Chapter 5 of
Canadian Cities in Transition:
New Directions in the Twenty-First Century (Fourth Edition)

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Getting Serious about Urban Sustainability: Eco-Footprints and the Vulnerability of 21st Century Cities[1]

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> "At the heart of this assessment is a stark warning. Human activity is putting such a strain on the natural functions of the Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted." (MEA, 2005: 5)

Introduction: Framing the Analysis

This chapter is concerned with the long-term sustainability of cities. My starting premise is that because of accelerating global ecological change, cities everywhere are facing unprecedented challenges to their functional integrity and even survival. Unprecedented challenges require unprecedented solutions.

In keeping with this reality, I depart from most urban scholarship which assumes a humanities and social science perspective. Instead, I approach 'the urban question' from a mainly biophysical point of view. Accelerating global change makes clear that society will not be able to assure the sustainability of cities without a much fuller understanding of cities as ecological entities subject to biophysical laws.

With this in mind, the chapter begins with a brief consideration of the organic origins of cities and subsequent evolution of cities. Permanent settlements became possible as a result of technology-induced changes in the ecological 'niche' of humans ten millennia ago. However, the subsequent alienation of urban techno-industrial society from nature has produced modern cities that are not only incomplete as human ecosystems but that exist in essentially hostile relationship to the natural ecosystems that sustain them.

The next section uses ecological footprint analysis to illustrate the ecological load imposed on the natural world by people and to estimate the *de facto* surface area of Earth occupied *ecologically* by the inhabitants of modern cities to sustain their material lifestyles. Pay attention, urban planners! The eco-footprints of typical cities are hundreds of times larger than their political or built-up areas. In any functionally meaningful sense, doesn't this 'hinterland' area constitute urban land as much as does a parking lot within the city limits?

I then consider the increasing vulnerability of modern cities to global ecological change. Urbanization represents the greatest mass migration of people ever. More people will be added to the world's cities in the first three or four decades of the 21st Century, mostly through inmigration, that had accumulated on the entire planet by 1930! But urbanization implicitly

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assumes climate stability, reliable supplies of vital resources and geopolitical calm. Just how secure will the world's six billion urbanites be if cities are besieged by climate change, rising sea levels, energy and food shortages and resultant violent conflicts by mid to late century?

The final section examines the ecological leverage that cities can exercise in society's general quest for sustainability. What can cities do to decrease their eco-footprints and enhance their own survival prospects? How might rethinking the 'city-as-ecosystem' help humanity to live sustainably within the carrying capacity the earth?

Setting the Ecological Stage

While few people think of them as such, cities are biophysical entities. The fundamentally *organic* nature of cities is underscored by the fact that permanent settlements are actually a product of a change in human ecological circumstances. 'The city' is an emergent phenomenon made possible by people's adoption of agriculture ten millennia ago. Humanity's slowly-developing ability to produce regular food surpluses triggered a truly "autocatalytic process—one that catalyses itself in a positive feedback cycle, going faster and faster once it has started" (Diamond, 1997). More food made higher population densities possible, enabled large permanent settlements with the specialized skills and inventiveness this implies, and shortened the time-spacing between children. This, in turn, enabled the higher populations to produce still more people which increased both the demand for food and the technical and organizational capacity to produce it.

The first small, more or less permanent human settlements thus appeared barely 9000 years ago and it was another 1500 years before the first real cities, with socially stratified societies and marked division of labour, emerged in south-west Asia (today's "Middle East") around 5500 BC. In short, while we tend today to take the existence of cities for granted, cities actually have a remarkably short history. They have been part of human reality for merely 1.5 percent of the time since 'modern' humans, *Homo sapiens*, stumbled onto the world stage about 500,000 years ago.

But there is more to this story than 'surplus food leads to urban civilization.' The shift from the nomadic hunter-gatherer lifestyle to a more agriculture-based settlement-centred way of life represents a major transformation of human ecological reality and may well constitute the most critical branch-point to date in the evolution of *Homo sapiens*. First, consider that with large-scale agriculture, people switched from merely taking what wild nature had to offer, to manipulating entire landscapes in order to redirect as much as possible of nature's productivity to strictly human ends. In this way, humans became the most significant 'patch-disturbance' species on Earth (Rees, 2000). Indeed, agriculture and agriculture-induced urbanization constitute a great leap forward in an accelerating process that has gradually seen humans become the most important geological force changing the face of the planet.

Second—and, regrettably, given the enormous ecological impacts of industrial cities—the very process of urbanization insulates city-dwellers from the negative consequences of human ecological dysfunction. Initially, the migration of people to cities distances them physically from the ecosystems that support them and thus from the direct negative consequences of subsequent landscape degradation. Even more important, the separation of people's lives and livelihoods *from* the land diminishes urbanites' sense of felt connectedness *to* the land. (Marx called this problem "metabolic rift".) In short, humanity's seeming abandonment of the countryside is critically reshaping billions of peoples' spatial relationships and psychological sensitivities to nature. Thus doubly blinded, many urbanites, particularly in high-income developed countries, remain blissfully unaware that they remain ecological actors and of the growing threat their consumer lifestyles pose to distant ecosystems upon which they still remain utterly dependent.

One effect of this alienating process is that city-dwellers generally don't think of 'the city' in ecological terms. Even urban scholars have only recently acknowledged and begun to study the human ecological dimensions of urbanization and cities. Most discussions of urbanization still view the process mainly as a demographic or economic phenomenon made possible by the intensification of agriculture, increased resource productivity, and improvements in communications and transportation technology. Cities are perceived as concentrations of people; areas dominated by the built environment; places of intense social interaction; the seats of government; hotbeds of political conflict; the nexus of national transportation and communication systems; and as the engines of national economic growth—but rarely as a biological phenomenon. Some observers actually (falsely) interpret urbanization as evidence that humanity is *transcending* nature, that the human economy is 'decoupling' from 'the environment.'

Modern humans' failure to appreciate themselves as ecological beings reflects a deep cognitive bias. Over the past three hundred years, our evolving techno-scientific paradigm has erected a self-serving perceptual barrier between humanity and the rest of the natural world. Indeed, this so-called 'Cartesian dualism' is a defining characteristic of industrial society that strongly reinforces the physical and psycho-separation of urban humans from their roots in nature.

This chapter is intended to address this perceptual gap. A major purpose is to show that, while urbanization represents a dramatic shift in urbanites' spatial/psychological relationships to the land, *there is no corresponding change in eco-functional relationships*. Indeed, far from reducing people's dependence on productive ecosystems urbanization generally implies an increase in our *per capita* 'ecological footprints.' From this perspective, urbanization and the modern city remain bio-ecological phenomena fully explicable only in light of human evolutionary history and fundamental biophysical laws. Failure to understand ourselves and our cities as ecological agents will doom our quest for global sustainability and exposes an increasingly vulnerable global urban civilization to the spectre of collapse.

Cities and the Human Ecosystem

By now almost everyone interested in cities is familiar with the term 'urban ecosystem'. Prominent urban analysts have long recognize that the city could be conceived as an ecosystem (e.g., Douglas, 1981) and today there is even a scientific journal called *Urban Ecosystems*. Nevertheless, the concept itself remains ambiguous. For example, a majority of the papers in *Urban Ecosystems* focuses on the impacts of urbanization on non-human plants and animals or on remnant 'natural' ecosystems within the city. This shows that most natural scientists who study 'urban ecosystems' cast the city as a somewhat unnatural habitat for *other* species.[2] To ecologists, the 'urban ecosystem' consists of the assemblage of non-human species in the city and the purpose of their inquiries is to determine how these species have adapted to the structural and chemical characteristics of the 'built environment' (Rees, 2003). Remarkably, humans are

[2] One paper in the March 2009 issue of the journal even struggles with the question of whether "the ecosystem concept [is] relevant when humans are part of the system" (Pickett and Grove, 2009). The remaining eight articles focus on other aspects of non-human ecology.

excluded from the analysis except as their actions affect these other species. This conception of urban ecosystems is a clear reflection of the Cartesian dualism that separates people from nature in the human mind.

On the other hand, those who do acknowledge humans as the major ecological actors in the city err if they see 'the city' *per se* as the modern human ecosystem. To qualify as a complete human ecosystem, a city would have to contain a sufficient complement of producer organisms (green plants), macro-consumers (animals, including humans), mico-consumers (bacteria and fungi) and abiotic factors to support its human population indefinitely. Any complete ecosystem consists of a self-organizing, self-sustaining assemblage of living species existing in complementary relationship with each other and the physical environment. Ecosystems are energized by the unidirectional cascade of solar energy and maintained in perpetuity by the continuous recycling of chemical nutrients.

Clearly from this perspective, no modern city qualifies as a functionally complete human ecosystem. Some essential defining parts are missing altogether (e.g., virtually the entire relevant producer complex) and others (micro-consumers) are insufficiently abundant for functional integrity. As significantly, the spatial separation of people from the rest of their supportive ecosystems (e.g., agricultural and forest lands) inhibits the on-site application of organic matter and the recycling of phosphorus, nitrogen, and other nutrients and contained in human wastes. In effect, urbanization transforms local, integrated, cyclical ecological production systems into global, horizontally disintegrated, unidirectional, throughput systems (Rees, 1997). (Ironically, the resultant continuous 'leakage' of nutrients from farmland in shipments of food to cities threatens to undermine organic agriculture even as it gains ground in the urban marketplace.)

On a crude but illustratively useful level, an apt metaphor of the city might be a livestock feedlot (Rees, 2003). Like cities, feedlots are densely populated almost entirely by a single macro-consumer species—for example, cattle (or pigs, or chickens, which are raised using even more constrained industrial methods). However, the grain fields that produce the feed for feedlot animals may be located hundreds of kilometres from the feedlot itself. Also missing are adequate populations of micro-consuming decomposers. Having separated the functionally inseparable, industrial feed-lots short circuit even the possibility of within-system decomposition and nutrient recycling. As a result, vast quantities of manure containing vital nutrients are often not re-deposited on range-or cropland for nutrient recycling, but rather are disposed of inappropriately, contaminating soils, surface, and subsurface waters at a distance and over large areas.[3]

Of course, cities are more ecologically complex than feedlots. However, in structural terms cities are to their human inhabitants what feedlots are to cattle. The largest and functionally most important components of urbanites' ecosystems—the assemblage of producer organisms that feed them and provide them with oxygen, most of the micro-consumers that complete their nutrient cycles and the various sub-systems that perform myriad other vital life-support functions—are all found in rural 'environments' increasingly scattered all over the planet. Also, like feedlots, cities generate enormous quantities of waste that cannot be assimilated within the city, making cities the major source of pollution of the global commons. In short, cities are nodes of intense resource consumption and waste generation entirely dependent for their survival on the productive and assimilative capacities of ecosystems

[3] Since livestock feedlots are a sub-system of the human urban industrial system, it is not surprising that they are eco-structurally similar to cities.

increasingly located at great distance from the cities themselves. In both ecological and spatial terms, 'the city' constitutes only a fraction of the total urban-centred human ecosystem.

The Human Ecological Footprint

The next question is: just how big is the human ecosystem? How much of the productive capacity of the ecosphere do humans need to sustain urban industrial society? One way to approach this question is through ecological footprint analysis (Rees, 1992; Wackernagel and Rees, 1996). A variant and extension of energy and material flows assessment (Haberl et al., 2004), eco-footprint analysis (EFA) starts from a comprehensive inventory of the annualized energy and material flows required to support any specified population—an individual, a city, a nation or the entire world. We also quantify the flows of certain critical wastes generated in this production/consumption process, particularly carbon dioxide (the carbon footprint). Eco-footprinting is further based on the fact that many of these material and energy flows can be converted into a corresponding area of productive land and water ecosystems. Thus, we formally define the ecological footprint of a specified population 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; 2006).[4]

The area of a population's theoretical eco-footprint (EF) depends on four factors: the population size, 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 and the productive land and water area captured by EFA represents much of the "natural capital" (the productive natural resource base or *biocapacity*) required to meet the study population's consumptive and assimilative demand.[5] One can even interpret the eco-footprint in thermodynamic terms as the area of natural 'solar collector' needed to regenerate the biomass and chemical energy equivalents of the useful resources and fossil energy consumed and dissipated by the study population.

It is important to recognize that population EFs constitute mutually exclusive appropriations of nature. The biocapacity used by one population is not available for use by another. True, the grain grown in a particular region may wind up in export shipments to several countries, but the total area of cropland involved is the sum of the areas required by the individual populations. In the final analysis, *all human populations are competing for the productive capacity (biocapacity) of the earth*.

Table 5.1 shows the equivalence-adjusted[6] *per capita* EFs and domestic biocapacities for a selection of countries from among the richest to among the poorest using 2005 data from the *Living Planet Report 2008* (WWF, 2008). Note the vastly larger load imposed on the ecosphere by wealthy mainly urban consumers compared to that imposed by mainly rural peasants. The

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[4] For full details of the method, including inclusions, exceptions and limitations, see Rees (2003; 2006) WWF (2008) and various links at http://www.footprintnetwork.org/en/index.php/GFN/

[5] EFA obviously does not capture the entire human impact on Earth, only those dimensions for which the ecosphere has regenerative capacity. For example, various wastes such as ozone depleting chemicals or the toxic chemical residues accumulating in our food chain cannot be converted into a corresponding ecosystem area.

[6] To enable fair comparisons among countries, the national EF and biocapacity data in Table 1 are presented in terms of global hectares, i.e., the equivalent area of ecosystems of global average productivity.

citizens of wasteful high-income countries like the US and Canada have average EFs of six to 10 global hectares (gha), or up to 20 times larger than the EFs of the citizens of the world's poorest countries such as Bangladesh and Malawi. European countries and Japan typically have *per capita* EFs in the four to six gha range. China is fairly representative of the emerging economies which show rapidly growing EFs of 1.5 to three gha. These data reflect the growing global income gap: the richest 20 percent of the human family spend more than 75 percent of world income; the poorest 20 percent subsist on just 1.5 percent (UNDP 2007).

The final column of Table 5.1 shows each country's 'overshoot factor.' This is a simple ratio of the national average eco-footprint compared to *per capita* domestic biocapacity. Countries with overshoot factors larger than one impose a greater burden on the ecosphere than can be supported by their domestic ecosystems. That is, these countries are at least partially dependent on trade and on exploitation of the global commons to maintain their current lifestyles (i.e., average *per capita* consumption levels). The Netherlands, for example, uses almost four times as much productive land/water outside its borders as is found within the country. Japan's demand for biocapacity is eight times its domestic supply. Such countries are running 'ecological deficits' with the rest of the world.

A few countries with overshoot ratios less than one are still living within their 'natural incomes' and thus seem to have ecological surpluses. They only 'seem to have' surpluses because the extra biocapacity is generally being traded away to cover the ecological deficits of other countries. The agricultural, forestry and fisheries surpluses of Canada, for example, serve a large export market. Trade therefore contributes proportionately to the on-going degradation of the nation's soils, forests and fish stocks (Kissinger and Rees, 2009).

Ominously, the world as a whole is in a state of overshoot (Table 5.1). Human demand exceeds the earth's regenerative capacity by about 30 per cent. We are living, in part, by depleting and dissipating as waste, the enormous stocks of potentially renewable natural capital (fish, forests, soils, etc.) that have accumulated in ecosystems over millions of years.

The Global Reach of Cities

Cities, of course, are virtually all ecological deficit. Urban populations are almost totally dependent on rural people, ecosystems and life-support processes increasingly scattered all over the planet (Girardet, 2004; Newman and Jennings, 2008; Rees 1992, 2003). In some respects, this relationship is a two-way, mutualistic one—rural areas benefit from urban markets, the products of urban factories, urban-based services, technology transfers from urban areas, etc. However, while rural populations have survived historically without cities the ecological dependence of urbanites on 'the hinterland' is absolute. *There can be no urban sustainability without rural sustainability* even if the 'rural' for any particular city is scattered all over the planet. Understanding the nature of rural-urban interdependence is essential to understanding the total human ecosystem and to urban sustainability.

In theory, estimating the eco-footprint of a city is no different from estimating that of an entire country. In practice, however, matters are more complicated, particularly by the lack of local data. No statistical or planning agencies monitor the flow of biophysically significant goods and services across municipal boundaries. While some urban EF studies do attempt to compile local data, others use 'quick and dirty' extrapolation from national eco-footprint estimates, sometimes with adjustments for local conditions, income differences, etc. (e.g. FCM, 2005). This method produces more accurate city footprint numbers for highly urbanized high-income countries than for less-urbanized poorer countries.

So, just how great is a typical modern city's debt to the global countryside? Despite methodological and data-quality differences, urban eco-footprint studies invariably show that the EFs of typical modern high-income cities exceed their geographic or political areas by two to three orders of magnitude. For example:

- Based on locally-adjusted *per capita* EF estimates, the people of Toronto and Vancouver 'occupy' an ecosystem area outside their municipal boundaries 292 and 390 times larger respectively than the cities themselves (FCM, 2005). Even the lower-density metropolitan areas of these cities have EFs 57 times bigger than the respective urban regions (Table 5.2). The citizens of Toronto and Vancouver might want to contemplate the implications of this growing extra-territorial dependence as they sprawl out over Canada's most productive farmland in an era of global change. (Where will they turn when they can no longer import essential foods from distant elsewheres?)
- Under varying management assumptions to cope with regional waste management issues, Folke *et al*. (1997) estimated that the 29 largest cities of the Baltic region require for resources and certain categories of waste assimilation, an area of forest, agricultural, marine, and wetland ecosystems 565-1130 times larger than the area of the cities themselves.
- With a population of 33 million and a *per capita* EF of about 4.9 gha, metropolitan Tokyo's total eco-footprint is 161,700,000 gha. However, the entire domestic biocapacity of Japan is only about 76,860,000 gha. In short, Tokyo, with only 26 per cent of the Japan's population, lives on an area of productive ecosystems 2.1 times larger than the nation's entire terrestrial biocapacity.[7] Clearly if Japan were required by changing global circumstances to subsist on its domestic biocapacity, the country would have difficulty supporting even the population of its capital city.
- Warren-Rhodes and Koenig (2001) estimated that Hong Kong, with almost seven million people, has a total eco-footprint of 332,150 to 478,300 km^2 (5.0-7.2 ha *per capita*) (the range reflects two estimates of carbon sink land requirements). Hong Kong's eco-footprint is at least 303 times the total land area of the Hong Kong Special Administrative Region (1097 km^2) and 3020 times the built-up area of the city (110 km^2) .

These data show clearly that in material terms, 'sustainable city' is an oxymoron (Rees, 1997). Modern cities are urban black holes sweeping up the productivity of a vastly larger and increasingly global resource hinterland and spewing an equivalent quantity of waste back into it. They are compact nodes of consumption living parasitically on the productivity and assimilative capacity of a vastly larger 'undeveloped' area, portions of which may be thousands of kilometres from the built-up area at the centre.

While some have interpreted the consumptive and polluting power of cities as an anti-urban argument, it is nothing of the sort. Cities do have enormous ecological footprints; however, as we shall see, cities actually offer several advantages over more dispersed settlement patterns in the quest for sustainability.

Eco-footprinting also suggests several other paradoxes about current perceptions of cities. For example, why is the lifeless asphalt of the mall parking lot considered to be urban land, while cropland vital to the survival of the city but is not? What does it mean for urban planning if 99.5 per cent of the *de facto* urban (eco)system lies outside the municipal boundaries, out of sight

[7] The area of Japan is only about 37,770,000 ha but Japan's terrestrial ecosystems are considerably more productive than the world average. This increases the country's biocapacity to almost 77,000,000 gha.

and beyond the control of those it supports? Perhaps we should redefine what we mean by urban (eco)system.

Finally, eco-footprinting underscores a material reality that is all but ignored in the sustainability literature—no individual, no city nor even country can achieve sustainability on its own if the system of which it is a part is unsustainable. Vancouver, Toronto or Montreal might become exemplars of sustainable urban design and lifestyles but, if the global system of which they are a part remains on an unsustainable path, then even our model cities would be taken down by, for example, severe climate change, depleted resources, and resultant geopolitical instability. Given such interdependence, the best any sub-global system can attain independently is a state of quasi-sustainability. 'Quasi-sustainable' describes that level of economic activity and energy/material consumption per capita which, if extended to the entire system, would result in global sustainability (Rees 2009). In 2009, quasi-sustainability implies a per capita eco-footprint of about 2.1 gha (2.1 gha represents an equitable per capita share of global biocapacity). Since Canadians' average eco-footprint is 7.1 gha per capita, we would have to reduce consumption by 70% to meet the quasi-sustainability standard!

The Vulnerability of Modern Cities

Increasing global interdependence obviously has enormous implications for the security of urban populations in an era of global change. Cities have grown so large and have such enormous eco-footprints not because size necessarily confers great advantage but simply because they could—globalization and trade have historically assured the abundant supplies and uninterrupted flows of the energy and other material resources required to grow the modern metropolis. But this raises an increasingly awkward question in an era of global change: just how secure is any city of millions, or even a relative 'town' of 100,000, if resource scarcity, shifting climate or geo-political unrest threaten to cut it off from vital sources of supply? There are several inter-related reasons to believe this is not an idle question. For example:

1. Reliable food supplies should be of increasing concern to urbanizing populations (Kissinger and Rees, 2009). Global grain production is levelling off. Yet, just to keep pace with UN medium population growth projections, agricultural output will have to increase by over 50 per cent by 2050 and improving the diets of malnourished people would push this toward 100 per cent.[8] Achieving increases of this magnitude may be difficult. By 1990, 562 million hectares (38 per cent) of the world's roughly 1.5 billion hectares of cropland had become significantly eroded or otherwise degraded; 300 million hectares (21 per cent) of cultivated land—enough to feed almost all of Europe—has been lost to production, and we are still losing five to seven million hectares annually (FAO, 2000; SDIS, 2004). Depending on the climate and agricultural practices, topsoil is being 'dissipated' 16 to 300 times as fast as it is regenerated. So far, the impact has been masked because we have managed to substitute fossil fuel for depleted soils and landscape degradation—but that may be about to change.
2. Cities are very much the product of abundant cheap fossil fuel. Indeed, no other resource has changed the structure of economies, the nature of technologies, the balance of geopolitics, and the quality of human life as much as petroleum (Duncan and Youngquist, 1999). Fossil fuels, especially oil, currently supply about 85% of humanity's total energy demand and are essential for transportation, space and water heating and the

[8] This situation is complicated by the diversion of grain, expecially maize, to biofuels production.

generation of electricity. Oil is also a major factor in the green revolution. Mechanization, diesel-powered irrigation, the capacity to double-crop, and agro-chemicals (fertilizers and pesticides) made from oil and natural gas account for 79-96% of the increased yields of wheat, rice and maize production since 1967 (Cassman, 1999; Conforti and Giampietro, 1997). For all these reasons, some analysts argue that the peaking of global petroleum extraction (see Figure 5.1) anticipated by 2010 represents a singular event in modern history and poses a greater challenge to geopolitical stability and urban security than any other factor (Campbell 1999; Duncan and Youngquist, 1999; Laherrere, 2003). In addition to shrinking the supply and exploding the price of food, 'peak oil' could have an enormous impact on urban transportation, urban form and structure, and even the future size of cities.

3. Other analysts see climate change as the greatest threat to urban civilization. Even modest shifts in weather patterns could disrupt historic water availability and distribution thus undermining both agricultural production and urban water supplies. By some accounts, more severe climate change could bring the world to the edge of anarchy (e.g., CSIS, 2007; Schwartz and Randall, 2003). In *The Age of Consequences*, Washington's Center for Strategic and International Studies suggests that human-induced climate change driven by burning fossil fuels could end peaceful global integration as various nations contract inwardly to conserve what they need—or expand outwardly to *take* what they need—for survival. In the event of "severe climate change", corresponding to an average increase in global temperature of 2.6°C by 2040 (now deemed to be increasingly likely) major nonlinear changes in biophysical systems will give rise to major nonlinear socio-political events. Shifting climate will force internal and cross-border migrations as people abandon areas where food and water are scarce. People will also flee rising seas and areas devastated by increasingly frequent droughts, floods and severe storms. Dramatic increases in migration combined with food, energy and water shortages will impose great pressure on the internal cohesion of nations. War is likely and nuclear war is possible (CSIS, 2007).

Recent climate studies increase the probability of such dismal scenarios (e.g., Anderson and Bows, 2008; Hansen *et al*., 2008). Current loose 'targets' for controlling climate change include stabilization of carbon dioxide at 350 parts per million by volume (it is currently 380 ppmv) and maintaining temperature increases below 2 C°. However, according to Anderson and Bows (2008) "an optimistic interpretation of the current framing of climate change implies that stabilization [of green house gases] much below 650 ppmv CO_2e [carbon dioxide equivalents] is improbable." This is partly because, in order to stabilize at 650 ppmv CO_2e, the majority of OECD nations will soon have to begin decarbonizing at rates in excess of 6% per year which would likely require *a planned economic recession* (Anderson and Bows, 2008). We should note that atmospheric GHG concentrations of 650 ppmv CO_2e imply a catastrophic 4 C° increase in mean global temperature, c.f. the mere 2.6 C° increase assumed in CSIS's already horrific 'severe climate change' scenario. Models suggest that 4 C° warming would be sufficient to convert much of the US, Southern Europe, China, India, Africa, and South America in to uninhabitable wastelands (see Vince, 2009), displacing billions of people and jeopardizing prospects for maintaining any form of global civilization.

The good news in all this is that determined action to address climate change could help avoid the peak oil problem and *vice versa*. For example, if the world were to take the action necessary to reduce CO_2 emissions by 6% per year to avoid the worst of climate change, the drop in demand for oil would keep pace with or exceed the anticipated decline in extraction rate.

Toward the 'One Planet' City

> "Industrialized world reductions in material consumption, energy use, and environmental degradation of over 90 per cent will be required by 2040 to meet the needs of a growing world population fairly within the planet's ecological means" (BCSD, 1993).

This is a world in overshoot yet both population and *per capita* consumption are increasing and material expectations are rising all over the world. This is a fundamentally unsustainable situation—to raise just the present world population sustainably to North American material standards would require the bio-capacity of four additional Earth-like planets (Rees, 2006). The *really* inconvenient truth is that, to achieve sustainability, global energy and material through-put must decrease, not grow.

Techno-industrial society is a self-proclaimed science-based society but we are not acting consistently with our best science. The risks associated with anticipated global change certainly demand major restructuring and may well require a planned economic contraction. For sustainability with greater equity, wealthy countries will have to free up the ecological space necessary for needed growth in the developing world (Rees, 2008). High-income nations should therefore work to limit the energy and material throughput required to sustain urban life (Lenzen et al., 2004; Newman and Jennings, 2008; Rees, 2009). To achieve one planet living, Canadians should be taking steps now now to reduce their eco-footprints by 70% from 7.4 gha to their 'equitable Earth-share' of 2.1 gha *per capita*; similarly, Americans need to trim their eco-footprints by 78% (see Table 1).[9]

Clearly, achieving such targets will require a dramatic shift in prevailing economic beliefs, values, and particularly consumer lifestyles—as much as 60-70% of the material flows through cities are attributable to personal consumption. Fortunately, the technology is available to make this a relatively painless transition (Weizsäcker et al., 1995). Moreover, "managing without growth" is both economically possible and could well *improve* quality of life (see Victor, 2008).

Regrettably, there is scant evidence that the necessary cultural shift is underway. Certainly no national government, the United Nations nor any other official international organizations have begun openly to contemplate the implications for humanity if the science is correct, let alone articulate in public the kind of policy responses the science evokes. Despite repeated warnings that staying our present course spells catastrophe for billions of people (MEA, 2005; USC, 1992), the modern world remains mired in a swamp of cognitive dissonance and collective denial (Rees, 2009).

Consequently, mainstream responses to our ecological conundrum to date do not address the fundamental problem but seem designed instead to reproduce the *status quo* by other means. Such 'innovations' as hybrid cars, green buildings, smart growth, the new urbanism, green

[9] Cuba, South Africa and Thailand are examples of countries with per capita eco-footprints in the sustainable range.

consumerism and even much of the eco-cities movement, all assume that we can achieve sustainability through technological innovation and greater material and economic efficiency. This is a conceptual error—historically efficiency has actually *increased* consumption by, for example, raising incomes and lowering prices. With more money chasing cheaper goods and services, throughput rises. In effect, improved efficiency simply makes industrial growth-bound society more efficiently unsustainable.

The urban sustainability multiplier

> "The climate crisis won't be solved by changing light bulbs and inflating your tires more, planting a tree and driving a little less. It's going to require a truly fundamental shift in how we build our cities and live in them" (Register, 2009)

Getting serious about urban sustainability obviously requires more determined action than society has yet been willing to contemplate. Fortunately, the very factors that make wealthy cities weigh so heavily the ecosphere—the concentration of people and the localized intensity of energy/material consumption and waste generation—also give them considerable economic and technical leverage in shrinking their eco-footprints .

To enable cities to take full advantage of this leverage, provincial and municipal governments must create the land-use legislation and zoning by-laws that urban planners need to eliminate sprawl and consolidate and densify existing built-up areas. Compact cities have the potential to be vastly less energy- and material-intensive than today's sprawling suburban cities. The economies of scale and agglomeration economies associated with high-density settlements confer a substantial 'urban sustainability multiplier' on cities (Rees, 1999). For example:

- lower biophysical and economic costs *per capita* of providing piped treated water, sewer systems, waste collection, and most other forms of infrastructure and public amenities;
- a greater range of options for material recycling, re-use, re-manufacturing, and a concentration of the specialized skills and enterprises needed to make these things happen;
- reduced *per capita* demand for occupied land;
- greater possibilities for electricity co-generation, district heating/cooling and the use of waste process heat from industry or power plants, to reduce the *per capita* use of fossil fuel for water and space-heating;
- more opportunities for co-housing, car-sharing and other cooperative relationships that have lower capital requirements (consumption) per household and individual;
- more ways greatly to reduce the (mostly fossil) energy consumption by motor vehicles through walking, cycling, and public transit;
- more 'social contagion', facilitating the spread of such more nearly sustainable life-style choices (e.g., 'voluntary simplicity');
- the potential to implement the principles of low through-put 'industrial ecology' (i.e., the ideal of closed-circuit industrial parks in which the waste energy or materials of some firms are essential feed-stocks for others).

Walker and Rees (1997) show that the increased density and consequent energy and material savings associated with condos and high-rise apartments, compared to single-family houses, can reduce that part of the *per capita* urban ecological footprint associated with housing type and related transportation needs by about 40 percent.[10]

As noted, however, efficiency gains alone will not enable society to achieve 'one-planet living'. Sustainability and security demand that cities everywhere become less consumption-driven and more materially self-reliant. Indeed, cities may be forced down this unfamiliar path either by the rising cost of oil-based transportation or the rapid phase-out of fossil fuels needed to avoid severe climate change (target: at least 80% decarbonization by 2050). Certainly there is no place for the fossil-fueled automobile—or any cars at all—in the eco-cities of the future (Register 2009). For these reasons, urban designers must begin now to rethink cities so they function as complete ecosystems. This is the ultimate form of bio-mimicry.

Bio-mimicry at the city level requires the re-localization of many ecological and economic functions. The least vulnerable and most resilient urban eco-system might be a new form of regional eco-city state (or bioregion) in which a densely built-up core is surrounded by essential supportive ecosystems.[11] The central idea is to consolidate as much as possible of the city's productive hinterland in close proximity to its consumptive urban core. In effect, without preventing essential trade, this would internalize the currently widely scattered external eco-footprints of our cities into more compact and manageable city-centred regions that could function as complete human ecosystems. Such a transformed homeplace, "…rather than being merely the site of consumption, [would], through it very design, produce some of its own food and energy, as well as become the locus of work for its residents" (Van der Ryn & Calthorpe, 1986). Eco-city states would be less a burden on, and more a contributor to, the life-support functions of the ecosphere than contemporary cities.

Most importantly, the bioregional city would reconnect urban populations both physically and psychologically to 'the land'. Because inhabitants would be more directly dependent on local ecosystems they would have a powerful incentive—currently absent—to manage their land and water resources sustainably in the face of global change. (Ideally, political control over the productive land and resource base of the consolidated region would pass from the provincial to new eco-city state governments.) Less reliant on imports, their populations would be partially insulated from climate vagaries, resource shortages and distant violent conflicts. Note that if the entire world were organized into a system of self-reliant bioregions, managed to conserve adequate *per capita* stocks of natural capital, the aggregate effect would be global sustainability.

It is also worth noting that Canada is one of the few countries with sufficient space and resources that many of its cities could readily be reorganized along bioregional lines. Conversely, for many large cities, particularly wealthy cities in small countries, reorganization into bioregions is no longer an option. Remember Tokyo with its eco-footprint spanning two Japans? The best such cities can do in the face of global change is to reduce their material demands as much as possible and hope their national governments can negotiate reliable supplies of vital resources from areas that still have surplus capacity. It may not be possible for all cities to be self-sustaining, but in a crowded world, every city has an obligation to contribute to global

[10] Many North Americans fear density but the city of Vancouver illustrates that excellent urban design can actually draw families from the suburbs to live in high-density urban communities. In 2008, the city actually had to restrict further high-rise development in its high-amenity downtown core because it was displacing office development.

[11] For a history and philosophy of the bioregional movement, see Carr (2005).

sustainability by taking appropriate action within its own boundaries (McGranahan & Satterthwaite, 2003).

Of course, 'appropriate action' will vary greatly among cities. This discussion has focused mainly on the sustainability implications of global change for wealthy cities. We should therefore acknowledge that many millions of people live under deplorable conditions in the barrios, slums and squatter settlements of Third-World cities. The greatest environmental problems facing these people are inadequate diets and the lack of potable water and sanitary sewage. Unlike the already wealthy, the world's urban poor would therefore benefit from rising incomes and greater consumption. The world community should be assisting them to *increase* their eco-footprints. In this light, an appropriate strategy for rich and poor cities alike would be to manage gross consumption so that average *per capita* eco-footprints converge from above and below toward 2.1 gha, each person's equitable share of global biocapacity.[12]

Epilogue

Historically, environmental concerns about cities were confined to the local public health effects of, air, water and land pollution that still preoccupy impoverished cities today. However, the four-fold rise in human numbers and the order of magnitude increase in economic activity during the 20th Century undermined basic life-support systems and raised ecological concerns to the global scale.

Despite increasing costs and risks, the world community remains addicted to material growth. Thus many studies of urban metabolism seem concerned mainly with alternative technologies and better resource management that would enable cities to maintain their growth trajectories (e.g., Brunner, 2007). Kennedy *et al.* (2007) acknowledge that, with modernization, energy, material, and water throughput is increasing, even on a *per capita* basis; that we should therefore expect greater loss of ecosystem function and bio-diversity, and that; *if necessary*, urban policy makers might consider strategies to slow exploitation. However, the authors convey no particular sense of urgency. Similarly, Decker *et al.* (2000) recognize the accelerating degradation of earth systems, but imply a fairly smooth succession to the point where "modern megacities will… begin to climax when global fossil fuel reserves are exhausted and global water and food resources are maximally utilized." Few academic studies acknowledge the possibility of implosion or urge the kind of dramatic response to prevent it that now seems justified by global change science.

This chapter attempts to fill the gap. I argue that we are witnessing the dissipative destruction of essential ecosystems and vital life-support functions and that the process is accelerating with population growth and rising material expectations. Given the increasing probability of severe climate change, resource shortages, large-scale population displacements and resultant geopolitical chaos, the world is justified in taking decisive action now. The 'transition' to sustainability will be anything but smooth and predictable if there is further delay—urban civilization itself is at stake.

Environmental scientists are sometimes dismissed as purveyors of gloom and doom but, if the science is correct, it is our present heading that leads us toward the abyss. Things needn't be that way. Humans are a self-proclaimed intelligent species uniquely capable of forward planning. Properly warned, we should theoretically be able to manage our way out of the crisis.

[12] Note that as the human population increases and productive ecosystems are degraded, this 'equitable Earth-share' will decline.

As a first step, society must acknowledge that (un)sustainability represents both gross market failure and the greatest collective problem humankind has ever faced. We are all part of the same eco-systemic hierarchy in which all sub-systems (e.g., cities and nation-states) are dependent on the operational integrity of the whole (the ecosphere itself) for survival. For perhaps the first time in history, individual self-interest now coincides with humanity's collective interest on the level of basic survival.

In these circumstances, government intervention in the economy for the common good is both necessary and justifiable. Indeed, achieving global sustainability will require a concerted *inter*governmental program including global population control, the development of more satisfying but less material-intense lifestyles and reshaping our cities in the image of natural ecosystems. Rich countries, at least, will have to abandon the idea of continuous economic growth and learn to share the economic and ecological output of the planet more equitably. The immediate material goal of this endeavour should be to reduce gross consumption and waste production to match the regenerative capacity of the ecosphere. The ultimate objective is to create a positive future for all characterized by ecological stability, greater social equity and enhanced economic security. Recognition that no person, city or nation can be sustainable on its own should be an incentive for collective action.

The transition to an ecologically sustainable urban society is a 100-year project and there is no excuse not to begin immediately. Certainly the problems of both first and third world cities are well documented and many partial solutions have been proposed (e.g., Marcotullio and McGranahan, 2007; Martine *et al*., 2008; Satterthwaite, 1999). Some of the best and most accessible handbooks for urban sustainability are explicitly based on treating cities as true ecosystems (Register, 2006; Newman & Jennings 2008). The only question is whether our growth-addicted global culture is capable of acknowledging and responding to the challenge in time. *H. sapiens* is facing its greatest test of whether we are truly a rational species. Humanity can continue to thrive, but only if urban civilization adapts purposefully to living within the carrying capacity of Earth.

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Table 1: The Eco-Footprints and Biocapacities of Selected Nations (data from WWF 2008)

Country	***Per capita* eco-footprint (global ha)**	***Per capita* domestic biocapacity (gha)**	**Overshoot factor**
World	**2.7**	**2.1**	**1.3**
United States	9.4	4.9	1.9
Australia	7.8	15.4	0.5
Canada	7.1	20.0	0.4
Greece	5.9	1.7	3.5
United Kingdom	5.3	1.6	3.3
France	4.9	3.0	1.6
Japan	4.9	0.6	8.2
Germany	4.2	1.9	2.2
Netherlands	4.0	1.1	3.6
Hungary	3.5	2.8	1.3
Mexico	3.4	3.3	1.0
Malaysia	2.4	2.7	0.9
Brazil	2.4	7.3	0.3
China	2.1	0.9	2.3
Thailand	2.1	0.8	2.6
Peru	1.6	4.0	0.4
Ethiopia	1.4	1.0	1.4
Nigeria	1.3	1.0	1.3
Indonesia	0.9	1.4	0.6
India	0.9	0.4	2.3
Bangladesh	0.6	0.3	2.0
Malawi	0.5	0.5	1.0

Table 2: The Eco-Footprints of Toronto and Vancouver (global average hectares)

City or region	Population (2006)	*Per capita* eco-footprint (gha)	Area (hectares)	Total eco-footprint (gha)	Ratio of EF to actual area
Vancouver	578,041	7.71	11,400	4,456,696	390
Metro Vancouver	2,116,580	7.71	278,736	16,318,832	57
Toronto	2,503,281	7.36	63,000	18,424,148	292
Greater Toronto	5,555,912	7.36	712,500	40,891,512	57

Figure 1: Oil and Gas Production Profiles, 2007 Base Case
(Source: ASPO Newsletter No. 91, July 2008)