achieving sustainability: Reform or transformation? *Journal of Planning Literature* **9**, 343-361.

Rees, W. E. 1996. Revisiting carrying capacity: Area-based indicators of sustainability. *Population and Environment* **17**, 195-215.

Rees, W. E. 1997a. Is ‘sustainable city’ an oxymoron? *Local Environment* **2**, 303-310.

Rees, W. E. 1997b. Urban ecosystems: The human dimension. *Urban Ecosystems* **1**, 1, 63-75.

Rees, W. E. 1999. The built environment and the ecosphere: A global perspective. *Building Research and Information* **27**, 4/5: 206-220.

Rees, W. E. and M. Wackernagel. 1994. Ecological footprints and appropriated carrying capacity: measuring the natural capital requirements of the human economy. *In Investing in Natural Capital: The Ecological Economics Approach to Sustainability*, A-M. Jansson, M. Hammer, C.Folke, and R. Costanza, eds. Island Press, Washington, pp.362-390.

Rees, W. E. and M. Wackernagel. 1996. Urban ecological footprints: Why cities cannot be sustainable and why they are a key to sustainability. *Environ. Impact Assess. Rev.* **16**, 223-248.

Sale, K. 1985. *Dwellers in the Land: The Bioregional Vision*. Sierra Club Books, San Francisco.

Schneider, E and J Kay. 1994. Life as a manifestation of the second law of thermodynamics. *Mathematical and Computer Modeling* **19**, 6-8, 25-48.

Simon, J. and H. Kahn (eds.) 1984. *The Resourceful Earth: A Response to Global 2000*. Basil Blackwell, Oxford..

UN. 1995. *World Urbanization Prospects: The 1994 Revision*. The United Nations, New York.

UNCHS. 1996. *An Urbanizing World: Global Report on Human Settlements 1996*. (United Nations Centre for Human Settlements) Oxford University Press, Oxford and New York.

UNEP. 1999. *Global Environmental Outlook 2000 (GEO-2000)*. United Nations Environmental Program, Nairobi.

UNDP. 1998. *Urban Transition in Developing Countries*. United Nations Development Program, The United Nations, New York.

Van der Ryn, S. and P. Calthorpe. 1986. *Sustainable Communities: A New Synthesis for Cities and Towns*. Sierra Club Books, San Francisco.

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human Domination of Earth's Ecosystems. *Science* **277**, 494-499.

Wackernagel, M. and W.E. Rees. 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island, BC and Philadelphia, PA.

Wackernagel, M., L. Onisto, P. Bello, A.C. Linares, I.S.L. Falfán, J.M Garcia, A.I.S. Guerrero, and M.G.S. Guerrero. 1999. National natural capital accounting with the ecological footprint concept. *Ecological Economics* **29**, 375-390.

Worldwatch Institute. 1995. *State of the World, 1995*. Worldwatch Institute, Washington.