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Ecological Footprints and the Pathology of Consumption

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This chapter examines key aspects of the human ecology of the City of Vancouver and its region in the Lower Fraser River Basin of British Columbia, Canada. Ecology is about relationships and the particular relationships to be examined here are the resource flows that connect the citizens of the Vancouver region to the rest of the biophysical world. My basic objective is to establish a framework from which to assess the long-term ecological sustainability of the human society living in the Lower Fraser Basin.

The work of our task force is directed toward building "healthy and sustainable communities." Thus, a primary question to be asked is whether the people of the Lower Fraser exist in healthy relationship with the natural environment. We believe, that for all our technological wizardry, human beings are still very much dependent on nature for survival. In fact, much of our work is premised on the belief that individual health and well-being depends on community health and that both of these, in turn, are dependent on the health of local ecosystems and the ecosphere.

Prevailing Perceptions

In this context, it may surprise some readers to know that for all the concern in recent years about the so-called "environmental crisis," human ecology is an ill-developed field. By this I mean that there are relatively few studies that examine human beings as ecological entities in their own right, as if they were *integral components* of particular ecosystems. True, more environmental studies and assessments have been conducted in the past thirty years than in all previous human history. However, these studies almost invariably focus on the impact of human beings *in here* on the quality of the environment *out there*. In short, "environmental science" as practised today reflects a deep-seated bias that permeates scientific industrial society: the tendency to perceive human beings as somehow separate and apart from nature.

Following the popular media for a week would convince anyone that our

culture sees "the environment" as an optional backdrop to human affairs. The latter is the real play. We acknowledge nature for its aesthetic and recreational value, and everyone agrees that a clean environment is preferable to a dirty one. However, there is little appreciation that the integrity of ecosystems may actually be essential to human survival. We may worry about polluted beaches or fret about the collapse of a fishery, but most of the concern is over the potential effect on human health or the economy. Rarely do we interpret such trends or events as signalling a fundamental dysfunction in the relationship between industrial "man" and the ecosphere. More rarely still do we seriously consider changing our ways to enable nature to recover – when push comes to shove, it's economic growth and human wants that take precedence over the environment. "You can't stop progress" captures the popular sentiment pretty well.

One major consequence of this human-centred cultural bias is already implicit in the above. If industry pollutes our favourite stream, poor logging practices destroy vital salmon habitat, or CFCs deplete the ozone layer, we say we have *environmental* problems. We "externalize" the issue (to use the economists' unconsciously revealing term). There is little real appreciation that the problem – and ultimately the solution – resides within us. Indeed, when we do act to improve matters, the frequent response is a technical fix aimed at enabling society to carry on pretty much as before. Stream contaminated? Build a swimming pool and chlorinate the drinking water (or import it in bottles from France). Fishery in trouble? "Fix" nature by building a hatchery.

An Alternative Perspective

The ecological approach advanced in this chapter presents a very different perspective from that of mainstream environmental science. To begin, it recognizes that, whatever we may think, the fact is that humankind is still very much a part of nature. We can therefore analyze humanity's ecological niche in much the same way as we would that of any other species. What are the important connections and dependencies between humans and other species? What biophysical processes in nature are essential for maintenance of the human enterprise?

As we begin to answer such questions, we find that far from being independent of nature, people today make greater demands on the natural world than at any previous time in history. What mammal is the dominant predator in the sea? Why humans, of course! We don't usually think of ourselves as marine mammals, but no other species comes close to matching humanity's take from the world's oceans. The global fish catch represents 8 percent of total net marine primary production (net photosynthesis) and 25 to 35 percent of the productivity of estuaries and coastal shelves. (These rich habitats represent only 10 percent of the area, but 96 percent of the

humanity's ocean "harvest") (Pauly and Christensen 1995). So it is on land. Humans are the greatest macroconsumer in most of the world's grasslands and forests, directly consuming or otherwise diverting for their own use about 40 percent of the net product of terrestrial photosynthesis (Vitousek et al. 1986). Indeed, human beings may well be the dominant consumer organism in all the major ecosystems on Earth. Peculiar situation for a species that considers itself unconstrained by nature!

Other examples of humanity's expanding role in nature abound. More artificial nitrate is now applied to the world's croplands than is fixed from the atmosphere by microbial activity and other natural processes combined (Vitousek 1994); the rate of human-induced species extinctions is approaching the extinction rates driven by "the great natural catastrophes at the end of the Paleozoic and Mesozoic era – in other words, [they are] the most extreme in the past 65 million years" (Wilson 1988); "residuals" discharged by industrial economies are depleting stratospheric ozone and altering the preindustrial composition of the atmosphere, and both these trends contribute to the threat of climate change, itself the most potent popular symbol of human-induced global change.

These data bring us back to the question posed at the outset. Just how healthy or sustainable is the ecological niche that industrial society has carved for itself? The empirical evidence cited above suggests that the aggregate scale of economic activity is already capable of altering global biophysical systems and processes in ways that jeopardize both global ecological stability and geopolitical security. Yet the problems so far are mainly the result of production and consumption by just the richest quarter of the world's human population. What then can we say about a global development path (as set by the United Nations, the World Bank, and other mainstream institutions) that suggests that a five- to ten-fold increase in industrial output can be anticipated over the next half-century as the population increases to nine or ten billion and the rest of the world catches up to European and North American levels of material well-being (WCED 1987)?

Coming to Grips with Reality

Driven by an uncritical worship of economic growth, it seems that consumption by humans threatens to overwhelm the ecosphere from within. This is clearly a pathological relationship. The continuous growth of any species in nature is an unnatural condition that can be purchased only at the expense of other species and the integrity of the ecosystem as a whole.

Indeed, any relationship in which the vitality of one organism is sustained by sapping the vitality of another is, by definition, a parasitic one. The distinguishing feature of parasitism is "the subversion, co-option, or undermining of the self-regenerative or autopoietic capacity of the host" (Peacock 1995). "Looked at from the point of view of other organisms,

humankind therefore resembles an acute epidemic disease, whose occasional lapses into less virulent forms of behaviour have never yet sufficed to permit any really stable chronic relationship to establish itself" (McNeill 1976, cited in Peacock 1995).[1] While it may seem extreme to interpret humans and their economy in such unsavoury terms, it may also be wholly realistic. If we don't understand the problem, we have little chance of finding workable solutions.

Simply acknowledging the truth is a necessary first step in stimulating new thinking about human development options. Noting that many of our so-called environmental problems are now global in scope or common to every continent, World Bank ecologist Robert Goodland (1991) emphasizes that humanity is confronting a whole new class of limits to growth. Similar data bring economist Herman Daly to argue that the world has reached an historic turning-point, a point at which the world must shift from the assumptions of "empty-world" to those of "full-world" economics (Daly 1991).

I agree unambiguously with Goodland and Daly. My starting premise in this chapter is that humanity is facing an unprecedented crisis that is slowly (for now) but inexorably undermining the integrity of the ecosphere and with it the full potential of humankind. This creeping malaise is driven by the dominant values and behaviours of an increasingly global consumer society. However, temporarily shielded by seeming material abundance from the ecological and social consequences of their own lifestyles, the business and political leaders, and many of the citizens of those high-income countries in a position to address the problem, remain in a state of deep denial. Worse, the ecologically naïve models of their technical and economic advisors have convinced them that the "surest way to improve [the] environment is [for everyone] to become rich" (Beckerman 1992, cited in Ekins 1993).

A major objective of this chapter, therefore, is to explain and illustrate an analytic tool that graphically depicts human ecological reality. This tool, ecological footprint analysis, gains its strength by focusing on the continuous stream of energy and material resources that connect humans and their economy to the ecosphere at both ends (inputs and outputs) of the production and consumption stream.[2] Converting estimates of the material flows associated with any defined population to the area of land and water required to produce or assimilate these flows produces an estimate of the true ecological footprint of that population on the Earth. In short, ecological footprint analysis produces a simple and readily understandable area-based index of sustainability. This method enables direct comparisons of the ecosystem area needed to support the specified population with available supplies of productive land. Emphasizing physical reality in this way clarifies and quantifies the ecological dimensions of the global crisis,

points to related problem areas, and suggests policy directions that might contribute to resolving the dilemma.

The primary ecological question in today's world is: Are humans living within nature's means? Conventional analyses of the economy are not even capable of asking this question, but the methods outlined in this chapter provide one way of answering it. Some of the science and terminology may be intimidating. However, the concepts themselves are not difficult to understand and the analysis is facilitated by a case example from Vancouver and the Lower Fraser Basin. The final sections further ground the analysis by outlining some concrete policy implications for both local and higher political levels.

Framing the Analysis

Many biophysically oriented scientists agree that the "full-world economics" proposed by Herman Daly will be an economics based on principles of ecology and the second law of thermodynamics. While the second law is arguably the ultimate governor of all economic activity, it is totally ignored in conventional economic models. This is partially because neoclassical economics seems fixated by the first law (which says that energy may be transformed from one form to another but is never created nor destroyed) and by the law of conservation of mass (which says that the mass of the inputs to any chemical reaction are precisely equal to the mass of the outputs). These physical laws seem to suggest that we can never run out of anything. Unfortunately, this simplistically optimistic interpretation ignores the *qualitative* changes that occur in every energy and material transformation. Simply put, the use of any rich source of energy or matter changes it in ways that reduce its potential for any future use – ashes and smoke are not the equivalent of the original lump of coal. This peculiar reality is a property of the second law. The following section links the second law firmly to human ecology through the much-maligned concept of carrying capacity.

Introducing the Second Law

> In a sufficiently long time-frame, it becomes evident that the most important [potential] scarcity is of thermodynamic potential.
> – R.S. Berry (Berry 1972)

The second law of thermodynamics states that the entropy of any isolated system always increases. This means that if a system is cut off from supplies of high-grade energy and matter, it will gradually run down – internal energy spontaneously dissipates, gradients disappear, and the system becomes increasingly unstructured and disordered in an inexorable slide

toward thermodynamic equilibrium. The latter is a state in which "nothing happens or can happen" (Ayres 1994).

What is often forgotten is that *all* systems, whether isolated or not, are subject to the same forces of entropic decay. In other words, any complex differentiated system has a natural tendency to erode, dissipate, and unravel. The reason self-producing, self-organizing systems such as the human body or modern cities do not "run down" in this way is that they are able to import available energy and material (essergy)[3] from their host environments which they use to maintain their internal integrity. Such systems also export the resultant entropy (waste and disorder) back into their hosts. Modern formulations of the second law therefore suggest that all highly ordered systems develop and grow (increase their internal order) "at the expense of increasing disorder at higher levels in the systems hierarchy" (Schneider and Kay 1994).[4] Because such *systems* continuously degrade and dissipate available energy and matter, they are called "dissipative structures."

Of what relevance is this to sustainability? The human economy (or any subset such as a modern city) is a prime example of a highly ordered, dynamic, far-from-equilibrium dissipative structure. At the same time, it is an open, growing, subsystem of the materially closed, nongrowing ecosphere (Daly 1992). It follows that the economy can grow and develop (i.e., remain in a dynamic nonequilibrium state) only because it is able to extract useful energy and material (essergy) from the ecosphere and discharge its wastes back into it. Unfortunately, the hierarchical nature of this relationship implies that beyond a certain point, *the cost of continuous economic growth is the increasing entropy or disordering of the ecosphere*. (Note that the ecosphere develops and maintains itself by dissipating solar energy, i.e., by increasing the entropy of the solar system.) Thermodynamic law thus suggests a new physical criterion for sustainable development: an economy or a community exists in a sustainable state *if there is no significant increase in the net entropy of its host ecosystem(s)*. In other words, essergy production by the ecosphere must be adequate to balance entropy output by the economy.

Revisiting Carrying Capacity

The notion that humanity may be up against a new kind of physical limit has rekindled the Malthusian debate about human carrying capacity (see, for example, *Ecological Economics* 15: 2 [November 1995]). Carrying capacity is usually defined as the maximum population of a given species that can be supported indefinitely in a defined habitat without permanently impairing the productivity of that habitat. However, because we humans seem to be capable of continuously increasing the human carrying capacity of Earth by eliminating competing species, by importing locally scarce resources, and through technology, conventional economists and planners generally reject the concept as irrelevant to people. As Herman Daly (1986) critically

observes, the prevailing vision assumes a world in which the economy floats free of any environmental constraints. This is a world "in which carrying capacity is infinitely expandable" – and therefore irrelevant.

By contrast, we have already noted that the economy is an inextricably embedded subsystem of the ecosphere. Despite our technological and economic achievements, humankind remains in a state of "obligate dependence" on the productivity and life-support services of the ecosphere (Rees 1990). The trappings of technology and culture aside, human beings remain biophysical entities. From a trophodynamic perspective, the relationship of humankind to the rest of the ecosphere is similar to those of thousands of other consumer species with which we share the planet. We depend for both basic needs and the production of cultural artifacts on energy and material resources extracted from nature, and *all* this energy/matter is eventually returned in degraded form to the ecosphere as waste.

The major material difference between humans and other species is that, in addition to our biological metabolism, the human enterprise is characterized by an industrial metabolism. In second law terms, all our toys and tools (the human-made "capital" of economists) are "the exosomatic equivalent of organs" and, like bodily organs, require continuous flows of energy and material to and from "the environment" for their production and operation (Sterrer 1993).

The second law forces thus an uncomfortable reinterpretation of the nature of economic activity. In effect, it shows that what we usually think of as economic production is actually consumption – nature is the real producer. As Georgescu-Roegen (1971) observes, "valuable natural resources [from nature] enter the economic process, and valueless waste is thrown out." Moreover, because of the thermodynamic inefficiency of energy/material transformations, any economic activity necessarily consumes more essergy than is contained in the useful product. At best, therefore, the economic process can be said to extract economic goods and services – rather inefficiently – from energy and material produced elsewhere in the ecosphere.

The Constant Capital Stocks Criterion for Sustainability

Because of humanity's continuing functional dependence on ecological processes, some analysts have stopped thinking of natural resources as mere "free goods of nature." Ecological economists now regard the species, ecosystems, and other biophysical entities that produce required resource flows as forms of "natural capital" and the flows themselves as types of essential "natural income" (Pearce, Markandya, and Barbier 1989; Victor 1991; Costanza and Daly 1992). This capital theory approach provides a valuable insight into the meaning of sustainability: no development path is sustainable if it depends on the continuous depletion of productive capital.

From this perspective, society can be said to be economically sustainable only if it passes on an undiminished per capita stock of essential capital from one generation to the next (Solow 1986; Pearce et al. 1989; Victor 1991; Pearce 1994).[5] This "constant capital stocks" criterion is obviously closely related to the "no increase in net entropy" criterion described above.

In the present context, the most relevant interpretation of the constant stocks criterion is as follows: "Each generation should inherit an adequate per capita stock of natural capital assets no less than the stock of such assets inherited by the previous generation."[6]

Because of its emphasis on maintaining natural (biophysical) capital intact, the foregoing is a "strong sustainability" criterion (Daly 1990). The prevailing alternative interpretation would maintain a constant *aggregate* stock of human-made and natural assets. This latter version reflects the neoclassical premise that manufactured capital can substitute for natural capital and is referred to as "weak sustainability" (Daly 1990; Pearce and Atkinson 1993; Victor, Hanna, and Kubursi 1995).

Ecologists advocate strong sustainability because it best reflects known biophysical principles and the *multifunctionality* of biological resources "including their role as life support systems" (Pearce et al. 1989). Most importantly, strong sustainability recognizes that manufactured and natural capital "are really not substitutes but complements in most production functions"(Daly 1990). In other words, many forms of biophysical capital perform critical functions that cannot be replaced by technology.[7] For sustainability, therefore, a critical minimal amount of natural capital must be conserved intact and in place. This will ensure that the ecosystems upon which humans depend remain capable of continuous self-organization and production.[8]

In this light, the fundamental ecological question for sustainability is whether remaining *natural* capital stocks (including other species populations and ecosystems) are adequate to provide the resources consumed, and assimilate the wastes produced by the anticipated human population into the next century, while simultaneously maintaining the general life-support functions of the ecosphere. In short, is there adequate human carrying capacity? At present, of course, both the human population and average consumption are increasing while the total area of productive land and stocks of natural capital are fixed or in decline. Shrinking carrying capacity may therefore soon become the single most important issue confronting humanity.

Carrying Capacity as Maximum Human Load

> An environment's carrying capacity is its maximum persistently supportable load.
> – William Catton (Catton 1986)

The issue becomes clearer if we define human carrying capacity not as a maximum population but rather as the maximum (entropic) "load" that can safely be imposed on the environment by people (Catton 1986). Human load is clearly a function not only of population but also of average per capita consumption. Significantly, the latter is increasing even more rapidly than the former because of (ironically) expanding trade, advancing technology, and rising incomes. As Catton (1986) observes, "the world is being required to accommodate not just more people, but effectively 'larger' people." For example, in 1790, the estimated average daily energy consumption by Americans was 11,000 kilocalories per capita. By 1980, this had increased almost twenty-fold to 210,000 kilocalories per day (Catton 1986). As a result of such trends, load pressure relative to carrying capacity is rising much faster than is implied by mere population increases.[9]

Ecological Footprints: Measuring Human Load

By inverting the standard carrying capacity ratio and extending the concept of load, my students and I have developed a powerful tool for assessing human carrying capacity. Rather than asking what population a particular region can support sustainably, the critical question becomes, How large an area of productive land and water is needed to sustain a defined population indefinitely, *wherever on Earth that land is located* (Rees 1992; Rees and Wackernagel 1994)? In the language of the previous section, we ask how much of the Earth's surface is appropriated to support the load imposed by a referent population, whatever its trading relationships or technological status. Most importantly, this approach overcomes the economists' argument that trade and technology can eliminate local resource constraints, making carrying capacity irrelevant to human beings. Ecological footprinting recognizes (1) that trade does not actually increase global productive capacity but merely shuffles it around, and (2) that all material transformations have a material basis whatever the level of technological sophistication.

Since most forms of natural income (resource and service flows) are produced by terrestrial and aquatic ecosystems,[10] it should be possible to estimate the area of land/water required to produce indefinitely the quantity of any resource or ecological service used by a defined population at a given level of technology. The sum of such calculations for all significant categories of consumption would provide a conservative area-based estimate of the "in-place" natural capital requirements of that population. We call this area the population's true "ecological footprint."

A simple two-step thought experiment serves to illustrate the ecological principles behind this approach. First, imagine what would happen to Vancouver, as defined by its political boundaries, if it were enclosed in a

glass or plastic bell-jar completely closed to material flows. This means that the human system so contained would be able to rely only on whatever remnant ecosystems were trapped within the hemisphere.

It is obvious to most people that the city would cease to function and its inhabitants would perish within a few days. The population (and economy) contained by the bell-jar would have been cut off from both vital resources and essential waste sinks, leaving it to starve and suffocate at the same time. In other words, the ecosystems contained within our imaginary human terrarium would have insufficient carrying capacity to service the ecological load imposed by the contained population.

The second step pushes us to contemplate urban ecological reality in more concrete terms. Let's assume that our experimental city is surrounded by a diverse landscape in which cropland and pasture, forests and watersheds – all the different ecologically productive land types – are represented in proportion to their actual abundance on the Earth, and that adequate fossil energy is available to support current levels of consumption using prevailing technology. Let's also assume our imaginary glass enclosure is elastically expandable. The question now becomes, How large would the bell-jar have to grow before the city at its centre could sustain itself indefinitely and exclusively on the land and water ecosystems and the energy resources contained within the capsule?[11] In other words, what is the total area of different ecosystem types needed continuously to support all the consumption activities carried out by the people of our city as they go about their daily activities? Answering this question would provide an estimate of the de facto ecological footprint of the city. Formally defined, the ecological footprint (EF) is the total area of productive land and water required on a continuous basis to produce the resources consumed and to assimilate the wastes produced by a specified population, wherever on Earth that land is located.

The ecological footprint is an area-based measure of the population's demand for goods and services provided by self-producing natural capital. Thus, ecological footprinting recognizes that photosynthesis and dependent ecological processes are the major means by which the ecosphere neutralizes the disorder produced by economic production/consumption processes. (For sustainability, the net essergy produced by the ecosphere must at least offset the entropy pumped out by the economy.) This, in turn, requires that an adequate area of productive ecosystem remain in place for every significant increment of consumption.

The Method in Brief

The basic calculations for ecological footprint estimates are conceptually simple. Typically, we estimate average annual consumption (c_i, usually in kilograms) of each major consumption item (i) used by the study popula-

tion, usually from published data. Much of the data needed for preliminary assessments is readily available from national statistical tables on, for example, energy, food commodities, or forest products production and consumption. For many categories, national statistics provide both production and trade figures from which consumption can be trade-corrected as follows:

trade-corrected consumption = production + imports - exports

The next step is to estimate the land/water area (a_i) "appropriated" by the study population for the production of each consumption item. We do this by dividing annual consumption of each item (c_i) by land productivity or yield for that item (y_i, usually in kilograms per hectare).[12] Thus:

$$a_i = c_i / y_i = (kg_i / kg_i \times ha^{-1})$$

Similar calculations can be made for the land/water required to assimilate certain waste products such as carbon dioxide.

We then compute the total ecological footprint of the population (F_p) by summing the ecosystem areas appropriated by all the individual consumption goods or services. Thus:

$$F_p = \sum_{i=1}^{n} a_i$$

Finally we obtain the per capita ecological footprint (f_c) of individuals in the study population by dividing the population eco-footprint by population size (N): Thus:

$$f_c = F_p / N$$

Figure 1.1 provides a sample calculation showing the land requirement for paper consumption by the average Canadian (in this example, consumption and yield are in cubic metres per year).

Our eco-footprint calculation is structurally similar to the more familiar representation of human environmental impact, $I = PAT$, where P is population size, A is a measure of affluence, and T represents technology (Ehrlich and Holdren 1971; Holdren and Ehrlich 1974). The ecological footprint is, in fact, a measure of population impact expressed in terms of appropriated land area. The size of the footprint will of course, reflect the affluence (material consumption) and technological sophistication of the subject population.

So far, our EF calculations are based on items in five major categories of consumption – food, housing, transportation, consumer goods, and ser-

Figure 1.1

Productive forest area required for paper production by an average Canadian

Question: How much productive forest is dedicated to providing pulp-wood for the paper used by the average Canadian? ("Paper" includes food wrappings, other packaging, reading material, and construction paper.)

Answer: Each Canadian consumes about 244 kilograms of paper products each year. In addition to the recycled paper that enters the process, the production of each metric ton of paper in Canada currently requires 1.8 m^3 of wood. For ecological footprint analyses, an average wood productivity of 2.3 m^3/ha/yr is assumed. Therefore, the average Canadian requires:

$$\frac{244 \text{ kg/cap/yr} \times 1.8 \text{ m}^3\text{/t}}{1{,}000 \text{ kg/t} \times 2.3 \text{ m}^3\text{/ha/yr}} = 0.19 \text{ ha/capita of forest in continuous production for paper.}$$

vices – and on eight major land-use categories. However, we have examined only one class of waste flow in detail. We account for carbon dioxide emissions from fossil energy consumption by estimating the area of average carbon-sink forest that would be required to sequester them ([carbon emissions/capita]/[assimilation rate/hectare]), on the assumption that atmospheric stability is a prerequisite of sustainability. (Ours is a relatively conservative approach. An alternative is to estimate the area of land required to produce the biomass energy equivalent [ethanol] of fossil energy consumption. This produces a larger energy footprint than the carbon assimilation method.) Full details of EF calculation procedures and more examples can be found in Rees and Wackernagel (1994); Wackernagel and Rees (1996); Rees (1996a); and Wackernagel et al. (1999).

The Ecological Footprints of Modern Cities and High-Income Regions

Canada is one of the world's wealthiest countries. Its citizens enjoy very high material standards by any measure. Indeed, ecological footprint analysis shows that the total land required to support present consumption levels by the average Canadian is at least 4.3 hectares (2.3 hectares for carbon dioxide assimilation alone). Thus, the per capita ecological footprint of Canadians (their average "personal planetoid") is almost three times their "fair Earthshare" of 1.5 hectares[13] (Rees 1996a; Wackernagel and Rees 1996).

Footprinting Vancouver and Its Region

Let's apply this result to our study area – the Lower Fraser Basin of British Columbia. In many respects, it is typical of high-income regions anywhere. Within this area, the City of Vancouver had a 1991 population of 472,000

and an area of 11,400 hectares (114 square kilometres). Assuming a per capita land consumption rate of 4.3 hectares,[14] the 472,000 people living in Vancouver require, conservatively, 2 million hectares of land for their exclusive use in order to maintain their current consumption patterns (assuming such land is being managed sustainably). However, the area of the city is, again, only about 11,400 hectares. This means that the city population appropriates the productive output of a land area *nearly 180 times larger than its political area* to support its present consumer lifestyles.

We can also estimate of the marine footprint of the city's population based on fish consumption. Available data suggest a maximum sustainable yield from the oceans of about 100 million tonnes of fish per year. First we divide the global fish catch by total productive ocean area. About 96 percent of the world's fish catch is produced in shallow coastal and continental shelf areas that constitute only 8.2 percent of the world's oceans (about 29.7 million square kilometres). Average annual production is therefore about 32.3 kilograms of fish per productive hectare (.03 hectares per kilogram of fish). Since Canadians consume an average of approximately 23 kilograms of marine fish annually, their marine footprint is about 0.7 hectares each. If we add this per capita marine footprint to the terrestrial footprint, the total area of Earth needed to support Vancouver's population is 2.36 million hectares, or more than 200 times the geographic area of the city.

While these findings might seem extraordinary, other researchers using our methods have obtained similar results for other modern cities. British researchers have estimated London's ecological footprint for food, forest products, and carbon assimilation to be 120 times the surface area of the city proper (IIED 1995). Folke, Larsson, and Sweitzer (1994) report that the aggregate consumption of wood, paper, fibre, and food (including seafood) by the inhabitants of twenty-nine cities in the Baltic Sea drainage basin appropriates an ecosystem area 200 times larger than the area of the cities themselves. (While this study includes a marine component for seafood production, it has no energy land component.)[15]

Extending our Vancouver example to the entire Lower Fraser Basin (population of 1.78 million) reveals that even though only 18 percent of the region is dominated by urban land use (i.e., most of the area is rural agricultural or forested land), consumption by its human population "appropriates" through trade and biogeochemical flows the ecological output and services of a land area about 14 times larger than the region's 5,500 square kilometres. In other words, the people of the Lower Fraser Basin, in enjoying their consumer lifestyles, have overshot the terrestrial carrying capacity of their home territory by a factor of 14. Put yet another way, analysis of the ecological load imposed by the regional population shows that at prevailing material standards, *at least* 90 percent of the ecosystem area needed to support the Lower Fraser Basin actually lies outside the region itself.

Table 1.1

Estimated ecological footprints of Vancouver and the Lower Fraser Basin (terrestrial component only)

Geographic unit	Population	Land area (ha)	Ecological footprint (ha)	Overshoot factor
Vancouver City	472,000	11,400	2,029,600	178.0
Lower Fraser Basin	1,780,000	555,000	7,654,000	13.8

These results are summarized in Table 1.1.

In summary, the sustainability of the Lower Fraser Basin of British Columbia is dependent on imports of natural goods and services from an area elsewhere on Earth vastly larger than the study area itself. Lower Fraser Basin residents consume 14 times the natural income produced by their own natural capital. In effect, however healthy the region's economy appears to be in monetary terms, the Lower Fraser Basin is running a massive ecological deficit with the rest of Canada and the world.

The Hidden Foot of the Global Economy

This situation is typical of high-income regions and even of some entire countries. Most highly urbanized industrial countries run an ecological deficit about an order of magnitude larger than the sustainable natural income generated by the ecologically productive land within their political territories (Table 1.2). The last two columns of Table 1.2 represent low estimates of these per capita deficits. (N.B. More recent data produce greater eco-footprints and deficits [Wackernagel et al. 1999].)

These data throw new light on current world development models. For example, Japan and the Netherlands both boast positive trade and current account balances measured in monetary terms, and their populations are among the most prosperous on earth. Densely populated yet relatively resource- (natural capital) poor, these countries are regarded as stellar economic successes and held up as models for emulation by the developing world. At the same time, we estimate that Japan has a 2.5 hectare per capita and the Netherlands a 3.3 hectare per capita ecological footprint, which gives these countries national ecological footprints about eight and fifteen times larger than their domestic territories respectively. (Note that the larger figures in Table 1.2 are based on domestic areas of ecologically productive land only.) The marked contrast between the physical and monetary accounts of such economic success stories raises difficult developmental questions in a world whose principal strategy for sustainability is economic growth. Global sustainability cannot be deficit-financed; simple physics dictates that *not all countries or regions can be net importers of biophysical capacity*.

Table 1.2

Ecological deficits of the urban-industrial countries[1]

Country	Ecologically productive land (ha) *a*	Population (1995) *b*	Ecologically productive land per capita (ha) *c = a/b*	National ecological deficit per capita (ha) *d = footprint - c*	(in percent available) *e = d/c*
Countries with 2-3 ha footprints				**Assuming a 2.5 ha footprint**	
Japan	30,417,000	125,000,000	0.24	2.26	940
Countries with 3-4 ha footprints				**Assuming a 3 ha footprint**	
Belgium	1,987,000	10,000,000	0.20	2.80	1,400
Britain	20,360,000	58,000,000	0.35	2.65	760
France	45,385,000	57,800,000	0.78	2.22	280
Germany	27,734,000	81,300,000	0.34	2.66	780
Netherlands	2,300,000	15,500,000	0.15	2.85	1,900
Switzerland	3,073,000	7,000,000	0.44	2.56	580
Countries with 4-5 ha footprints				**Assuming Cdn 4.3 and US 5.1 ha footprints**	
Canada	434,477,000	28,500,000	15.24	(10.94)	(250)
United States	725,643,000	258,000,000	2.81	2.29	80

1 Footprints estimated from studies by Ingo Neumann of Trier University, Germany; Dieter Zürcher, Infras Consulting, Switzerland; and our own analysis using World Resources Institute (1992) data.

Source: Abstracted and revised from Wackernagel and Rees (1996). Ecologically productive land means cropland, permanent pasture, forests, and woodlands as compiled by the World Resources Institute (1992). Semiarid grasslands, deserts, and icefields are not included.

It is worth noting in this context that Canada is one of the few high-income countries that consumes less than its natural income domestically (Table 1.2). Low in population and rich in natural resources, this country has yet to exceed domestic carrying capacity. However, Canada's natural capital stocks are being depleted by exports of energy, forest, fish, and agricultural products to the rest of the world. In short, the apparent surpluses in Canada are being incorporated by trade into the ecological footprints of other countries, particularly those of deficit economies, such as Japan and the United States (although the entire Canadian surplus would be insufficient to satisfy just the US deficit!). How should such biophysical realities be reflected in local and global strategies for ecologically sustainable socioeconomic development?

Cities and Sustainability

Ecological footprint analysis underscores that as a result of the enormous increase in per capita energy and material consumption made possible by (and required by) technology, and universally increasing dependencies on trade, *the ecological locations of high-density regions no longer coincide with their geographic locations*. Twentieth-century cities and industrial regions are dependent for survival and growth on a vast and increasingly global hinterland of ecologically productive landscapes. Cities necessarily appropriate the ecological output and life-support functions of distant regions all over the world by means of both commercial trade and natural flows of energy and material through the ecosphere. This observation highlights a potentially critical reality that should be obvious but is often ignored or forgotten in conventional development planning: *no city or urban region can achieve sustainability on its own*. Regardless of the sensitivity of urban land use and environmental policies to ecological concerns, a prerequisite for sustainable cities is sustainability of the countryside.

The other side of this dependency coin is the impact urban populations and cities have on the ecosphere. Combined with rising material standards and the spread of consumerism, the mass migration of humans to the cities in this century has turned urban industrial regions into nodes of intense consumption. The wealthier the city and the more connected it is to the rest of the world, the greater the entropic load it is able to impose on the ecosphere through trade and other forms of economic leverage. However, most biophysical resources and life-support services are produced outside the cities. Seen in this light and contrary to popular wisdom, the seeming depopulation of many rural areas does not mean the latter are being abandoned in any functional sense. While most of the people may have moved elsewhere, rural lands and ecosystem functions are being exploited more intensely than ever in the service of newly urbanized populations. Indeed, while the countryside could be viable without the city, there could be no city without the countryside.[16]

Cities and the Entropy Law

The populations of so-called "advanced" high-income countries are 75 percent or more urban, and estimates suggest that over 50 percent of the entire human population will be living in urban areas by the end of the century. If we accept the Brundtland Commission's estimate that the wealthy quarter of the world's population consumes over three-quarters of the world's resources (and therefore produces at least 75 percent of the wastes), then the populations of wealthy cities are responsible for about 60 percent of current levels of resource depletion and pollution. The global total contribution from cities is probably 70 percent or more.

In effect, cities have become entropic black holes drawing in energy and matter from all over the ecosphere and returning all of it in degraded form back to the ecosphere. This relationship is an inevitable expression of the second law of thermodynamics (cities are prime examples of highly ordered dissipative structures). This means that in the aggregate, cities (and the human economy) can operate sustainably only within the thermodynamic load-bearing capacity of the ecosphere. Beyond a certain point, the cost of material economic growth will be measured by increasing entropy or disorder in the environment. Recall that this process is the essence of parasitism. The enormous drain imposed on the ecosphere by high-income societies has changed consumption by humans into a planetary disease.

We would expect this point – the point at which consumption by humans chronically exceeds available natural income – to be revealed through the continuous depletion of natural capital: reduced biodiversity; fisheries collapse; air, water, and land pollution; deforestation; ozone depletion; desertification; and so on. Such trends are the stuff of daily headlines. We seem to be witnessing the destructuring and dissipation of the ecosphere, a continuous increase in global net entropy. By this criterion, society should acknowledge that the present global economy is unsustainably bankrupt. With prevailing technology, it can grow and maintain itself only by simultaneously consuming and polluting its host environment. As argued by World Bank ecologist Robert Goodland, "current throughput growth in the global economy cannot be sustained" (Goodland 1991). We have already reached the entropic limits to growth.

This brings us back to Daly's (1991) warning that with the onset of global ecological change, the world has reached an historic turning point that requires a conceptual shift from empty-world to full-world economics (and ecology). Ecological footprint analysis underscores the urgency of making this shift. As noted, the productive land "available" to each person on Earth has decreased rapidly with the explosion of human population in this century. Today, there are only 1.5 hectares of such land for each person, including wilderness areas that probably shouldn't be used for any

other purpose. At the same time, the land area "appropriated" by residents of richer countries has steadily increased. The present per capita ecological footprints of North Americans (4 to 5 hectares) represent at least three times their fair share of the Earth's bounty. By extrapolation, if everyone on Earth lived like the average North American, the total land requirement would exceed 26 billion hectares. However there are fewer than 9 billion hectares of such land on Earth. This means that we would need three such planets to support just the *present* human family. In fact, we estimate that resource consumption and waste disposal by the wealthy quarter of the world's population alone exceeds global carrying capacity by up to 30 percent (Wackernagel and Rees 1996). (Again, these are underestimates based on the assumption that our present land endowment is being used sustainably, which it is not.)

Cities and Global Trade

Acknowledging the energy and material dependence of cities also forces recognition of the city's role as an engine of economic growth and global trade. According to the conventional view, trade increases both incomes and carrying capacity. Individual trading regions can export local surpluses and thereby earn the foreign exchange needed to pay for imports of locally scarce resources. Hence, both the economy and the population are free to grow beyond limits that would otherwise be imposed by regional carrying capacity. The fact that 40 percent of global economic growth today is sustained by trade supports this argument.

There are, however, serious flaws in the conventional interpretation. First, trade reduces the most effective incentive for resource conservation in any import region, the regional population's otherwise dependence on local natural capital. For example, the Vancouver region's seasonal access to cheap agricultural imports from California and Mexico reduces the potential income from local agricultural land.[17] Fraser Valley farmers themselves therefore join developers in pressing for conversion of agricultural land to urban uses, which produce a higher short-term return. Because of trade, the consequent loss of foodlands in the Fraser basin proceeds without immediate penalty to the local population. Indeed, the latter are actually rewarded in the short term by the boost to the local economy. Ironically, then, while appearing to do the opposite, trade actually *reduces* both regional and global carrying capacity by facilitating the depletion of the total stock of natural capital. By the time market prices reflect incipient ecological scarcity, it will be too late to take corrective action.

By throwing new light on commercial trade and natural flows, ecological footprint analysis also suggests a disturbing interpretation of contemporary North-South relationships. Much of the wealth of urban industrial countries comes from the exploitation (and sometimes liquidation) of

natural capital, not only within their own territories but also within their former colonies. The energy and material flows in trade thus represent a form of thermodynamic imperialism. The low entropy represented by commodity imports are required to sustain growth and maintain the internal order of the so-called "advanced economies" of the urban North. However, expansion of the human enterprise proceeds at the expense of "a net increase in [global] entropy as natural resource [systems] and traditional social structures are dismembered" (Hornborg 1992a, 1992b). Colonialism involved the forceful appropriation of extraterritorial carrying capacity, but today, economic purchasing power secures the same resource flows. What used to require territorial occupation is now achieved through commerce! (Rees and Wackernagel 1994).

In summary, the structure of trade, as we know it at present, is a curse from the perspective of sustainable development (Haavelmo and Hansen 1991). To the extent that competitive open global markets and liberated trade accelerate the depletion of essential natural capital, it is counterproductive to long-term sustainability. Trade only appears to increase carrying capacity. In fact, by encouraging all regions to exceed local limits, by reducing the perceived risk attached to local natural capital depletion, and by simultaneously exposing local surpluses to global demand, uncontrolled trade accelerates natural capital depletion, reducing global carrying capacity, and increasing the ultimate risk to everyone (Rees and Wackernagel 1994).

Toward Urban Sustainability

Ecological footprint analysis not only measures our ecological deficit or "sustainability gap" (Rees 1996a), it also provides insight into strategies for sustainable urban development. To begin, it is important to recognize that cities are themselves vulnerable to the negative consequences of overconsumption and global ecological mismanagement. How economically stable and socially secure can a city of ten million be if distant sources of food, water, energy, or other vital resource flows are threatened by accelerating ecospheric change, increasing competition, dwindling supplies, or civil or international strife? Does the present pattern of global development, one that increases interregional dependence on vital natural income flows that may be in jeopardy, make ecological or geopolitical sense? If the answer is "no" or even a cautious "possibly not," present circumstances may already warrant a restoration of balance away from the present emphasis on global economic integration and interregional dependency toward enhanced ecological independence and greater intra-regional self-reliance. (If all regions were in ecological steady-state, the aggregate effect would be global stability.)

To reduce their dependence on external flows, urban regions and whole countries may chose to develop explicit policies to invest in rehabilitating

their own natural capital stocks and to promote the use of resources such as local fisheries, forests, and agricultural land. This would increase regional independence, creating a hedge against rising international demand, global ecological change, and potentially reduced productivity elsewhere.

Certainly in terms of food and fibre production, the Vancouver region is exceptionally well positioned to enhance its self-reliance. The metropolitan area (including the suburb cities of Richmond and Delta) is sprawling short-sightedly out over the richest farmland in Canada. As previously noted, prevailing short-term thinking (abetted by agricultural subsidies in the United State) results in the undervaluing of local croplands in agricultural use relative to urban residential or commercial use, despite the existence of the provincial Agricultural Land Reserve (ALR) system.

This could change. Rather than seeing the ALR as a barrier to development, Richmond, for example, could use its agricultural endowment to help move itself forward – that is, "develop" – as a prototype sustainable city. With appropriate policy support from the provincial and federal governments, maximizing food self-reliance could be part of this plan.[18] Increasing consumer interest in quality organic foods (low ecological impact), producer-consumer food co-ops, community truck gardens, and urban agriculture, along with growing consumer distrust of international agribusiness, suggest that the public may be ahead of the politicians on this issue.

Were the local and regional population to reinhabit its own landscape in this way, it would not only enhance the viability of the Lower Mainland agricultural community and help ensure the preservation of vital natural capital assets, it would also help reestablish regional urbanites' lost sense of connectedness to, and dependence on, the land. This could only stimulate greater interest in the broader issue of regional sustainability.

Although enhanced regional self-reliance is a desirable goal on several grounds, we are not arguing for regional closure. In any event, total self-sufficiency is not in the cards for most modern urban regions. The more important issue before us is to define an appropriate role of cities in achieving global sustainability. The key question is, How can we assure "that the aggregate performance of cities and urban systems within nations and worldwide is compatible with sustainable development goals" (Mitlin and Satterthwaite 1994)? And, we would add, compatible with shrinking global carrying capacity?

Ecological Strengths and Weaknesses of Cities

A major conclusion of ecological footprint analysis and similar studies is that urban policy should strive to minimize the disruption of ecosystems processes, and massively reduce the energy and material consumption, associated with cities. Various authorities share the view of the Business

Council on Sustainable Development that "industrial world reductions in material throughput, energy use, and environmental degradation of over 90 percent will be required by 2040 to meet the needs of a growing world population fairly within the planet's ecological means" (BCSD 1993). This "decoupling" of the economy from the ecosphere will require a continuous gain in energy and material efficiency for the next several decades. The most effective way of achieving this might be a sweeping overhaul of tax policy (ecological fiscal reform) to create the necessary economic incentives for conservation (see Rees 1995a).

Accelerating global change is increasingly accepted as evidence that remaining natural capital stocks are inadequate to support the material demands of even the *present* human population. This means that natural capital stocks must actually be *enhanced* to satisfy the basic needs of the presently poor and to restore global entropic balance. Moreover, since the richest quarter of the human population alone (mostly living in high-income cities) has appropriated virtually the entire productive capacity of the planet (Wackernagel and Rees 1996), it also challenges the presently rich to reduce their ecological footprints to free up needed ecological space for others. A sustainable world will be a more equitable world. (The need to arrest population growth is self-evident.)

Addressing these issues shows that cities present both unique problems and opportunities. First, the fact that cities concentrate both human populations and resource consumption results in a variety of ecological impacts that would not occur, or would be less severe, with a more dispersed settlement pattern. For example, cities produce locally dangerous levels of various pollutants that might otherwise safely be dissipated, diluted, and assimilated over a much larger area.

More importantly, from the perspective of ecosystems integrity, cities also significantly alter natural biogeochemical cycles of vital nutrients and other chemical resources. Removing people and livestock far from the land that supports them prevents the economic recycling of phosphorus, nitrogen, other nutrients, and organic matter back onto farm and forest land. As a consequence of urbanization, local, cyclically integrated ecological production systems have become global, horizontally disintegrated, entropic throughput systems. For example, instead of being returned to the land, Vancouver's daily appropriation of Saskatchewan mineral nutrients goes straight out to sea. As a result, agricultural soils are degraded (half the natural nutrients and organic matter from much of Canada's once-rich prairie soils have been lost in a century of mechanized export agriculture), and we are forced to substitute nonrenewable artificial fertilizer for the once renewable real thing. All this calls for much-improved accounting for the hidden costs of cities, of transportation, and of mechanized agriculture,

and a redefinition of economic efficiency to include ecological factors.

While urban regions certainly disrupt the ecosystems of which they are a part, the sheer concentration of population and consumption also gives cities enormous leverage in the quest for global sustainability. Advantages of urban settlements include (based on Mitlin and Satterthwaite 1994):

- 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, reuse, remanufacturing, 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, cogeneration, 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.

For a fuller appreciation of urban leverage, let's examine this last option in more detail. It is commonplace to argue that the private automobile must give way to public transportation in our cities and just as commonplace to reject the idea as politically unfeasible. However, political feasibility depends greatly on public support. The popularity of the private car for urban transportation is in large part due to underpriced fossil fuel, numerous other hidden subsidies (up to $2,500 per year per vehicle), and the absence of viable alternatives. Suppose we gradually move toward full-cost pricing of urban auto use and reallocate a significant proportion of the auto subsidy to public transit. This would make public transportation faster, more convenient, more comfortable than at present, and vastly cheaper than private cars. Whither political feasibility? People would demand improved public transit with the same passion they presently reserve for increased road capacity for their cars.

Most importantly, the shift in incentives and modal split would not only be ecologically more sustainable but also both economically more efficient and socially more equitable. (It *should* therefore appeal to both the political right and left.) Over time, it would also contribute to better air quality, improved public health, greater access to the city, more affordable housing, more efficient land use, the hardening of the urban fringe, the conservation of food lands, and levels of urban density at which at least direct subsidies to transit become unnecessary. In short, because of complex systems linkages, seriously addressing even a single issue in the city can stim-

ulate change in many related factors contributing to sustainability. Rees (1995b) has previously called this the "urban sustainability multiplier." Again, if people come to understand that support for sustainability-oriented policies will actually increase their personal well-being while enhancing their communities, then nothing can hold us back.

Note, in this context, that ecological footprint analysis provides a useful tool to compare the relative effectiveness of alternative urban development patterns, transportation technologies, and so on, in reducing urban ecological impacts. For example, Walker (1995) has shown that the increased density associated with high-rise apartments compared to single-family houses reduces those components of the per capita ecological footprint associated with housing type and urban transportation by 40 percent. Urban structure and form clearly have a significant impact on individual resource consumption patterns.

At the same time, we should recognize that many human impacts that can be traced *to* cities have little to do with the structure, form, or other properties *of* cities per se. Rather, they are a reflection of societal values and behaviour and of individual activities and habits. For example, the composition of one's diet may not be much related to place of residence. Similarly, that component of a dedicated audiophile's ecological footprint related to his or her consumption of stereo equipment will be virtually the same whether he or she resides in a village or a metropolis. In short, if the fixed elements of an individual's footprint require the continuous output of two hectares of land scattered about the globe, it doesn't much matter where that individual resides. This impact would occur regardless of settlement pattern.

There are, of course, other complications. People often move to cities because of greater economic opportunities. To the extent that the higher incomes associated with urban life result in increased average personal consumption (*net* of any savings resulting from urban agglomeration economies), the urban ecological footprint may well expand beyond the base case. Ironically, many categories of elevated urban consumption may not even contribute to improved material welfare. Higher clothing bills, cleaning costs, and increased expenditures on security measures are all part of urban life that contribute little to relative welfare while adding to the city's total eco-footprint.

To reiterate, the real issue is whether the material concentrations and high population densities of cities make them inherently more or less sustainable than other settlement patterns. What is the materially optimal size and distribution of human settlements? Should we strive for single centres or multinucleated patterns of regional development? The evidence is mixed, and until we know the answer to these questions, it is pointless to speculate on ecological grounds whether policy should encourage or discourage further urbanization. In the meantime, we in the wealthiest cities must do what we

can to create cities that are more ecologically benign (including, perhaps, learning to live more simply, that others may live at all). More on this below.

Investing in Social Capital

As noted, conventional approaches to sustainability require unbridled optimism in the power of technological innovation to reduce the material throughput of the economy. This is a predictable response from the industrial scientific or expansionist paradigm that prevails in international development circles today.

The problem is that technological fixes address neither the fundamental cultural values nor the growth ethic that have produced the ecological crisis and that lie at the heart of the mainstream paradigm. Arguably, therefore, by focusing exclusively on potential efficiency gains, policy makers may overlook other effective alternatives. One such option is to consider the efficacy of investing in social capital. If building up our stocks of social capital can substitute for the perceived need to accumulate manufactured capital, then *large reductions in society's ecological footprint may be possible even without technological efficiency gains* (see also Carr, this volume).

Welfare and Income

At least two lines of evidence encourage exploration of the social dimensions of sustainability. The first is revealed in the interesting relationship between income (consumption) and well-being. Available data show that life expectancy initially rises rapidly with per capita income but then levels off and is virtually flat between $10,000 and $25,000. It appears that 90 percent or more of the gain in life expectancy is "purchased" by the time income reaches $7,000 to $8,000 per annum[19] (World Bank 1993: Fig. 1.9; see also Hertzman and Kelly, this volume). Similar relationships hold for such other health and social indicators as reduced fecundity, infant survival, and literacy (Rees, unpublished data).

Seven to eight thousand dollars is only a quarter to a half of the per capita income of the world's wealthier countries. It seems clear, therefore, that quite substantial reductions in consumption by people in these countries might well be possible before there would be any significant deterioration in human welfare as measured by standard "objective" indicators. We should also note that various studies show that subjective happiness or well-being is not correlated with income in the middle and upper income range. Indeed, people's perception of their own social and health status seems more a factor of relative social position than of absolute material wealth.

These data pose a serious challenge to conventional assumptions about the social need for continuous economic growth. They suggest that a healthy and sustainable society may, in fact, be possible at relatively mod-

est income levels, even without any dramatic restructuring of society or social relationships.

The Case of Kerala

The second argument for investing in social capital can be found in the state of Kerala, India. With an annual income per capita of only $US 350, Kerala has achieved a life expectancy of 72 years (the norm for states earning $US 5,000 or more per capita), a fertility rate of less than two, and a high-school enrollment rate for females of 93 percent. According to Alexander (1994), "extraordinary efficiencies in the use of the earth's resources characterize the high life quality behavior of the 29 million citizens of Kerala." Similarly, Ratcliffe (1978, 140) claims that Kerala refutes "the common thesis that high levels of social development cannot be achieved in the absence of high rates of economic growth ... Indeed, the Kerala experience demonstrates that high levels of social development – evaluated in terms of such quality of life measures as mortality rates and levels of life expectancy, education and literacy, and political participation – are consequences of public policies and strategies based not on economic growth considerations but, instead, on equity considerations." The state of Kerala invests much of its meagre public wealth in public health and education, with particular attention to the education of girls and women.

The point here is not to suggest that Kerala, with its unique political and cultural history, is a direct model for others to follow. Rather, it is simply to emphasize that every society and culture is in part a social construction, not entirely the product of natural laws. In short, *there is nothing sanctified about our high-throughput industrial culture*. Kerala shows that a high quality of life with minimal impact on the Earth is possible through the accumulation of social rather than manufactured capital. As such, it is a hopeful example that other people in other cultures – Vancouver, Richmond, possibly even in the global village as a whole – may also be able to organize in ways that distribute nature's limited bounty more equitably. There is no intrinsic reason why we cannot learn to live sustainably in a low throughput economic steady-state.

Policy Implications

Empirical evidence suggests that the economy has already exceeded carrying capacity, yet we seem more determined than ever to address the problems of sustainability and persistent poverty through a new round of vigorous growth.[20] This is a potentially dangerous path. It depends on the assumption that technological efficiency gains alone will succeed in reducing the human ecological footprint on the Earth, even as the consumption of goods and services rises by as much as ten-fold.

At the same time, there is clear evidence that meaningful social relationships and supportive community-based social infrastructure may be more effective than technology in reducing the demand for energy and material. Policy makers would therefore be well advised to consider the "soft" alternative toward sustainability. Relevant questions include:

- How can the state facilitate the community-level shift in personal and social values implicit in a more caring society?
- What circumstances facilitate the development of sharing and mutual aid as a mode of life even in the face of material scarcity?
- What kinds of formal and informal social relationships enhance peoples' sense of self-worth and personal security?
- Which of these personal relationships and community qualities reduce the compulsion to consume and accumulate private capital? In other words, what forms of social capital can substitute for manufactured capital?
- What sorts of policies would facilitate the development of these forms of social capital?

So far, material industrial society has avoided such questions in the production-consumption debate. However, addressing these issues would contribute not only to ecological sustainability but also to filling the spiritual void and general social malaise that increasingly seems to plague high-income, high-consumption societies.

Epilogue: Can We Get There from Here?

Ours is an urban industrial culture, and there can be no doubt that cities are among the brightest stars in the constellation of human achievement. At the same time, ecological footprint analysis shows that they act as entropic black holes, sweeping up the output of whole regions of the ecosphere much larger than themselves (Rees 1997a). There is a clear causal linkage between global ecological change and such concentrated local consumption. In this light, national and provincial and state governments should assess what powers might be devolved to, or shared with, the municipal level to enable cities better to cope with the inherently urban dimensions of sustainability.

Meanwhile, international agencies and national powers must recognize that policies for local, provincial or state, or national sustainability have little meaning without firm international commitment to the protection and enhancement of remaining common-pool natural capital and global life-support services. There can be no ecological sustainability without international agreement on the nature of the sustainability crisis and the difficult solutions that may be necessary at all geographic scales.

It seems that government intervention on behalf of the common good at

all levels is an essential element of sustainability. The prevailing pattern of deregulation and freer markets fuels material growth, and we cannot depend on money prices to tell us much about ecological scarcity or the "invisible foot" of the marketplace. Indeed, if we stay our present course in the blind hope that things will all work out, humans may well become the first species to document in exquisite detail the factors leading to its own demise (without acting to prevent it).

This points to the wild card in the sustainability dilemma: will humanity be able to muster the political will to act decisively and coherently to address its most communal of problems? Are there any circumstances short of imminent global collapse in which the presently rich would be willing to consider any significant reduction in their own material prospects that the poor might live at all?[21] Are we even able to contemplate the international protocol needed to coordinate and facilitate the ecological fiscal reform required to stimulate the needed efficiency revolution? Kerala illustrates the plasticity of human social organization and provides reason to hope for cultural adaptation, at least on the local or regional level. On the other hand, as Lynton Caldwell (1990) observes, "the prospect of worldwide cooperation to forestall a disaster ... seems far less likely where deeply entrenched economic and political interests are involved. Many contemporary values, attitudes, and institutions militate against international altruism. As widely interpreted today, human rights, economic interests, and national sovereignty would be factors in opposition. The cooperative task would require behavior that humans find most difficult: collective self-discipline in a common effort."

In this light, empirical evidence on the relationship between ecological decline and sociopolitical stability provides cold comfort. Recent studies suggest that "in many parts of the world, environmental degradation seems to have passed a threshold of irreversibility" and "that renewable resource scarcities of the next 50 years will probably occur with a speed, complexity, and magnitude unprecedented in history" (Homer-Dixon, Boutwell, and Rathjens 1993). Meanwhile, work on environmentally related social strife suggests that "so long as [ecological] decline is seen as temporary, advantaged groups are likely to accept policies of relief and redistribution as the price of order and the resumption of growth. Once it is accepted as a persisting condition, however, they will increasingly exert economic and political power to regain their absolute and relative advantages" (Gurr 1985, 38-9). In short, in the absence of a concerted shift in values and material behaviour, the increasing disordering of regional ecosystems and the ecosphere may well be accompanied by increasing social entropy – the breakdown of civil order within countries and increasing turbulence in international relations. Global change and social inertia make poor bedfellows.

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Notes

1 Kent Peacock's (1995) paper is an excellent discussion of this concept.
2 This contrasts with economic analyses, which focus on monetary flows. Money, however, is an abstraction that tells us little about the state of the ecosphere (and the quantity of money knows no theoretical limits).
3 Energy and matter is "available" if it has potential to do real work. For example, some of the chemical energy in a stick of wood is available – it can be used to heat my coffee. However, I can do nothing with the much larger quantity of heat energy contained by a swimming pool at air temperature. The shorthand for available energy/matter is "essergy."
4 It is obviously the second law that makes the economy a potential parasite on the ecosphere.
5 Admittedly, the heterogeneity and interdependence of various forms of natural capital make this criterion difficult to operationalize. For example, ecosystems are constantly developing and evolving, and there are many combinations of natural capital stocks that could be sustainable. However, this does not detract from the general principle that for each potentially viable combination, sustainability requires some minimal individual and aggregate quantity of these component stocks.
6 "Natural assets" encompasses not only material resources (e.g., petroleum, the ozone layer, forests, soils) but also process resources (e.g., waste assimilation, photosynthesis, soils formation). It includes renewable as well as exhaustible forms of natural capital. Our primary interest here is in essential renewable and replenishable forms. Note that the depletion of nonrenewables could be compensated for through investment in renewable natural capital.
7 Moreover, manufactured capital is made from natural capital.
8 The only ecologically meaningful interpretation of constant stocks is in terms of constant *physical* stocks as is implied here. However, some economists interpret "constant capital stock" to mean constant monetary value of stocks or constant resource income over time (for a variation on this theme, see Pearce and Atkinson 1993). These interpretations allow declining physical stocks as value and market prices rise over time.
9 This increase in the entropic "size" of humans strengthens the argument of twentieth-century neo-Malthusian ecologists over that of the original nineteenth-century Malthusians. People were effectively smaller then!
10 Exceptions include the ozone layer and the hydrologic cycle, both of which are purely physical forms of natural capital.
11 For simplicity's sake, the question as posed does not include the ecologically productive land area needed to support other species independent of any service they may provide to humans.
12 We generally use world average productivities for this step in ecological footprint calculations. This is a reasonable first approximation, particularly for trade-dependent urban regions importing ecological goods and services from all over the world. Local productivities are necessary, however, to calculate actual local and regional carrying capacity.
13 There are only about 8.8 billion hectares of ecologically productive land on Earth (including those areas that should be left untouched to preserve biodiversity). If this were allocated evenly among the 1995 human population of 5.9 billion, each person would receive 1.5 hectares.
14 Subsequent, more refined analyses have increased the per capita eco-footprint of Canadians to 7.7 hectares, including the marine component (Wackernagel et al. 1999).
15 The final (published) analysis showed these cities to have an ecological footprint 565 to 1,130 times larger than the area of the cities themselves (Folke et al. 1997).
16 This is not to say that rural residents do not benefit from the products and services of cities. There is certainly a two-way exchange. However, rural "dependence" on cities generally involves nonessential factors. In contrast, cities are "obligate dependents" on their hinterlands.

17 The competitive advantage to imports comes from superior climate and longer growing season, abundant cheap labour, and direct and indirect subsidies (e.g., California producers pay a fraction of the real cost of providing their irrigation water).
18 The prevailing doctrine of efficiency through specialization and trade as reflected in present federal trade policy (e.g., NAFTA) militates against local self-reliance. Instead, we become enmeshed in a network of long-distance and potentially insecure interdependencies.
19 Figures in "international dollars" based on purchasing power.
20 This often seems like a convenient way to avoid addressing inequity through policies to redistribute wealth.
21 Ironically, one of the effects of global restructuring under prevailing expansionist policies has been a marked *increase* in income disparity in many countries, including the United States (see *The Economist* November 5-11, 1994, for several articles on "slicing the cake").

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