Our Ecological Footprint

REDUCING HUMAN IMPACT ON THE EARTH

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FOOTPRINTS AND SUSTAINABILITY

Confusion about the meaning of sustainability and why it matters has slowed progress toward achieving it. This confusion is not completely innocent but sometimes reflects the deliberate blurring of issues and conflicts of interest, as well as genuine fears. In this chapter, we try to untangle the confusion; we argue that sustainability is a simple concept — at least conceptually — and suggest that pondering the implications of the Ecological Footprint model helps us to understand at least the ecological requirements for a sustainable society.

The Sustainability Debate: A Simple Concept Leads to Conflicting Strategies

The sustainability challenge

Ever Since Rachel Carson's *Silent Spring* appeared in 1962, a burgeoning literature has substantiated the concern that the ecosphere, our life-support system, is being eroded at an accelerating pace. The list of threats to the life-support system in which we are embedded is overwhelming: deserts are encroaching on ecologically productive areas at the rate of 6 million hectares per year; deforestation claims over 17 million hectares per year; soil oxidation and erosion exceeds soil formation by 26 billion tonnes per year; fisheries are collapsing; the draw-down and pollution of ground water accelerates in many places of the world; as many as 17,000 species disappear every year; despite corrective action, stratospheric ozone continues to erode; industrial society has increased atmospheric carbon dioxide by 28 percent. All these trends are the result of either over-exploitation (excessive consumption) or excessive waste generation.[1] Since everything we consume eventually joins the waste stream, it is a convenient shorthand to say that the energy and material "throughput" of the human economy is beyond safe limits.

At the same time, many people are unable to meet even their basic requirements. As noted in the Introduction, 20 percent of the human population enjoys unprecedented wealth, including the bulk of the people in the "North." However, 20 percent earning less than 1.4 percent of the global income endures conditions of constant malnutrition. This segregation, accentuated by gender and ethnicity, goes beyond income. The fact that in 1990, just 3.5 percent of the world's cabinet ministers were women, and that 93 countries were without female ministers at all, is a visible symptom of a much deeper social inequality.[2]

Concerned people have advocated a more responsible and equitable use of the ecosphere throughout the 20th century, but it was not until 1987 that *Our Common Future*, the report of the United Nations World Commission on Environment and Development (or Brundtland Commission), popularized the idea of "sustainable development." The destructive social and ecological effects of the prevailing approach to "development" had finally become a serious item on the political agenda.

The starting point for the Brundtland Commission's work was their acknowledgment that the future of humanity is threatened. *Our Common Future* opened by declaring:

> The Earth is one but the world is not. We all depend on one biosphere for sustaining our lives. Yet each community, each country, strives for survival and prosperity with little regard for its impacts on others. Some consume the Earth's resources at a rate that would leave little for future generations. Others, many more in number, consume far too little and live with the prospects of hunger, squalor, disease, and early death.[3]

To confront the challenges of over-consumption on the one hand and grinding poverty on the other, the Commission called for *sustainable development*, defined as "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In other words, the Commission recognized that the conventional economic imperative to maximize economic production must now be constrained — or perhaps we should say augmented — by both an ecological imperative to protect the ecosphere and a social imperative to minimize human suffering, today and in the future. For the first time, environment and equity became explicit factors in the development equation. Sustainable development therefore depends both on reducing ecological destruction (mainly by limiting the material and energy throughput of the human economy) and on improving the material quality of life of the world's poor (by freeing up the ecological space needed for further growth in developing countries and ensuring that the benefits flow where they are most needed).

Starting from the Brundtland definition, we argue that, conceptually, sustainability is a *simple* concept: it means living in material comfort and peacefully with each other within the means of nature. Despite this seeming simplicity, however, there is no general agreement on the policy implications of the concept (see Box 2.1). Some people are unconvinced there is a sustainability crisis at all, and others are frightened of the implications of

BOX 2.1: Sustainability and Sustainable Development: Some Clarification[4]

The need for humanity *to live equitably within the means of nature* is the underlying message of most definitions of sustainable development beginning with the Brundtland Commission's widely accepted call to "...[meet] the needs of the present without compromising the ability of future generations to meet their own needs." However, despite the widespread acknowledgement of the ecological and social symptoms of the problem, interpretations of sustainable development and its implications are contradictory, even within the Brundtland Commission's report.

One reason for conflicting interpretations of the fundamental sustainability message is obvious — the term "sustainable development" is itself treacherously ambiguous. Many people identify more with the "sustainable" part and hear a call for ecological and social transformation, a world of environmental stability and social justice. Others identify more with "development" and interpret it to mean more sensitive growth, a reformed version of the *status quo*. Sharachchandra Lélé writes that the various interpretations of sustainable development are caused not by poor understanding, but rather by ideological differences and reluctance of many to acknowledge the implications of the underlying message. The deliberate vagueness of the concept, even as defined by Brundtland, is a reflection of power politics and political bargaining, not a manifestation of insurmountable intellectual difficulty. Michael Redclift comments that "...unless we are *prepared to interrogate our assumptions* about both development and the environment and *give political effect* to the conclusions we reach, the reality of unsustainable development will remain...."

As suggested above, some of the confusion around "sustainable development" is rooted in general failure to distinguish between true development and mere growth. Economist Herman Daly clarifies the difference by defining "growth" as an increase in size through material accretion while referring to "development" as the realization of fuller and greater potential. In short, growth means getting bigger while development means getting better. For Daly, then, "sustainable development" is progressive social betterment without growing beyond ecological carrying capacity. Indeed, he regards "sustainable growth" as a nonsensical self-contradiction. Developing sustainability may actually require a *reduction* in aggregate economic throughput, while enabling the poor to consume *more*.

There are other ambiguities hidden in "sustainable development." It could refer to: a) the necessary conditions to live sustainably (a goal or state of being); b) the sociopolitical means of achieving the goal (a planning process); or, c) particular strategies to solve present problems (piecemeal solutions). Failure to clarify how the term is being used in a specific context can lead to fruitless misunderstanding. To some ears, the term *"developing sustainability"* is less ambiguous and is to be preferred over *"sustainable development."*

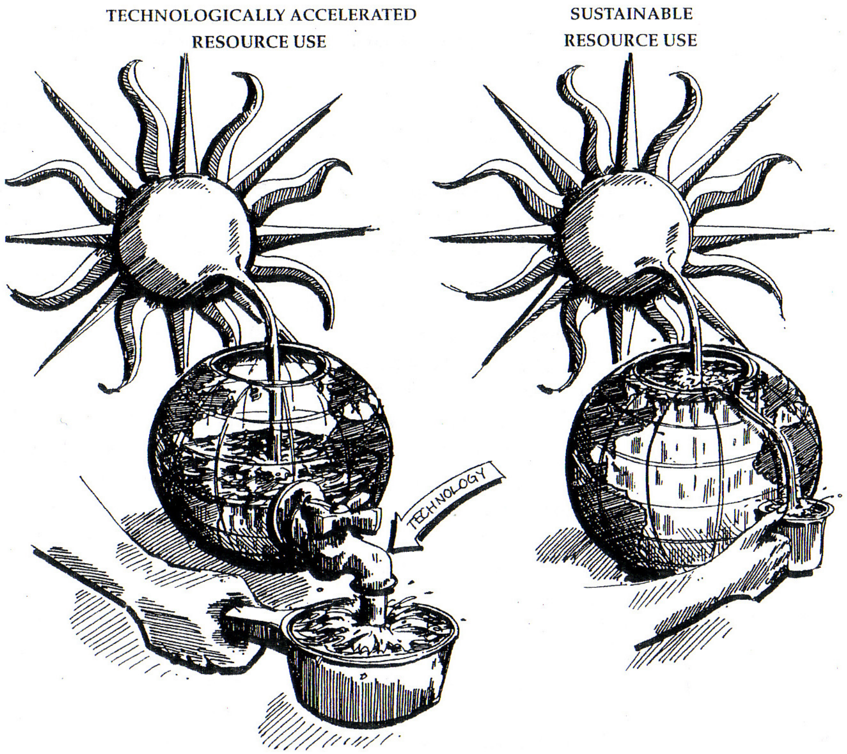

Figure 2.1: Sustainable Use: The Water Bucket Analogy.
Imagine a bucket being filled with water at a fixed rate. The water in the bucket is a capital stock that can be drawn upon only as rapidly as the bucket is being refilled. This balanced withdrawal rate is a form of sustainable income. Similarly, nature is a "bucket" that is continuously replenished by the sun: photosynthesis produces plant matter, the basis for all biological capital and most other life, and climatic, hydrological, and other biophysical cycles are solar powered too. Sustainability implies that nature's capital should be used no more rapidly than it can be replenished (right). However, trade and technology have enabled humankind progressively to exploit nature far beyond sustainable levels so that present consumption exceeds natural income (the "interest" on our capital). This leaves the next generation with depleted capital and less productive potential even as the population and material expectations increase (left).

acknowledging that there is.

Of course, if environmental scientists are correct (and we believe they are) the consequences of *not* acknowledging material constraints on the economy

BOX 2.2: On Natural Capital[5]

Natural capital refers to any stock of natural assets that yields a flow of valuable goods and services into the future. For example, a forest, a fish stock or an aquifer can provide a harvest or flow that is potentially sustainable year after year. The forest or fish stock is "natural capital" and the *sustainable* harvest is "natural income." Natural capital also provides such services as waste assimilation, erosion and flood control, and protection from ultraviolet radiation. (Thus, the ozone layer is a form of natural capital.) These life-support services are also counted as natural income. Since the flow of services from ecosystems often requires that they function as intact systems, the structure and diversity of the system may be an important component of natural capital.

Researchers typically focus on three categories of natural capital: renewable, replenishable and non-renewable. Renewable natural capital, such as living species and ecosystems, is self-producing and self-maintaining using solar energy and photosynthesis. Replenishable natural capital includes surface and ground water supplies and the stratospheric ozone layer. These stocks are non-living but are continuously restored, often through some other solar mechanism. By contrast, non-renewable forms of natural capital such as fossil fuel and minerals are analogous to inventories. Any use implies liquidating part of the stock. Since adequate stocks of self-producing and replenishable natural capital are essential for life-support (and are generally non-substitutable), we consider these categories of natural capital to be more important to sustainability than non-renewable forms.

It should be apparent from the above that Earth's "natural capital" is more than just an inventory of industrial resources; it comprises also those components of the ecosphere, and the structural relationships among them, whose organizational integrity is essential for the continuous self-production and self-regulation of the system itself. Indeed, it is this highly evolved structural and functional integration that makes the ecosphere the uniquely livable "environment" it is. In effect the ecosphere is produced, in part, by the very organisms it comprises. In addition, geoclimatic, hydrological and ecological cycles do not simply transport and distribute nutrients and energy but are among the self-regulatory, homeostatic mechanisms that stabilize conditions on Earth for all contemporary life-forms, including humankind. All these, too, are forms of natural capital.

are scarier than anything the shift to sustainability might imply. Our increasingly global consumer lifestyle — living as if there were no biophysical limits to nature — not only undermines global life-support but also threatens geopolitical stability. In this context, the good news is that today so many people today accept the sustainability challenge as the first step toward a more secure future. The bad news is that the economic and political mainstream shows little sign of recognizing biophysical constraints of any kind. Indeed, "official" world development institutions seem more convinced than ever that the shortest route to sustainability is through unrestrained economic expansion.

In short, conflicting interests, opposing world views, incompatible analyses, rising material expectations, and fear of change, have led to a disorienting array of interpretations of sustainability and how to achieve it. Little wonder progress of any kind is slow! The problem is that not all interpretations of sustainability can be equally valid. The assumptions and the facts upon which each is based must be subject to logical scrutiny and repeated "reality checks" against empirical evidence before their prescriptions are accepted. In this light, let's examine more closely our own premise that humans must learn to live with each other within the means of nature.

Strong sustainability: the ecological bottom-line condition for sustainability

As long as Earth is humanity's only home, sustainability requires that we live within the productive capacity of nature. To use an economic metaphor, humankind must learn to live on the income generated by remaining natural capital stocks. "Natural capital" includes not only all the natural resources and waste sinks needed to support human economic activity, but also those biophysical processes and relationships among components of the ecosphere that provide essential life-support "services" (see Box 2.2).

If we consume more than the interest or income from our natural capital we diminish our biophysical wealth. This undermines our future because, despite our increasing technological sophistication, humans remain in a state of "obligate dependence" on the productivity and life-support services of the ecosphere.[6] Thus, from an ecological perspective, adequate land and associated productive natural capital are fundamental to the prospects for continued humane existence on Earth. Significantly, both the human population and average consumption are presently increasing while the total area of productive land and natural capital stocks are fixed or in decline.

These trends beg the question of how much natural capital is enough. Should we strive to conserve or enhance our natural capital stocks ("strong sustainability") or, as many economists believe, are losses of natural capital acceptable if compensated through the substitution of an equivalent amount or value of human-made capital ("weak sustainability" — see Box 2.3)?[7]

Certainly there are many examples of how technology has been able to substitute for natural resources. Microwave transmission and optical fibres have greatly reduced the demand for copper. However, we argue that in many situations the substitution option does not apply — natural capital (e.g., the forest) is often a prerequisite for manufactured capital (e.g., the sawmill). In other cases, technology and manufactured capital will simply not be able to substitute for critical natural capital (e.g., the ozone layer) in the foreseeable future. Even in the best of circumstances, therefore, blind faith in substitution

BOX 2.3: Strong or Weak Sustainability?[7]

Many economists believe that "weak sustainability" is good enough. According to this view, society is sustainable provided that the aggregate stock of manufactured and natural assets is not decreasing. In other words, weak sustainability allows the substitution of equivalent human-made capital for depleted natural capital. From this perspective, the loss of the income-earning potential of a former forest is no problem if part of the proceeds of liquidation have been invested in factories of equivalent income-earning potential. By contrast, "strong sustainability" recognizes the unaccounted ecological services and life-support functions performed by many forms of natural capital and the considerable risk associated with their irreversible loss. (In addition to wood fibre, forests provide flood and erosion control, heat distribution, climate regulation, and a variety of other non-market functions and values.) Strong sustainability therefore requires that natural capital stocks be held constant independently of human-made capital. Some authors suggest that manufactured capital stocks must also be held constant for strong sustainability so there is no capital depreciation of any kind. We agree that this is to be preferred, but wish to emphasize the greater importance of maintaining adequate life-supporting natural capital. Remember too that if population and material expectations are rising, capital stocks should actually be enhanced — in other words, it is *per capita* stocks that must be increased.

The weakness of "weak sustainability" is best revealed in a study by David Pearce and Giles Atkinson. Starting from the weak sustainability assumption that natural and human-made capital are substitutable, they ranked the sustainability of 18 representative countries. They propose that "...an economy is sustainable if it saves more [in monetary terms] than the depreciation on its [hu]man-made and natural capital...." As a result, Japan, the Netherlands and Costa Rica head the list of sustainable countries, while the poorest nations in Africa are identified as the most unsustainable. This comparison demonstrates the ecological irrelevance of "weak sustainability." It fails to recognize that much of the so-called rich countries' money savings comes from the depletion of other countries' natural capital and exploitation of global common-pool assets. For example, the apparent economic sustainability of both Japan and the Netherlands depends on large-scale imports (see Box 3.5). In effect, high material standards are maintained by a massive but unaccounted ecological deficit with the rest of the world (including some of the countries labeled "unsustainable").

would be a risky option. As things stand, the pace of stock depletion and accelerating global change suggests that remaining natural capital stocks are already inadequate to ensure long-term ecological stability. In these circumstances, we believe that "strong sustainability" is a necessary condition for ecologically sustainable development. More explicitly, this condition is met only if each generation inherits an adequate stock of essential biophysical assets that is no less than the stock of such assets inherited by the previous generation. (If today's average material standards are to be maintained, this "inheritance" will have to be on a *per capita* basis to keep ahead of population growth.) This version of the "constant capital stocks" condition is independent of the state of the human-made capital stock (although, if possible, the latter should also be held constant *per capita*).

However radical "strong sustainability" may appear as a conservation measure, the concept is still highly anthropocentric (human-centered) and narrowly functional. Emphasis is on the minimum biophysical requirements for *human survival* without regard to other species. Certainly too (as our more sensitive students like to remind us), we do not experience the taste, feel and smell — the sheer sensual exuberance — of nature as "natural capital." However, the preservation of biophysical assets essential to humankind does imply the direct protection of whole ecosystems and thousands of keystone species, and many other organisms would benefit indirectly as well. In short, the most promising hope for maintaining both significant biodiversity and the experience of nature under our prevailing value system may well be ecologically enlightened human self-interest. Of course, should humankind shift to more ecocentric values, its own survival might be assured even more effectively. Respect for, and the preservation of, other species and ecosystems for their intrinsic and spiritual values would automatically ensure human ecological security.

We must also recognize that maintaining the ecological bottom-line is not in itself sufficient for sustainability. Certain minimal socioeconomic conditions must also be met to ensure the necessary consensus for short-term action and long-term geopolitical stability. In the final analysis, sustainability means securing a satisfying quality of life for everyone. Most importantly, therefore, we must work to achieve basic standards of material equity and social justice both within and between countries (an objective which seems to be *receding* today). We also need a shared commitment to our collective interest in the maintenance of the global commons, an idea still struggling to be heard amidst the sterile rhetoric of competitive economic globalization. If we do not satisfy these conditions we simply will not be able to develop the capacity to tackle global change and the inevitable conflicts it generates in a humane and co-operative manner.

Having spelled out the bottom-line for sustainability, we need to focus on how to put these conditions into practice. But let us proceed cautiously into the fixing mode — after all, the causes of many of our present problems are yesterday's "quick-fix" solutions. Significantly, in this light, even the Brundtland Commission's suggestions favor the technological fix.

The Brundtland Commission's proposed response

Many analysts have argued that the "solutions" proposed by the WCED are inconsistent with its own definition of sustainability. In fact, the Commission was curiously ambiguous in elaborating on its definition.[8] *Our Common Future* defines "needs" as the "...essential needs of the world's poor, to which overriding priority should be given...." It also acknowledges the "...limitations imposed by the state of technology and social organization on the environment's ability to meet [those needs]...." To people concerned about ecological integrity and social equity, this focus on "essential needs of the...poor" and "limitations" seemed to be a plea for political recognition of global economic injustice and limits to material growth. This guaranteed endorsement of *Our Common Future* by most mainstream environmental groups.

But there is another side to *Our Common Future* which guaranteed its message would be as enthusiastically received in corporate boardrooms everywhere. The report reassuringly asserts that "...sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the orientation of the technological development, and institutional change are made consistent with future as well as present needs...." Indeed, close reading reveals that the only "limitations" recognized by the commission are social and technological. Achieving sustainable development is therefore said to depend on broader participation in decision-making; new forms of multilateral co-operation; the extension and sharing of new technologies; increased international investment; an expanded role for transnational corporations; the removal of "artificial" barriers to commerce; and expanded global trade.

In effect, the Brundtland Commission equated sustainable development with "...more rapid economic growth in both industrial and developing countries..." on grounds that "...economic growth and diversification...will help developing countries mitigate the strains on the rural environment...." Consistent with this interpretation, the commission observed that "...a five- to ten-fold increase in world industrial output can be anticipated by the time world population stabilizes some time in the next century...." While this may seem like an extraordinary rate of expansion, it implies an average annual growth rate in the vicinity of only 3.5 to 4.5 percent over the next 50 years. Growth in this range has already produced a five-fold increase in world economic output since the Second World War.

In recognition of the additional stress this expansion implies for the environment, the commission cast sustainable development in terms of more material- and energy-efficient resource use, new ecologically benign technologies and "...a production system that respects the obligation to preserve the ecological base for development...." Notably absent from *Our Common Future*, however, is any analysis of the causes of the poverty and inequity the Commission seeks to address or of whether the required growth would be biophysically sustainable under any conceivable production system. Nor did the commission confront arguments that under prevailing conditions liberalized trade and conventional efficiency gains may actually work against sustainability (see Chapter 4).

For such reasons, critics of the Brundtland Commission label its growth-dependent interpretation of sustainable development as a "...menace in as much as it has been co-opted [by the mainstream]...to perpetuate many of the worst aspects of the expansionist model under the masquerade of something new...." Even popular commentators condemn the use of the term "sustainable development" as "...dangerous words now being used...to mask the same old economic thinking that preaches unlimited consumption in the crusade to turn more land into glorified golf courses, deadly suburban ghettos, and leaking garbage holes (so-called landfill sites)...."[9]

Little wonder there is so much tension among various interests in their efforts to define sustainability and so much public disillusion with the concept. In today's materialistic, growth-bound world, the politically acceptable is ecologically disastrous while the ecologically necessary is politically impossible. Developing sustainability strategies that are consistent with the ecological bottom-line therefore depends on the convergence of ecological and political practicality. This is where the Ecological Footprint comes in: it is a consciousness-raising tool that can help us to develop a common understanding of the problem and explore the implications of alternative solutions. As such, it can help translate strong sustainability into planning action.

The Ecological Footprint: A Tool for Planning Toward Sustainability

Measuring progress toward sustainability: the dos and don'ts

Gaining acceptance for strong sustainability hinges on finding a meaningful unit to measure the natural capital requirements of the economy. Is nature's productivity sufficient to satisfy present and anticipated demands by the human economy indefinitely? This question seems so self-evidently crucial to sustainability that it is difficult to imagine how policy analysts in government, the private sector and universities can continue systematically to ignore it.

Part of the problem is that conventional economic models see the human economy as one in which the factors of production (e.g., labor, capital, information) are near perfect substitutes for one another and in which using any factor more intensely guarantees an increase in output. Any other resource limitation can be relieved by trade. In effect, this vision assumes a world with infinitely expandable carrying capacity.

Another difficulty is that conventional analysis is based on the circular flow

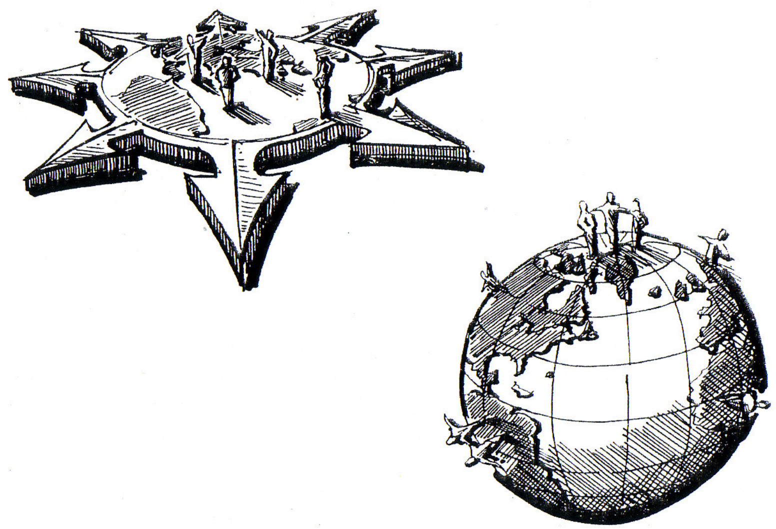

Figure 2.2: Flat-earth Versus Round-earth Economics.
Conventional economics is "flat-earth" economics. It implicitly sees the world extending without limit in all directions and imposing no serious constraints on economic growth. By contrast, ecological economics recognizes the world as a finite sphere. All resources come from the Earth and go back to it in degraded form. The only "income" from outside is sunlight, which powers material cycles and the web of life. Economic activity is therefore ultimately constrained by the regenerative capacity of the ecosphere.

of exchange value (money flows) between households and firms and back again as exemplified by standard measures of GDP. Physical measures of natural capital, natural income, and subsequent energy/material transformations are simply not part of the analysis (Figure 2.3). Indeed, mainstream models of growth and sustainability lack any representation of the biophysical "infrastructure" and the time-dependent processes upon which the economy depends and which are basic to an ecologically informed approach (Figure 2.4). Most important, there is no reference to modern interpretations of the Second Law of Thermodynamics which see the economy as a complex "dissipative structure" embedded within the ecosphere (see Box 2.4 for a more detailed explanation). Many critical questions raised by ecological and thermodynamic considerations are therefore invisible to mainstream approaches. It seems that

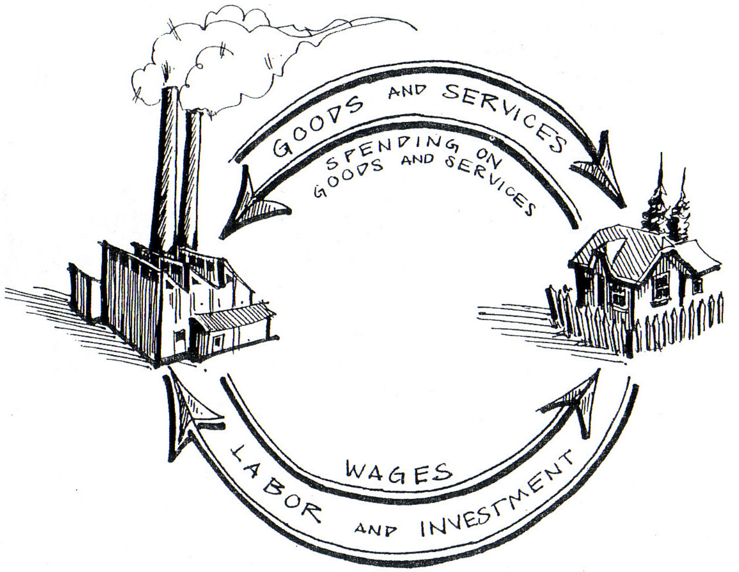

Figure 2.3: The economic perspective: circular flows. Conventional economics emphasizes the seemingly self-generating circular flows of money between firms and households in the marketplace. It thereby fails to account for either informal work or the value of ecological services, and is blind to the irreversible unidirectional material flows that sustain the economy.

conventional indifference to carrying capacity derives not from superior knowledge but, from conceptual weaknesses in standard analytic models.

One can monitor the availability of energy, matter, and other forms of natural income either in terms of *physical* measurements of natural capital stocks and flows or in terms of *monetary* measurements such as the dollar value of stocks and current prices for marketed goods and services. No doubt, money prices are critical for operating in the public domain. Financial analysis is crucial when developing budgets, or when deciding between building a school, a hospital or a theatre; business decisions are unthinkable without sound monetary analyses. However, we argue that monetary analyses are fatally flawed in assessing sustainability issues or natural capital constraints. Using money price to signal resource scarcity or natural capital depletion may be misleading for at least the following reasons (Figure 2.5)[10]:

One: Monetary interpretations of the constant natural capital requirement may mask declining physical stocks. For example, some economists suggest that the constant capital stocks condition for sustainability might be satisfied

if the money value of, or income from, capital is held more or less constant. According to neoclassical theory, the marginal price of increasingly scarce resource commodities should increase. If this premise holds true, rising prices (which should indicate increased scarcity) could hold the income from, or the

Box 2.4: The Entropy Law and the Economy/Ecology Conundrum

The Second Law of Thermodynamics (the "entropy law") states that the entropy of an isolated system always increases. This means that the system spontaneously runs down. All available energy is used up, all concentrations of matter are evenly dissipated, all gradients disappear. Eventually, there is no potential for further useful work — the system becomes totally degraded and "disordered." This has significant implications for sustainability:

» Non-isolated systems (such as the human body or the economy) are subject to the same forces of entropic decay as are isolated ones. This means that they must constantly import high-grade energy and material from the outside, and export degraded energy and matter to the outside, to maintain their internal order and integrity. For all practical purposes, this energy and material "throughput" is unidirectional and irreversible.

» Modern formulations of the Second Law therefore argue that all highly-ordered, far-from-equilibrium, complex systems necessarily develop and grow (increase their internal order) "at the expense of increasing disorder at higher levels in the systems hierarchy."*

» The human economy is one such highly-ordered, complex, dynamic system. It is also an open sub-system of a materially closed, non-growing ecosphere, i.e., the economy is *contained* by the ecosphere. Thus the economy is dependent for its maintenance, growth and development on the production of low entropy energy/matter (essergy) by the ecosphere and on the waste assimilation capacity of the ecosphere.

» This means that beyond a certain point, the continuous growth of the economy (i.e., the increase in human populations and the accumulation of manufactured capital) can be purchased only at the expense of increasing disorder (entropy) in the ecosphere.

» This occurs when consumption by the economy exceeds production in nature and is manifested through the accelerating depletion of natural capital, reduced biodiversity, air/water/land pollution, atmospheric change, etc.

* E. Schneider and J. Kay. 1992. *Life as a Manifestation of the Second Law of Thermodynamics.* Preprint from: *Advances in Mathemetics and Computers in Medicine.* (Waterloo, Ont.: University of Waterloo Faculty of Environmental Studies, Working Paper Series).

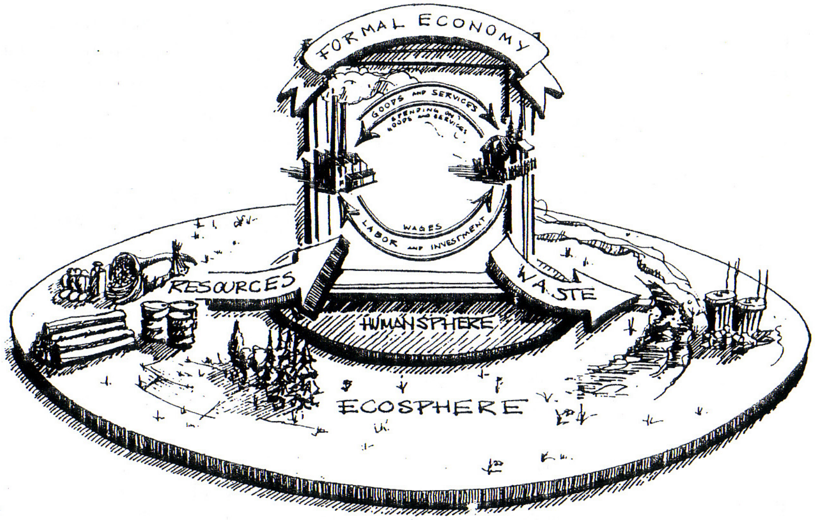

Figure 2.4: The ecological worldview.
The circular flows are actually sustained by the unidirectional throughput of ecological goods and services from and to the ecosphere (the "natural income" stream). All the energy and much of the matter that passes through the economy is permanently dissipated into "the environment" never to be used again.

total value of, a particular natural capital stock constant, while the physical stock is actually in decline. Thus, constant money income or stock value may foster the illusion of constant stocks while physical inventories shrink. In other cases, prices may fall (suggesting resource abundance) while the stock is depleted due to extra-market factors or improved extraction technology (as illustrated by mineral and fossil fuel prices in recent decades). In either case, market prices would mask the depletion of stocks.

Two: In any event, biophysical or eco-functional scarcity is poorly reflected in the marketplace. Market prices generally say nothing about the size of remaining natural capital stocks or whether there is some critical minimal stock size below which recovery is impossible. In short, prices do not monitor stock size or systems fragility, but only the commodity's short-term scarcity on the market. Even this is not quite true — market prices are more influenced by short-term demand; the state of technology (extraction, processing and transaction costs); the intensity of competition; the availability of substitutes; etc., than by market scarcity. For example, subsidies, low fuel costs, and high-tech factory freezer-trawlers enabled industrial fishers to access previously unreachable stocks of North Atlantic groundfish. This maintained market supply (and relatively low prices) even as the stocks were being depleted. In any case,

Figure 2.5: Measuring the World in Monetary Units Makes us Blind to the Ecological Constraints on Sustainability. Acknowledging the limitations of monetary assessments becomes an additional argument against "weak sustainability." As noted earlier, the weak criterion assumes the substitutability of human-made for natural capital, allowing (false) "trade-offs" in terms of equivalent stock values or income-generating potential. An alternative approach is to assess our natural capital requirements from an ecological and biophysical perspective.

fish prices have to compete with those of pork and chicken (substitutes) and do not sky-rocket even in the event of a fishery collapse.

Any remaining value of price as an indicator of scarcity of biophysical stocks is undermined by the behavior of complex systems. Conventional models assume smooth, reversible change in supply and prices. In fact, natural systems are more likely to be characterized by time lags and sudden irreversible change (or very long recovery times), systems behaviors that cannot be detected in the market.

Three: Monetary analyses are systematically biased against the future by discounting. Consider that at a discount rate of 5 percent, the present value of a dollar's worth of ecological service a life-span (76 years) from now is only about 2.5 cents. In other words, 2.5 cents put in the bank today at 5% would grow to about one dollar in 76 years. Discounting makes nature appear less valuable the further into the future we look. However, life depends on ecological continuity: for all we know, future generations will need the same amount of the same kinds of critical ecological goods and services *per capita* as we do today, whatever the discounted present (money) value of those goods. Nevertheless, we regularly sacrifice nature to development because the immediate short-term benefits exceed the (discounted) present value of foregone future benefits — or at least our estimate of what they will be. For example, paving over agricultural land for a shopping center today assumes that we know both the future value of the lost ecological productivity and that anticipated money profits will more than compensate for this loss. Both assumptions are increasingly risky in today's uncertain world. The value of human-made capital (the shopping center) today tells us less and less about its potential money income and nothing about the demand for food (natural income) tomorrow. The value

Figure 2.6: Carrying Capacity is traditionally defined as the maximum population of a species that can be sustained indefinitely in a given habitat.

ɔf natural capital to human life will almost certainly increase more rapidly than :hat of manufactured capital over time as evidence of ecological breakdown ɔecomes more compelling, whatever today's markets tell us. (For example, the ɜffective price of the stratospheric ozone layer went from zero to near infinity n just a few years in the absence of any market.) In this light, standard ıpproaches to discounting nature's services constitute a dangerous systematic ɔias against the future.

Four: The utility of monetary indicators is further diminished by market 'luctuations, which affect prices but not the ecological value or integrity of ıatural capital. For example, world price fluctuations are unrelated to local ·ircumstances or inter-regional variations, yet affect the relative economic trength of different regions and with it the perceived values of local natural apital. Money values and markets may therefore seriously alter local conser- 'ation and management practices respecting agricultural land, for example, ven though its inherent productivity and potential contribution to long-term ɔod security remains unchanged.

Five: Money values do not distinguish between substitutable goods and omplementary goods. Moreover, on monetary balance sheets, all prices are dded or subtracted as if goods that are priced the same are of equal importance ɔ human life —money equivalency equates the essential with the trivial. In ıct, of course, many goods and services of nature are virtual prerequisites to

life and therefore are not truly commensurate with some human-made gadget of equal dollar value. While there certainly is substitutability between various industrial resource inputs (glass fibres are replacing copper cables in communications and data transmission), this functional equivalency does not apply to all potential natural and manufactured capital trade-offs. In some cases, once nature has been over-exploited, no amount of manufactured goods will compensate for the loss of natural capital. To put fish on our dinner plates, both a fish stock *and* fishing boats are needed. Thus, even though the fishing fleet and canning factories may be worth as much in dollars as the fish stock, all the fishing equipment and processing plants in the world will not generate a single fish if the natural stock is destroyed. In short, more often than not, natural capital is a prerequisite for human-made goods, while the opposite is not the case.

Six: The potential for growth of money is theoretically unlimited, which obscures the possibility that there may be biophysical limits to economic growth. To use Herman Daly's metaphor, monetary analysis does not recognize the Plimsoll line, which indicates the maximum load capacity of a ship. Overloading (excessive growth) may eventually sink the ship. Pareto efficiency — the current criterion of macro-economic health — ensures only that the load is distributed in such a way that the ship sinks optimally!

Seven: Perhaps the most serious objection is that there are no markets for many critical natural capital stocks and life-support processes (e.g., the ozone layer, nitrogen fixation, global heat distribution, climatic stability, etc.). Conventional approaches to conservation and sustainability focus mainly on the money values of marketable resource commodities (e.g., timber and wood fibre) and are insensitive to the intangible (but ultimately more valuable) non-market functions of the natural capital that produces them (e.g., the forest ecosystem). The latter functions are destroyed by resource harvesting. Not surprisingly, therefore, economists today are devoting much attention to ways of "putting a price on nature." However, there are severe limitations on the possibilities of establishing valid shadow prices even for familiar ecological goods and services, and no possibility at all for those many functions whose existence is unknown (and may be inherently unknowable) before some breakdown occurs. In these circumstances, prices fail absolutely as scarcity indicators.

In summary, monetary approaches are blind to the requirements for ecological sustainability because they do not adequately reflect biophysical scarcity, social equity, ecological continuity, incommensurability, structural and functional integrity, temporal discontinuity, and complex systems behavior.

Learning from ecology: revisiting human carrying capacity

The renewed debate around the natural capital constraints on the economy demands that we revisit the ecological concept of carrying capacity.[11] Does it make sense to talk of the *human* carrying capacity of Earth? For purposes of game and range management, carrying capacity is usually defined as the

BOX 2.5: A Brief History of the Human Carrying Capacity Concept [13]

The oral history of concern about the relationship between people and land must go back thousands of years. Many Chinese and early Christian scholars worried about the destruction of habitat. Plato may have provided the first written account of human carrying capacity as he declared in *Laws*, Book V, that a

> ...suitable total for the number of citizens cannot be fixed without considering the land and the neighboring states. The land must be extensive enough to support a given number of people in modest comfort, and not a foot more is needed.

The first scholarly book on sustainable practice in the English language may be John Evelyn's *Sylva: A Discourse of Forest, Trees and the Propagation of Timber* published in 1664, two hundred years before George Perkins Marsh's study *Man and Nature* initiated the scientific debate in North America on nature's limited capacity to satisfy human demands.

Ecological accounting, the basis for carrying capacity assessments, can be traced back to at least as early as 1758. In that year, François Quesnay published his *Tableau Economique* in which the relationship between the productivity of land and wealth creation was discussed. Since then, many scholars have developed conceptual approaches and accounting procedures to analyze the relationship between people and nature.

Some of them looked at energy flows needed to support human activities. For example, in 1865 economist Stanley Jevons in *The Coal Question*, analyzed the importance of energy resources for the United Kingdom's economic performance. In the late 1800s, Serhii Podolinsky initiated the field of agricultural energetics. In the following decades, the eminent physicists Rudolf Clausius and Ludwig Boltzmann, and later Nobel Laureate Frederick Soddy, reflected upon the implications of the entropy law on economic development. Alfred Lotka introduced energy analysis to biology in the 1920s, and in the 1970s economist Nicholas Georgescu-Roegen challenged economics using thermodynamic principles.

Others have more explicitly examined the carrying capacity requirements of economies. For example, with his 1798 *Essay on the Principles of Population as It Affects the Future Improvement of Society*, Reverend Thomas Malthus initiated the debate on agriculture's seemingly limited ability to feed an ever larger human population. Even the Ecological Footprint has conceptual predecessors; in his above-mentioned book, Stanley Jevons observed that:

> the plains of North America and Russia are our [British] corn-fields; Chicago and Odessa our granaries; Canada and the Baltic are our timber-forests; Australasia contains our sheep-farms, and in Argentina and on the western prairies of North America are our herds of oxen; Peru sends her silver, and the gold of South Africa and Australia flows to London; the Hindus and the Chinese grow tea for us, and our coffee, sugar and spice plantations are all in the Indies. Spain and France are our vineyards and the Mediterranean our fruit garden, and our cotton grounds, which for long have occupied the Southern United States, are now being extended everywhere in the warm regions of the Earth.

Forty years later, in 1902, physicist Leopold Pfaundler calculated global carrying capacity, concluding that as an upper limit, ecological production could sustain about five people per hectare of land. In North America, William Vogt (1948) and Fairfield Osborn (1953) are associated with the renewed academic interest in carrying capacity questions. Georg Borgstrom in his various publications in the 1960s and early 1970s analyzed resource consumption in terms of "ghost acreage," which referred to imported agricultural carrying capacity. One of us (Rees) developed the "regional capsule" (subsequently the Ecological Footprint) concept in the early 1970s as a teaching tool to stimulate multi-disciplinary planning students to think about human carrying capacity. In 1980, William Catton added a new dimension to the human carrying capacity debate by describing the implications of overshoot — temporarily exceeding the long-term carrying capacity — and the subsequent population crash. G. Higgins and his collaborators produced a technical report in 1983 analyzing the population-supporting capacities of most developing countries for the United Nations Food and Agriculture Organization (FAO). In 1985, Ragnar Overby, then at the World Bank, proposed comparing economies by their demand on carrying capacity, and in 1986 M.A. Harwell and T.C. Hutchinson analyzed the loss of carrying capacity that would follow nuclear war. Most recently (1993) the Friends of the Earth (Netherlands) proposed the "environmental space" concept to help determine nations' fair shares of global productive/assimilative capacity.

These are only a few examples from the literature on human carrying capacity.

maximum population of a given species that can be supported indefinitely in a specified habitat without permanently impairing the productivity of that habitat. However, because of our seeming ability to increase human carrying capacity by eliminating competing species, by importing locally scarce resources, and through technology, this definition does not seems applicable to humans. Indeed, trade and technology are often cited as reasons for rejecting the concept of human carrying capacity out of hand.

This is an ironic error — shrinking carrying capacity may soon become the single most important issue confronting humanity. The reason for this becomes clearer if we define carrying capacity not as a maximum population but rather, following William Catton, as the maximum "load" that can safely and persistently be imposed on the ecosphere by people. Human load is a function not only of population but also of *per capita* consumption and the latter is increasing even more rapidly than the former due (ironically) to expanding trade and technology. This led Catton to observe that "...the world is being required to accommodate not just more people, but effectively 'larger' people...."[12] As a result, load pressure relative to carrying capacity is rising much faster than is implied by mere population increases.

These trends underscore the fact that despite our technological, economic and cultural accomplishments, human beings remain ecological beings. Like all other species we depend for both basic needs and the production of artifacts on energy and material resources extracted from nature. All this energy and matter is eventually returned to the ecosphere as waste. A full understanding of the human ecological "niche" must therefore include full consideration of the flows of available energy and matter into the economy and the return flows of degraded energy and material (wastes) back to the ecosystem.

Analysis of this biophysical "throughput" shows that humankind, through the industrial economy, has become the dominant consumer in most of the Earth's major ecosystems. By 1986, humankind — one species among millions — was already "appropriating," directly and indirectly, 40 percent of the net product of terrestrial photosynthesis and recent studies suggest that the human "take" from rich coastal marine environments is approaching 30 percent[14] (which may be beyond the sustainable yield — despite increasing effort, the world's fisheries catch has declined since 1989). What are the implications of such dominance for ecosystems integrity? Can it be safely extended? (Remember the North Atlantic groundfish stocks!) Meanwhile, such trends as ozone depletion and greenhouse gas accumulation show that critical global waste sinks are also filled to overflowing. All such data indicate that even today's levels of appropriation are unsustainable. The human "load" has grown to the point where total consumption already exceeds sustainable natural income.

Achieving ecological sustainability clearly requires that economic assessments of the human condition be based on, or at least informed by, ecological and biophysical analyses. The fundamental ecological question for ecological economics is whether remaining species populations, ecosystems and related biophysical processes (i.e., critical self-producing "natural capital" stocks), and the waste assimilation capacity of the ecosphere are adequate to sustain the anticipated load of the human economy into the next century while simultaneously maintaining the general life-support functions of the ecosphere. This

critical question is at the heart of ecological carrying capacity but is virtually ignored by mainstream approaches.[15]

Turning carrying capacity on its head: human Ecological Footprints

Determining the human population that a given region might support is problematic for two major reasons: first, the total ecological load imposed by any population will vary with such factors as average income, material expectations, and the level of technology (e.g., energy and material efficiency). In short, human carrying capacity is as much a product of cultural factors as it is of ecological productivity. Second, in a global economy, no region exists in isolation — people have access to resources from all over the world. Indeed, as previously noted, many people argue that trade overcomes any regional limits to growth imposed by local resource shortages.

Other factors further complicate the carrying capacity question. Unlike consumption by other animals, consumption by people is not determined solely by biology. Because of technology, the load imposed by our biological metabolism is vastly augmented by industrial metabolism. While most species consume little beyond their food, the bulk of human material consumption consists of manufactured non-food items such as energy, clothing, automobiles and a vast array of other consumer goods. In industrialized countries, such material consumption is positively encouraged by the culture of consumerism, and constrained only by spending power. Globally, of course, individual consumption levels vary by orders of magnitude: farm-hands in rural India might represent the lower extreme of the scale, board members of transnational companies the upper echelon.

Ecological Footprint analysis gets around some of the difficulties with "traditional" carrying capacity simply by inverting the usual carrying capacity ratio. The Ecological Footprint starts from the assumption that every category of energy and material consumption and waste discharge requires the productive or absorptive capacity of a finite area of land or water. If we sum the land requirements for all categories of consumption and waste discharge by a defined population, the total area represents the Ecological Footprint of that population on the Earth *whether or not this area coincides with the population's home region*. In short, the Ecological Footprint measures land area required per person (or population), rather than population per unit area. As we shall see, this simple inversion is far more instructive than traditional carrying capacity in characterizing the sustainability dilemma.

More formally, the Ecological Footprint of a specified population or economy can be defined as the area of ecologically productive land (and water) in various classes — cropland, pasture, forests, etc. — that would be required on a continuous basis

a) to provide all the energy/material resources consumed, and

b) to absorb all the wastes discharged
by that population with prevailing technology, *wherever on Earth that land is located.* Consumption by households, businesses and governments is included in the calculations. Note that because the Ecological Footprint is based on natural income flows, it also provides an area-based estimate of the natural capital requirements of the subject population.

As suggested above, the size of the Ecological Footprint is not fixed but is dependent on money income, prevailing values, other sociocultural factors, and the state of technology. Keep in mind, however, that whatever the specifics, the Ecological Footprint of a given population is the land area needed *exclusively* by that population. Flows and capacities used by one population are not available for use by others.

Complete Ecological Footprint analysis would include both the direct land requirements and indirect effects of all forms of material and energy consumption. Thus, it would include not only the area of different ecosystems (natural capital) required to produce renewable resources and life-support services (different forms of natural income) but also the land area lost to biological productivity because of contamination, radiation, erosion, salination, and urban "hardening" — the paving over or building up of land that makes it ecologically unproductive. It would also factor in non-renewable resource use insofar as it can account for processing energy and use-related pollution effects. At present, however, our assessments are based on a limited range of consumption items and waste flows. Every additional item would therefore increase the size of our existing estimates. In addition, the present calculations assume that the required land (e.g., in forestry or agriculture) is being used sustainably. However, this is not generally the case — croplands, for example, are typically degraded 10 times faster than they can regenerate. This means that although the calculated Ecological Footprints for industrial regions and countries are impressively large, they are, if anything, considerable under-estimates of the effective demand. The case could be made that our present estimates should be increased by a significant "sustainability factor" to account for such simplifying assumptions.

"Turning carrying capacity on its head" eliminates several objections to the application of the concept to humans. It is true, as critics claimed, that trying to measure human carrying capacity in terms of maximum supportable regional population is a futile exercise. Local populations are so influenced by culture, trade and technological factors that any relationship to local biophysical limits is obscured. Hong Kong, for example, is densely populated and wildly prosperous yet has very little natural carrying capacity, while many African countries with much larger biophysical capacities suffer from famine. The Ecological Footprint gets around this analytic problem by measuring the population's total load rather than the number of people. This recognizes that

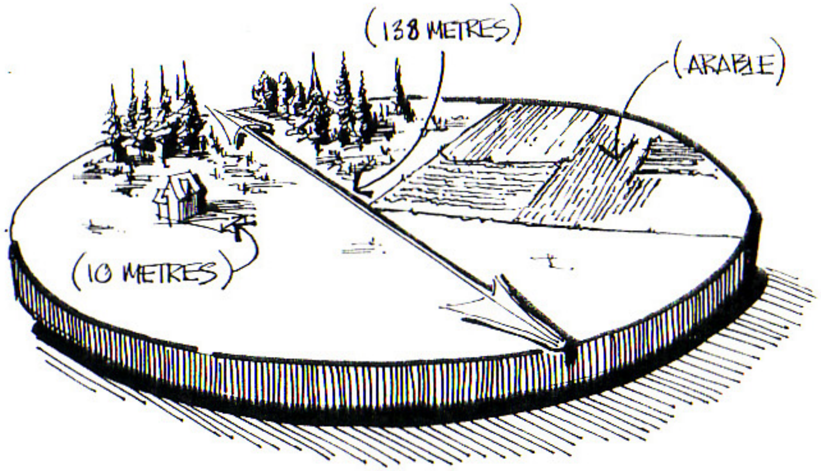

Figure 2.7: A fair Earthshare is the amount of land each person would get if all the ecologically productive land on Earth were divided evenly among the present world population. If your present Earthshare were a circular island it would have a diameter of just 138 metres. One sixth of your island would be arable land, the rest pasture, forest and wilderness, and built-up area. Clearly, as the population increases, our earthshares shrink. Also, for each person whose Ecological Footprint exceeds his/her fair earthshare by, say, a factor of three (as do North Americans'), three other people would have to content themselves with only a third of a share for global sustainability. —Any volunteers?

people have an impact somewhere even if it is obscured by trade and technology. Indeed, to the extent that trade seems to increase local carrying capacity, *it reduces it somewhere else.*

Our method summarizes a given population's impacts on nature by analyzing aggregate consumption (i.e., total load = population x *per capita* consumption) and converting this to a corresponding land area. We can thus produce a single measure of ecological demand (or natural capital requirements) which, unlike traditional carrying capacity, accounts for net trade and reflects both current income and prevailing technology. The Ecological Footprint so calculated can be compared to the area of the population's home region to reveal the extent to which local carrying capacity has been exceeded and therefore the population's dependence on trade. (Bits of a population's Ecological Footprint can be all over the world.) The Ecological Footprint also facilitates comparison between regions and thus reveals the effect of differing income levels and technology on ecological impact. It should be no surprise that while local capacity is severely limited, the Ecological Footprint of the

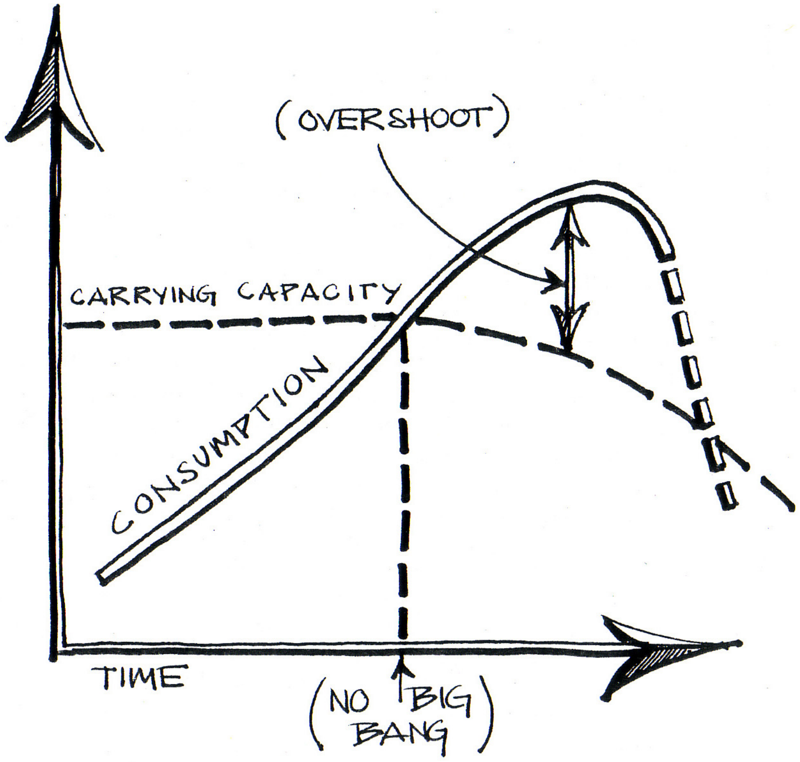

Figure 2.8: Overshoot is growth beyond carrying capacity. Carrying capacity limits can be overshot without a "big bang" because of the availability of large capital stocks. Harvests can still increase and money incomes rise, and while there may be indications of ecological stress, all else may seem normal. Ultimately, however, the consequences of eroded natural capital may be felt as eco-catastrophe and population crash.

average Hong Kong resident is vastly larger than that of an Ethiopian farmer!

The Ecological Footprint approach can be adapted to other sustainability assessments. For example, we could compute the Ecological Footprint of trade to reveal how much "carrying capacity" is embodied in a region's imports and how much capacity it gives up to produce the exports required to pay for its imports. Also, individual or average *per capita* Ecological Footprints[16] can be compared to the current *fair Earthshare*. A fair Earthshare is the amount of ecologically productive land available per person on Earth (with apologies to other species!). Today, this amounts to 1.5 hectares (3.7 acres), or a 122 metre square. Only 0.25 hectares (0.62 acres) of this are arable (Figure 2.7).

Perhaps importantly, Ecological Footprint analysis allows us to estimate the extent of global *overshoot* and the *ecological deficit* of any specified region or country. "Overshoot" is the amount by which humanity's total Ecological Footprint is bigger than global carrying capacity (see Figure 2.8). Beyond a certain point, the material growth of the world economy can be purchased only at the expense of depleting natural capital and undermining the life-support services upon which we all depend. In other words we are in overshoot when consumption by the economy exceeds natural income as indicated by ecological decline. The ecological or sustainability deficit is a measure of "local" overshoot. It estimates the difference between a defined region's or country's domestic ecological capacity and its actual Footprint. It therefore reveals the extent to which that region is dependent on extra-territorial productive capacity through trade or appropriated natural flows.

There is much evidence today that humanity's Ecological Footprint already exceeds global carrying capacity. Such overshoot is only possible temporarily and imposes high costs on future generations. Without a concerted effort today to reduce material throughput, our children will have to satisfy the natural income requirements and other needs of a larger population from much-diminished stocks of natural capital (real wealth).

How Ecological Footprint analyses can help advance sustainability

Measuring a wide array of human activities in terms of their Ecological Footprints makes it possible to compare their separate ecological impacts. At the same time, in contrast to conventional "one-shot" environmental assessments, Footprint analysis allows a cumulative approach to impact analysis. Every economic activity imposes a demand on the ecosphere and the Ecological Footprint shows how all these demands for food and fibre, non-renewable resources, waste absorption, urban development, and even maintaining biodiversity, compete for ecological space. (The expansion of the human enterprise necessarily "appropriates" resources and habitat from other species.)

The Earth is wondrously productive and has an enormous capacity to support people and their economies, to say nothing of other species. However, the production of many goods and services in the increasingly global marketplace is already based as much on natural capital depletion, including important self-producing forms such as fish stocks, as it is on sustainable flows. The Ecological Footprint concept is an effective tool in raising this emergent reality to consciousness. It is unfortunate that neither price nor product labels declare whether our consumption goods represent interest or the drawing down of nature's savings.

Using productive land area as a measurement unit makes Ecological Footprint analysis consistent with basic laws of physics, especially the laws of mass balance and thermodynamics. In particular, the modern world has to come to grips with the second-law axiom that any complex, self-organizing system (such as the economy) must have a continuous input of energy and matter from its "host" system to grow and maintain itself (i.e. to overcome its internal entropic decay — see Box 2.4). In this light, land or ecosystem area is a more appropriate accounting unit for the human economy than energy flux alone because it reflects both the quantity and quality of energy and matter available to the human economy. The key limiting factor for human life is not the amount of solar energy that falls on Earth, but what nature can do with it. For example, one lonely plant growing on one hectare of the Sahara desert is ecologically and economically less significant than one hectare of tropical forest, even though both receive the same solar radiation.

This last point emphasizes that the attributes of "land" go beyond the laws of thermodynamics. Land area not only captures planet Earth's finiteness, it can also be seen as a proxy for numerous essential life-support functions from gas exchange to nutrient recycling. The state of the biophysical world can therefore best be estimated from the state of the self-producing natural capital stocks that perform these functions. Keep in mind that these stocks themselves represent the biochemical energy that has accumulated in the ecosphere. The point is that land supports photosynthesis, the energy conduit for the web of life. This singular process distinguishes our planet from dead ones like Mars or Venus. Photosynthesis sustains all important food chains and maintains the structural integrity of ecosystems. It has miraculously transformed the originally inhospitable surface of the Earth into a self-producing and self-regulating ecosphere of spectacular abundance and diversity.

The Ecological Footprint reminds us that regardless of technology, humankind remains dependent on ecological goods and services and that these must be available in *increasing* quantities from somewhere on the planet as human populations and *per capita* consumption grow. As noted previously, the fundamental ecological question for sustainability is whether stocks of natural capital will be adequate to meet anticipated demand. Ecological Footprint analysis approaches this question directly. It provides a means to compare production by the ecosphere with consumption by the economy, thereby revealing whether there is ecological room for economic expansion or, on the other hand, whether industrialized societies have overshot local (and global) carrying capacity. In the latter case, the Ecological Footprint also reveals the sustainability gap confronting society. In short, Ecological Footprint analysis can help to determine the ecological constraints within which society operates; to shape policy to avoid or reduce overshoot; and to monitor progress towards achieving sustainability.

Ecological Footprint analysis by no means implies that living at carrying capacity is a desirable target. Rather, the Ecological Footprint is intended to show how dangerously close we have come to nature's limit. Ecological resilience and social well-being are more likely to be assured if the total human load remains substantially *below* Earth's carrying capacity. Living at the ecological edge compromises ecosystems' adaptability, robustness, and regenerative capacity, thereby threatening other species, whole ecosystems, and ultimately humanity itself.

Recognition of biophysical limits and the fact that human uses of nature are competing raises pertinent social and economic questions. For example, it forces over-consumers to face the otherwise hidden relationships and implicit trade-offs between their wealth and the poverty and human suffering that persists elsewhere. If these biophysical limits are real, should not mechanisms for redistribution be as prominent as economic efficiency and expansion are in plans to combat growing material inequity? Recognition that not everyone can become as materially rich as today's North Americans or Europeans without undermining global life-support should impose greater accountability on the wealthy and give the poor greater leverage in bargaining for development rights, technology transfers and other equity measures. Ecological Footprint analysis might therefore strengthen the case for international agreements on how to share the global commons and the Earth's productive capacity more equitably and how to use it more carefully.

The discussion so far has been relentlessly anthropocentric. However, Ecological Footprints also raises to consciousness humanity's disproportionate appropriation of energy/material flows and habitat that otherwise would be available for other species. Do we have an inherent right to so much of nature's productivity at the expense of the several million other species living on the planet?

In summary, by putting sustainability in simple but concrete terms, the Ecological Footprint concept provides an intuitive framework for understanding the ecological bottom-line of sustainability. This in turn stimulates public debate, builds common understanding and suggests a framework for action. The Ecological Footprint makes the sustainability challenge more transparent — decision-makers have a physical criterion for ranking policy, project, or technological options according to their ecological impacts. Finally, the Ecological Footprint underscores the global imperative for local action. It demonstrates that the ecological and social impacts of over-consumption reach far beyond our home regions. This introduces the moral dimension of sustainability and, by showing the contribution of both population growth and material consumption to global decline, emphasizes the need for policies to address them both. The following chapter describes specific applications of Ecological Footprint analysis.

Notes

1. For a more detailed discussion of these trends consult the Worldwatch Institute's annual *State of the World* and *Vital Signs* (NY: W.W. Norton), or the World Resources Institute, UNEP and UNDP's biannual *World Resources* (NY: Oxford University Press).
2. Worldwatch Institute, *Vital Signs* (NY: W.W. Norton, 1995)
3. The World Commission on Environment and Development (WCED) was chaired by Norwegian Prime Minster Gro Harlem Brundtland. The opening statement is from page 27 and the sustainable development definition from page 43 of its report, *Our Common Future* (NY: Oxford University Press, 1987).
4. Sustainability definitions are discussed in Sharachchandra M. Lélé, "Sustainable Development: A Critical Review," *World Development* Vol.19, No.6 (1991): 607-621; in the annex of David Pearce, Anil Markandya and Edward Barbier, *Blueprint for a Green Economy* (London: Earthscan Publications, 1989); and in William E. Rees, *Defining Sustainable Development* (The University of British Columbia, Vancouver: Centre for Human Settlements Publication, 1989). Further see Herman E. Daly, "Elements of Environmental Macroeconomics," in Robert Costanza, ed., *Ecological Economics: The Science and Management of Sustainability* (NY: Columbia University Press, 1991); Lester W. Milbrath, *Envisioning a Sustainable Society: Learning Our Way Out* (Albany, NY: State University of New York Press, 1989); and Michael Redclift, *Sustainable Development: Exploring its Contradictions* (London: Methuen & Co., 1987).
5. Liberally adapted from Robert Costanza and Herman E. Daly, "Natural capital and sustainable development," *Conservation Biology* Vol.1 (1992): 37-45 and William E. Rees, "Achieving Sustainability: Reform or Transformation?," *Journal of Planning Literature* Vol.9, No.4 (1995).
6. William E. Rees makes the case for "obligate dependence" in "Sustainable Development and the Biosphere: Concepts and Principles," *Teilhard Studies Number 23* (Chambersburg, PA: Anima Books (for American Teilhard Association for the Future of Man), 1990).
7. The weak-strong distinction was brought forward by both David Pearce *et al.* (1989, see above) and Herman Daly and John Cobb (*For the Common Good*, Boston: Beacon Press, 1989). Documents refuting the sustainability crisis are Marcus Gee, "Apocalypse Deferred: The End Isn't Nigh," in *The Globe and Mail*, 9 April 1994, D1-3; and, Julian L. Simon and Herman Kahn, eds., *The Resourceful Earth: A Response to Global 2000* (NY: B. Blackwell, 1984). David Pearce and Giles Atkinson's study is called "Capital Theory and the Measurement of Sustainable Development: An Indicator of 'Weak' Sustainability" in *Ecological Economics* Vol.8, No.2 (1993): 103-108.
8. The following quotes are from *Our Common Future*, pages 43, 9, 89, 213 and 65.
9. Duncan M. Taylor, "Disagreeing on the Basics: Environmental Debates Reflect Competing Worldviews," in *Alternatives* Vol.18, No.3 (1992): 26-33; and A. Nikiforuk, "Deconstructing Ecobabble: Notes on an Attempted Corporate Takeover," *This Magazine* Vol.24, No.3 (1990): 12-18.
10. References and complementary readings include: Herman E. Daly and Kenneth N. Townsend, eds., *Valuing the Earth: Economics, Ecology, Ethics* (Cambridge, MA: The MIT Press, 1993); Charles A.S. Hall, "Economic Development or Developing Economics: What Are Our Priorities," in Mohan K. Wali, *Ecosystem Rehabilitation, Volume 1: Policy Issues* (The Hague, the Netherlands: SPB Academic Publishing, 1992); Colin Price, *Time, Discounting and Value* (Oxford: Blackwell Publishers, 1993); Andrew Stirling, "Environmental Valuation: How Much is the Emperor Wearing?," *The Ecologist* Vol.23, No.3 (1993): 97-103; and Arild Vatn and Daniel W. Bromley, "Choices without Prices without Apologies," *Journal of Environmental Economics and Management* 26 (1994):129-148.
11. Abstracted in part from William E. Rees, "Revisiting Carrying Capacity: Area-Based Indicators of Sustainability," *Population & Environment* (1995, in press).
12. William Catton, "Carrying Capacity and the Limits to Freedom," paper prepared for the Social Ecology Session, *XI World Congress of Sociology*, New Delhi, India, 18 August 1986.
13. Plato in David F. Durham, "Carrying Capacity Philosophy," *Focus* Vol.4, No.1 (1994): 5-7; early Christian and Chinese scholars in William Ophuls and A. Stephen Boyan Jr., *Ecology and the Politics of Scarcity Revisited*, (NY: W.H. Freeman and Company, 1992) (original edition 1977); John Evelyn in James Garbarino, *Toward a Sustainable Society: An Economic, Social, and Environmental Agenda for our Children's Future* (Chicago: The Noble Press Inc., 1992); Alfred James Lotka, *Elements of Physical Biology* (Baltimore: Williams & Wilkins, 1925); Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process* (Cambridge, MA: Harvard University Press, 1971); Leopold Pfaundler, "Die Weltwirtschaft im Lichte der Physik" [The Global Economy from the Point of View of Physics], in *Deutsche Revue*, Richard Fleischer, ed., Vol.27, No.2 (April-June 1902): 29-38,171-182; William Vogt, *Road to Survival* (NY: William Sloane, 1948); Fairfield Osborn, *The Limits of the Earth* (Boston: Little, Brown and Co., 1953); Georg Borgstrom, *Harvesting the Earth* (NY: Abelard-Schuman, 1973); William E. Rees, "An Ecological Framework for Regional and Resource Planning" (The University of British Columbia, Vancouver: UBC School of Community and Regional Planning, 1977); William R. Catton, *Overshoot: The Ecological Basis of Revolutionary Change* (Urbana: University of Illinois Press, 1980); G. Higgins, A.H. Kassam, L. Naiken, G. Fischer and M. Shah, "Potential Population Supporting Capacities of Lands in the Developing World," Technical Report of FAO, IIASA and UNFPA Project Int/75/P13, *Land Resources for Populations of the Future* (Rome: FAO, 1983); Ragnar Overby, "The Urban Economic Environmental Challenge: Improvement of Human Welfare by Building and Managing Urban Ecosystems," presented at POLMET 85, Urban Environmental Conference, Hong Kong, 1985; M.A. Harwell and T.C. Hutchinson, *Environmental Consequences of Nuclear War*, Vol.II, SCOPE 28 (Chichester, UK: John Wiley, 1986); *Action Plan Netherlands*, Friends of the Earth (Netherlands). A fascinating intellectual history of a part of this debate, with particular reference to Serhii Podolinski, Ludwig Boltzmann, Rudolf Clausius, Frederick Soddy, is provided by agro-economist Juan Martinez-Alier, *Ecological Economics: Energy, Environment, and Society* (Oxford: Basil Blackwell, 1987).
14. Peter M. Vitousek, Paul R. Ehrlich, Ann H. Ehrlich and Pamela A. Mateson, "Human Appropriation of the Products of Photosynthesis," *BioScience* Vol.34, No.6 (1986): 368-373; and D. Pauly and V. Christensen, "Primary Production Required to Sustain Global Fisheries," *Nature* (forthcoming) 1995.
15. William E. Rees, "Achieving Sustainability: Reform or Transformation?," *Journal of*

Planning Literature Vol.9, No.4 343=361 (1995); and "Revisiting Carrying Capacity: Area-based Indicators of Sustainability," *Population & Environment* (1995, in press).

16. We have previously defined this individual footprint as the "personal planetoid." (See William Rees and Mathis Wackernagel, "Ecological Footprints and Appropriated Carrying Capacity: Measuring the Natural Capital Requirements of the Human Economy," in *Investing in Natural Capital: The Ecological Economics Approach to Sustainability*, ed. A-M. Jansson, M. Hammer, C.Folke, and R. Costanza (Washington: Island Press, 1994).

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3

FUN WITH FOOTPRINTS: METHODS & REAL-WORLD APPLICATIONS

If you would like to estimate the Ecological Footprint of projects, policies, programs or particular technologies, read this chapter. It describes our present approach to such calculations and gives examples of real-world applications.

Making the Ecological Footprint Idea Work

In theory, the Ecological Footprint (EF) of a population is estimated by calculating how much land and water area is required on a continuous basis to produce all the goods consumed, and to assimilate all the wastes generated, by that population. However, attempting to include all consumption items, waste types and ecosystem functions in the estimate would lead to intractable information and data-processing problems. We therefore use a simplified approach in our "real-world" research and in the examples to follow. In general, we:

- Base calculations on the assumption that the current industrial harvest practices (e.g., in agriculture and forestry) are sustainable, which they often are not.
- Include only the basic services of nature. As the assessments are refined, additional natural functions can be included. Human activities directly and indirectly appropriate nature's services through the harvest of renewable resources, extraction of non-renewable resources, waste absorption, paving over, fresh water withdrawal, soil contamination, and other forms of pollution (including ozone depletion). At this point, our research has concentrated on the first four activities.
- Try not to double-count when the same area of land provides two or more services simultaneously. For example, an area might be growing timber or pulp-wood while at the same time collecting water subsequently used for domestic purposes or irrigation. In this case, only timber production — the larger land area — would be included in the Footprint estimate.
- Use a simple taxonomy of ecological productivity involving eight land