OUR ECOLOGICAL FOOTPRINT

REDUCING HUMAN IMPACT ON THE EARTH

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NEW SOCIETY PUBLISHERS

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ECOLOGICAL FOOTPRINTS FOR BEGINNERS

Many of us live in cities where we easily forget that nature works in closed loops. We go to the store to buy food with money from the bank machine and, later, get rid of the waste either by depositing it in the back alley or flushing it down the toilet. Big city life breaks natural material cycles and provides little sense of our intimate connection with nature.

Obvious but Profound: We Depend on Nature

Despite this estrangement, we are not just *connected* to nature — we *are* nature. As we eat, drink and breath, we constantly exchange energy and matter with our environment. The human body is continuously wearing out and rebuilding itself — in fact, we replace almost all the molecules in our bodies about once a year. The atoms of which we are made have already been part of many other living beings. Particles of us once roamed about in a dinosaur, and some of us may well carry an atom of Caesar or Cleopatra.

Nature provides us with a steady supply of the basic requirements for life. We need energy for heat and mobility, wood for housing and paper products, and nutritious food and clean water for healthy living. Through photosynthesis green plants convert sunlight, carbon dioxide (CO_2), nutrients and water into chemical energy (such as fruit and vegetables), and all the food chains that support animal life — including our own — are based on this plant material. Nature also absorbs our wastes and provides life-support services such as climate stability and protection from ultraviolet radiation. Finally, the sheer exuberance and beauty of nature is a source of joy and spiritual inspiration. Figure 1.1 shows how very tightly human life is interwoven with nature, a connection we often forget or ignore. Since most of us spend our lives in cities and consume goods imported from all over the world, we tend to experience nature merely as a collection of commodities or a place for recreation, rather than the very source of our lives and well-being.

If we are to live sustainably, we must ensure that we use the essential products and processes of nature no more quickly than they can be renewed, and that we discharge wastes no more quickly than they can be absorbed. Even

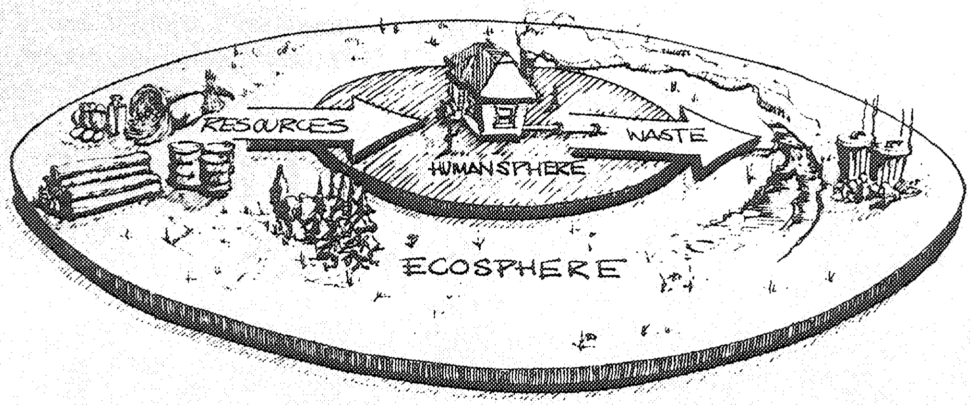


Figure 1.1: We are part of nature. Nature supplies material requirements for life, absorbs our wastes, and provides life-support services such as climate stabilization, all of which make Earth hospitable for people.

today, however, accelerating deforestation and soil erosion, fisheries collapse and species extinction, the accumulation of greenhouse gases and ozone depletion all tell us our current demands on nature are compromising humanity's future well-being. In spite of these trends, society operates as if nature were an expendable part of our economy. For example, agriculture, forestry and fisheries are considered to be mere extractive sectors of the economy, and since such primary activities contribute relatively little to the Gross National Product (GNP) of most industrialized countries, they are not considered to be particularly important. This perspective forgets that nature's products are indispensable to human well-being, however "insignificant" their dollar contribution to the country's GNP might be. Similarly, some people reduce the economy-ecology connection to pollution that directly threatens the health of people (e.g., urban air pollution). No doubt, this is an important problem but the emphasis on human health betrays a narrow ecological understanding. The economy's growing demands on nature endanger the planet's ability to support life on a much more fundamental level. Over-harvesting and waste generation not only reduce future productivity, but can lead to ecosystems collapse. So far, this phenomenon has been confined to the local or regional level (desertification in the African Sahel and the loss of North Atlantic groundfish stocks being recent examples). However, increasing evidence of global change is clear warning that human activity may now be undermining global life-support systems. The prospect of significant climate change, with its potential threat to food production and the safety of coastal settlements, should *in itself* be sufficient to force society to adopt a less cavalier attitude toward "the environment" that sustains us (to say nothing of 30 million other species).

What *is* an Ecological Footprint?

Ecological footprint analysis is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area. Typical questions we can ask with this tool include: how dependent is our study population on resource imports from "elsewhere" and on the waste assimilation capacity of the global commons?, and will nature's productivity be adequate to satisfy the rising material expectations of a growing human population into the next century? William Rees has been teaching the basic concept to planning students for 20 years and it has been developed further since 1990 by Mathis Wackernagel and other students working with Bill on UBC's Healthy and Sustainable Communities Task Force.

To introduce the thinking behind Ecological Footprint analysis, let's explore how our society perceives that pinnacle of human achievement, "the city." Ask for a definition, and most people will talk about a concentrated population or an area dominated by buildings, streets and other human-made artifacts (this is the architect's "built environment"); some will refer to the city as a political entity with a defined boundary containing the area over which the municipal government has jurisdiction; still others may see the city mainly as a concentration of cultural, social and educational facilities that would simply not be possible in a smaller settlement; and, finally, the economically-minded see the city as a node of intense exchange among individuals and firms and as the engine of production and economic growth.

No question, cities are among the most spectacular achievements of human civilization. In every country cities serve as the social, cultural, communications and commercial centers of national life. But something fundamental is missing from the popular perception of the city, something that has so long been taken for granted it has simply slipped from consciousness.

We can get at this missing element by performing a mental experiment based on two simple questions designed to force our thinking beyond conventional limits. First, imagine what would happen to any modern city or urban region — Vancouver, Philadelphia or London — as defined by its political boundaries, the area of built-up land, or the concentration of socioeconomic activities, if it were enclosed in a glass or plastic hemisphere that let in light but prevented material things of any kind from entering or leaving — like the "Biosphere II" project in Arizona (Figure 1.2). The health and integrity of the entire human system so contained would depend entirely on whatever was initially trapped within the hemisphere. It is obvious to most people that such a city would cease to function and its inhabitants would perish within a few days. The population and the economy contained by the capsule would have been cut off from vital resources and essential waste sinks, leaving it both to starve and to suffocate at the same time! In other words, the ecosystems contained within our imaginary human terrarium would have insufficient "carrying capacity" to support the ecological load imposed by the contained human population. This mental model of a glass hemisphere reminds us rather abruptly of humankind's continuing ecological vulnerability.

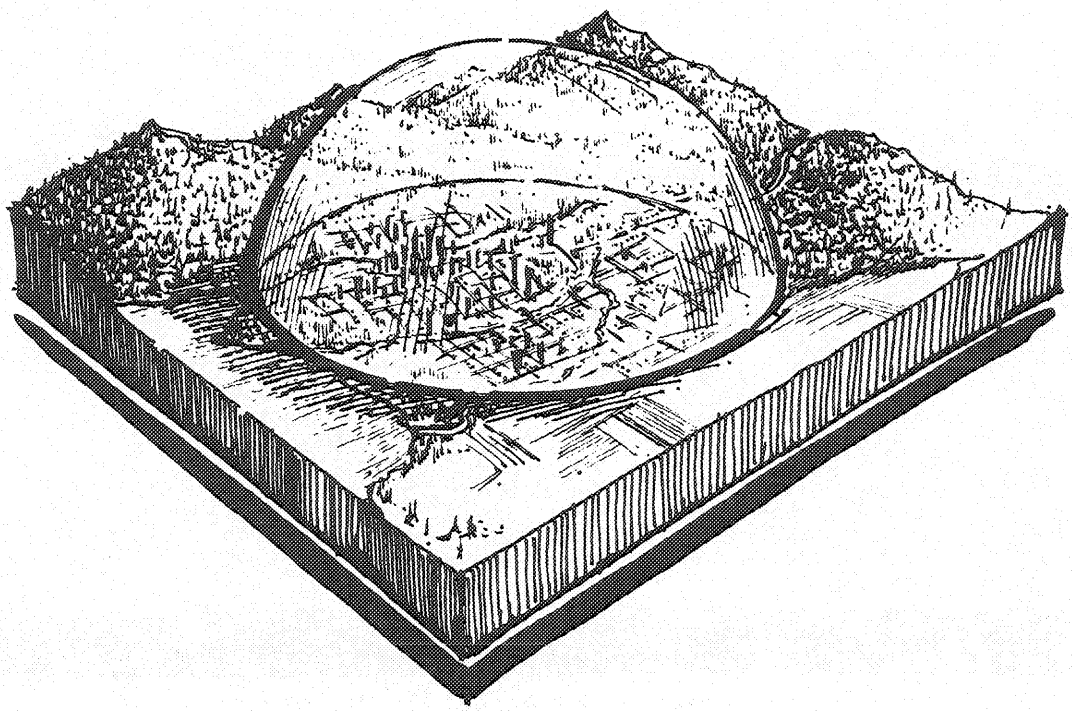


Figure 1.2: Living in a Terrarium.
How big would the glass hemisphere need to be so that the city under it could sustain itself exclusively on the ecosystems contained?

The second question pushes us to contemplate this hidden 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 hemisphere have to become before the city at its center could sustain itself indefinitely and exclusively on the land and water ecosystems and the energy resources contained within the capsule? In other words, what is the total area of terrestrial ecosystem types needed continuously to support all the social and economic activities carried out by the people of our city as they go about their daily activities? Keep in mind that land with its ecosystems is needed to produce resources, to assimilate wastes, and to perform various invisible life-support functions. Keep in mind too, that 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.

For any set of specified circumstances — the present example assumes current population, prevailing material standards, existing technologies, etc. — it should be possible to produce a reasonable estimate of the land/water area required by the city concerned to sustain itself. By definition, the total ecosystem area that is essential to the continued existence of the city is its *de facto* Ecological Footprint on the Earth. It should be obvious that the Ecological Footprint of a city will be proportional to both population and *per capita* material consumption. Our estimates show for modern industrial cities the area involved is orders of magnitude larger than the area physically occupied by the city. Clearly, too, the Ecological Footprint includes all land required by the defined population wherever on Earth that land is located. Modern cities and whole countries survive on ecological goods and services appropriated from natural flows or acquired through commercial trade from all over the world. The Ecological Footprint therefore also represents the corresponding population's total "appropriated carrying capacity."

By revealing how much land is required to support any specified lifestyle indefinitely, the Ecological Footprint concept demonstrates the continuing material dependence of human beings on nature. For example, Table 3.3 (pages 82-83) shows the Ecological Footprint of an average Canadian, i.e., the amount of land required from nature to support a typical individual's present consumption. This adds up to almost 4.3 hectares, or a 207 metre square. This is roughly comparable to the area of three city blocks. The column on the left shows various consumption categories and the headings across the top show corresponding land-use categories.

"Energy" land as used in the Table means the area of carbon sink land required to absorb the carbon dioxide released by *per capita* fossil fuel consumption (coal, oil and natural gas) assuming atmospheric stability as a goal. Alternatively, this entry could be calculated according to the area of cropland necessary to produce a contemporary biological fuel such as ethanol to substitute for fossil fuel. This alternative produces even higher energy land requirements. "Degraded Land" means land that is no longer available for nature's production because it has been paved over or used for buildings. Examples of the resources in "Services" are the fuel needed to heat hospitals, or the paper and electricity used to produce a bank statement.

To use Table 3.3 to find out how much agricultural land is required to produce food for the average Canadian, for example, you would read across the "Food" row to the "Crop" and "Pasture" columns. The table shows that, on average, 0.95 hectares of garden, cropland and pasture is needed for a typical Canadian. Note that none of the entries in the table is a fixed, necessary, or recommended land area. They are simply our estimates of the 1990s ecological demands of typical Canadians. The Ecological Footprints of individuals and whole economies will vary depending on income, prices, personal and prevailing social values as they affect consumer behavior, and technological sophistication — e.g., the energy and material content of goods and services.

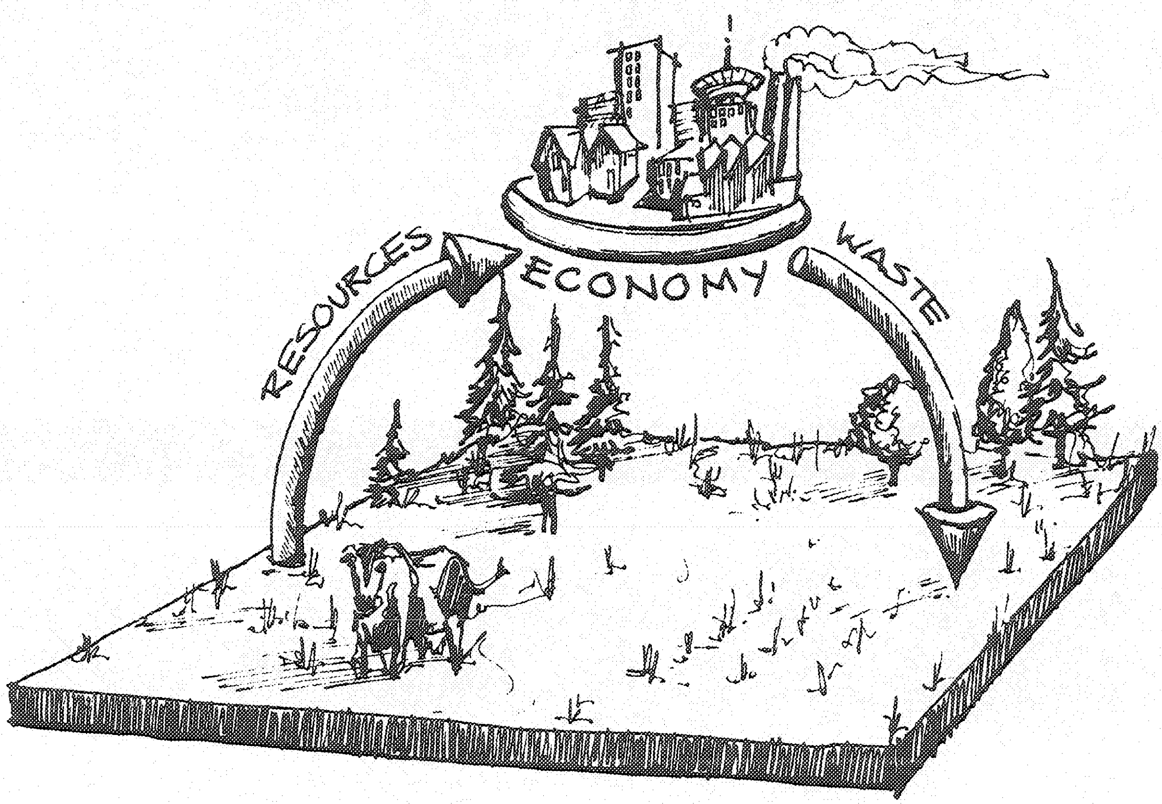


Figure 1.3: What is an Ecological Footprint?
Think of an economy as having an "industrial metabolism." In this respect it is similar to a cow in its pasture. The economy needs to "eat" resources, and eventually, all this intake becomes waste and has to leave the organism — the economy — again. So the question becomes: how big a pasture is necessary to support that economy — to produce all its feed and absorb all its waste? Alternatively, how much land would be necessary to support a defined economy sustainably at its current material standard of living?

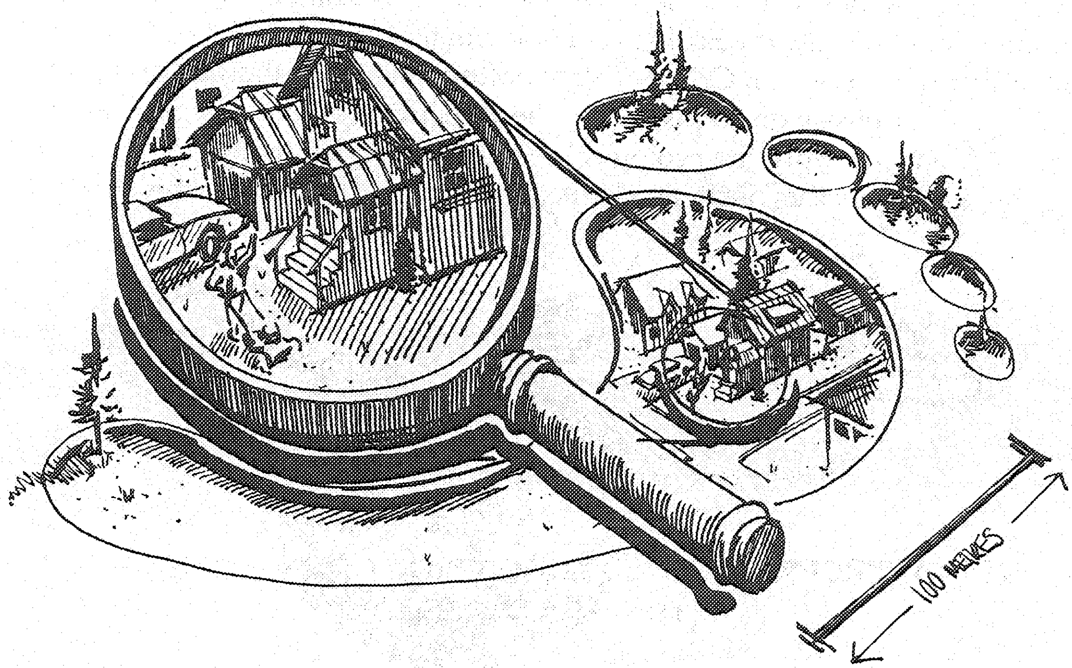


Figure 1.4: Your Footprint. The average North American Footprint measures 4 to 5 hectares or is comparable to three-plus city blocks.

So What? — The Global Context

Our economy caters to growing demands that compete for dwindling supplies of life's basics. The Ecological Footprint of any population can be used to measure its current consumption and projected requirements against available ecological supply and point out likely shortfalls. In this way, it can assist society in assessing the choices we need to make about our demands on nature. To put this into perspective, the ecologically productive land "available" to each person on Earth has decreased steadily over the last century (Figure 1.5). 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. In contrast, the land area "appropriated" by residents of richer countries has steadily increased. The present Ecological Footprint of a typical North American (4–5 ha) represents three times his/her fair share of the Earth's bounty. Indeed, if everyone on Earth lived like the average Canadian or American, we would need at least three such planets to live sustainably (Figure 1.6). Of course, if the world population continues to grow as anticipated, there will be 10 billion people by 2040, for each of whom there will be less than 0.9 hectares of ecologically productive land, assuming there is no further soil degradation.

Such numbers become particularly telling when used to compare selected geographic regions with the land they actually "consume." For example, in Chapter 3 we estimate the Ecological Footprint for the Lower Fraser Valley, east of Vancouver to Hope, B.C. This valley bottom has 1.8 million inhabitants for a population density of 4.5 people per hectare. In short, the area is far smaller than needed to supply the ecological resources used by its population. If the average person in this basin needs the output of 4.3 hectares (Table 3.3), then

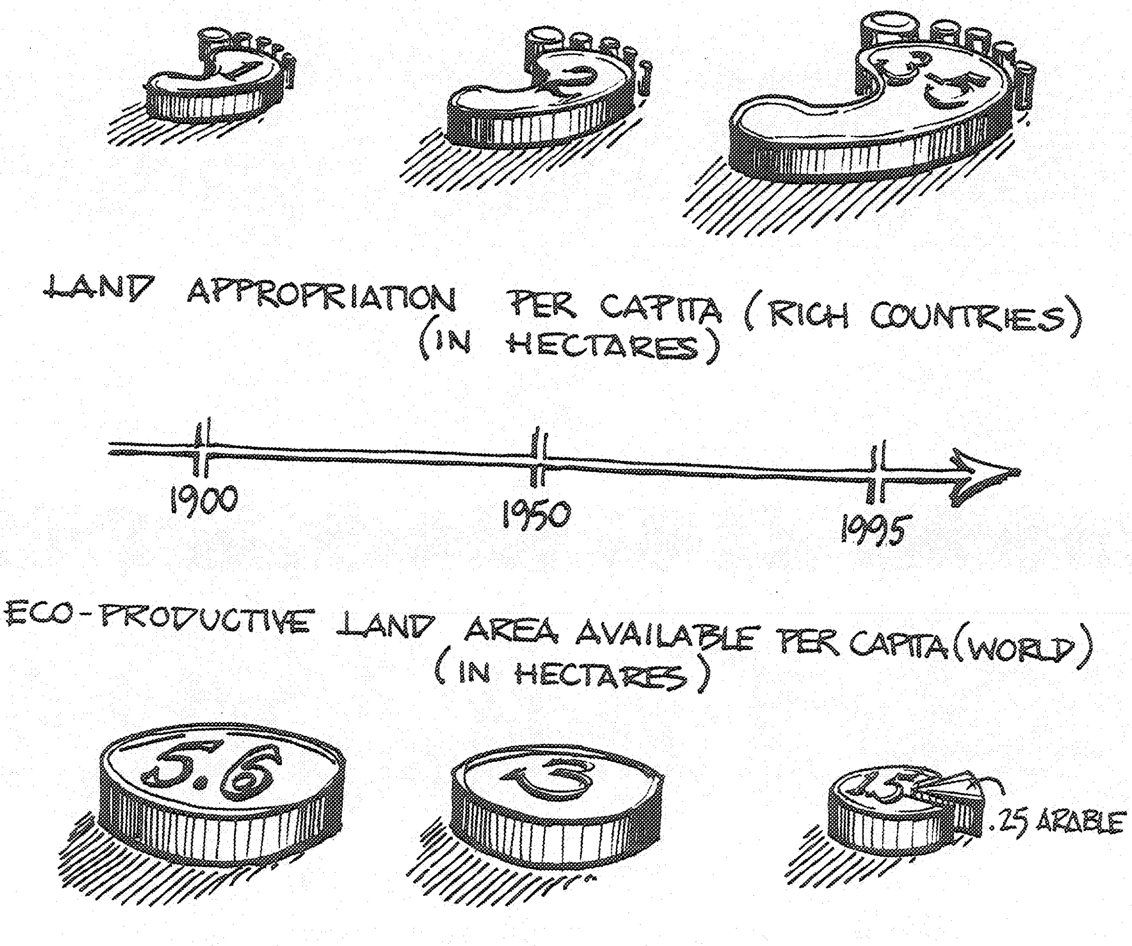


Figure 1.5: Our Ecological Footprints Keep Growing While Our per capita "Earth-shares" Continue to Shrink. Since the beginning of this century, the available ecologically productive land has decreased from over five hectares to less than 1.5 hectares per person in 1995. At the same time, the average North American's Footprint has grown to over 4 hectares. These opposing trends are in fundamental conflict: the ecological demands of average citizens in rich countries exceed *per capita* supply by a factor of three. This means that the Earth could not support even today's population of 5.8 billion sustainably at North American material standards.

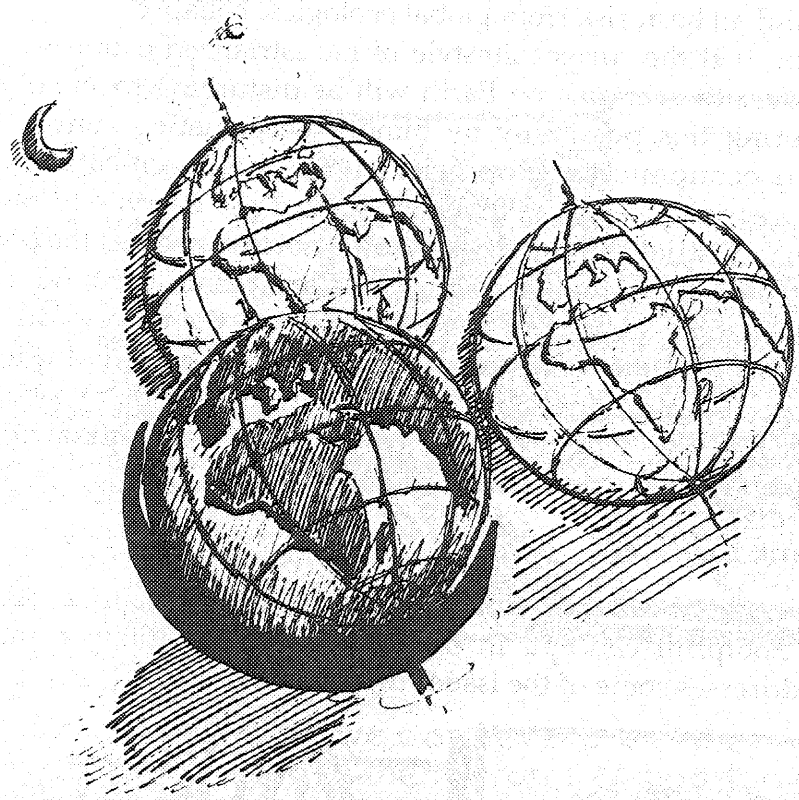


Figure 1.6: Wanted: Two (Phantom) Planets. If everybody lived like today's North Americans, it would take at least two additional planet Earths to produce the resources, absorb the wastes, and otherwise maintain life-support. Unfortunately, good planets are hard to find...

the Lower Fraser Valley depends on an area 19 times larger than that contained within its boundaries for food, forestry products, carbon dioxide assimilation and energy (Figure 3.5). Similarly, Holland has a population of 15 million people, or 4.4 people per hectare, and although Dutch people consume less than North Americans on average, they still require about 15 times the available land within their own country for food, forest products and energy use (Figure 3.8, Box 3.4). In other words, the ecosystems that actually support typical industrial regions lie invisibly far beyond their political or geographic boundaries.

A world upon which everyone imposed an over-sized Ecological Footprint would not be sustainable — the Ecological Footprint of humanity as a whole must be smaller than the ecologically productive portion of the planet's surface. This means that if every region or country were to emulate the economic example of the Lower Fraser Basin or the Netherlands, using existing technology, we would all be at risk from global ecological collapse.

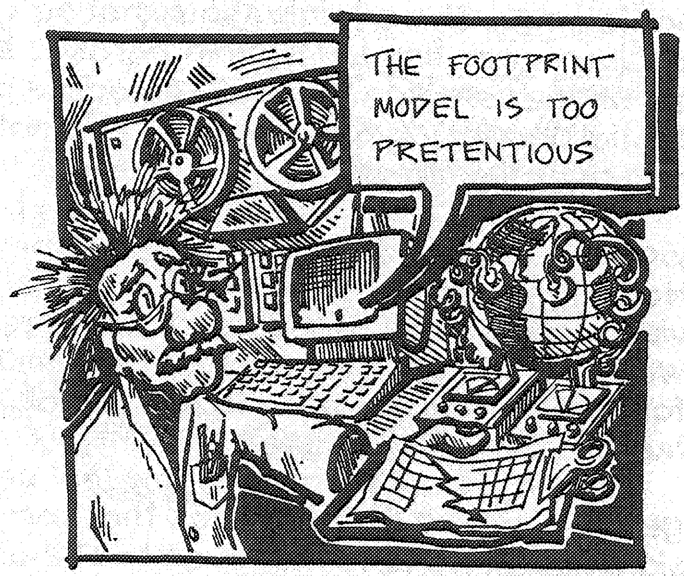
The notion that the current lifestyle of industrialized countries cannot be extended safely to everyone on Earth will be disturbing to some. However, simply ignoring this possibility by blindly perpetuating conventional approaches to economic development invites both eco-catastrophe and subsequent geopolitical chaos. To recognize that not everybody can live like people do in industrialized countries today is not to argue that the poor should remain poor. It is to say that there must be adjustments all round and that, if our ecological analyses are correct, continuing on the current development path will actually hit the less fortunate hardest. Blind belief in the expansionists' cornucopian dream does not make it come true — rather it side-tracks us from learning to live within the means of nature and ultimately becomes ecologically and socially destructive.

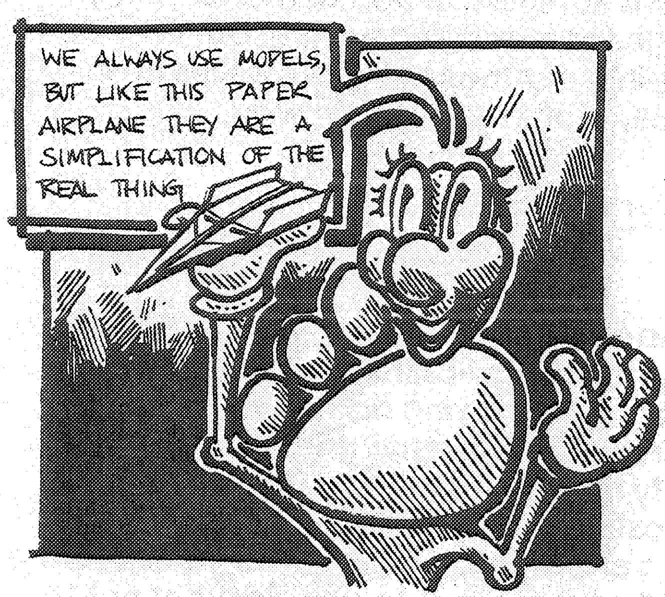
Dr. Footnote Explains

Various critics have raised well-reasoned objection to aspects of the Ecological Footprint concept. In this section, sustainability counsellor Dr. Footnote addresses some of the issues they have raised.

THE POWER OF SCIENCE:

Analytical Scientist: The Ecological Footprint is much too pretentious. For example, in spite of years of detailed and systematic research, we still do not know exactly how single organisms work (be they bacteria or blue whales), and we know even less about how they interact. We scientists work with models, but they are crude simplifications — and we can never prove them right. The best we can do is prove them wrong. As good scientists we must acknowledge our enormous ignorance of nature. We need to be humble. So, how can you claim that the complex interactions between people and nature can be reduced to a matter of hectares?





Dr. Footnote: You're right. The Ecological Footprint doesn't tell the whole story. However, while many people strive toward the absolute truth, a more relevant question is whether the knowledge we use is compatible with the phenomena that we observe. Know-ledge needs to be appropriate to the task. For example, Newton's mechanical laws were good enough to fly us to the moon, in spite of their shortcomings in light of Einsteinian relativity. Not knowing something with certainty should not deter us from taking action or counter-action. Let's avoid paralysis by analysis, but rather err on the safe side. We must advocate precaution where potential danger looms — even if we do not know the exact nature of the hazard.

The Ecological Footprint model may be simple — like any ecological model, it does not represent all possible inter-actions. However, it estimates the minimum land area necessary to provide the basic energy and material flows required by the economy. We don't look at pollution beyond carbon dioxide. If anything, therefore, our current Ecological Footprint calculations underestimate humanity's draw on nature.

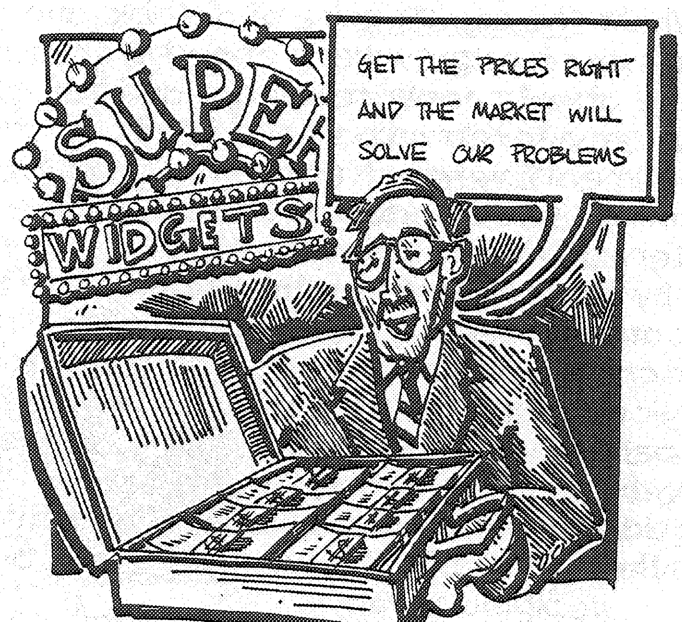
Even so, our calculations show that people have overshot global carrying capacity and that some people contribute significantly more to that overshoot than others. It is questionable, of course, whether humanity's Ecological Footprint should even approach the size of the Earth. Only a smaller Footprint provides any ecological resilience in the face of global change. In any case, today's ecological overshoot can only be temporary, and comes at a high cost to the future.

In short, we may not know exactly how nature works, but by using fundamental laws and known relationships we can calculate useful (under)estimates of human demands. They may not be precise enough for managing nature, but they do provide challenging guidelines for managing ourselves in an ecologically and socially more responsible way.

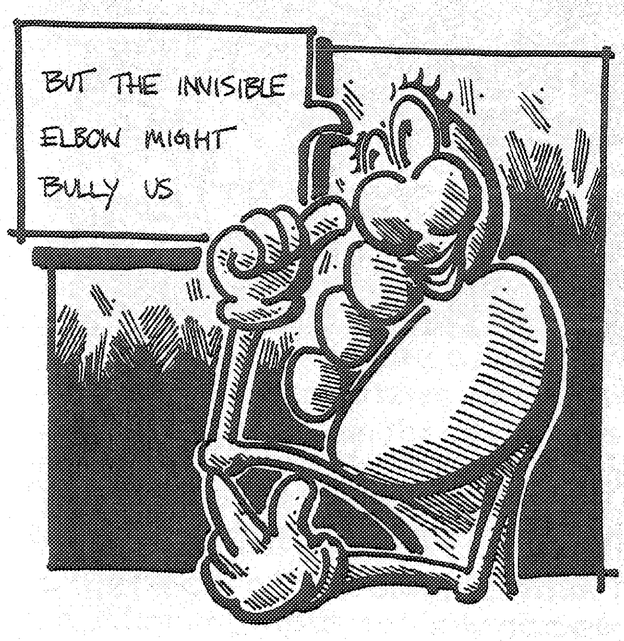
THE WISDOM OF THE MARKETPLACE:

Business person:
The trends are clear. Global income is rising faster than human population. Illiteracy is declining. Agri-cultural production has increased because it responds to growing demand. Life on the planet is better than ever. If we have environmental problems it is only because property rights are poorly defined or prices do not reflect the true costs. Once we get the prices right, the "Invisible Hand" will take care of those problems. Prices are the most effective way to tell people what to do and what not to

do and government interference should be kept to a minimum. Society's needs will then be met as people pursue their own individual interests.



Dr. Footnote: You're right, to a point. When nature's goods and services are underpriced they become over-used and abused, and the "Invisible Hand" that is supposed to automatically balance the market becomes the destabilizing "Invisible Elbow."[1] Thus, adjusting prices through depletion taxes and pollution charges, for example, can be effective in reducing activities that are ecologically destructive. However, the Invisible Hand may often depend on the Ecological Footprint to work its magic. Ecological Footprint analysis may help us to assess the true social costs of growth because it makes visible many impacts to which traditional monetary analysis is usually blind. But let's be realistic, the "free market" will not solve all our problems. Not everything of value can (or should) be privatized and not all nature's services can even be quantified, let alone priced.

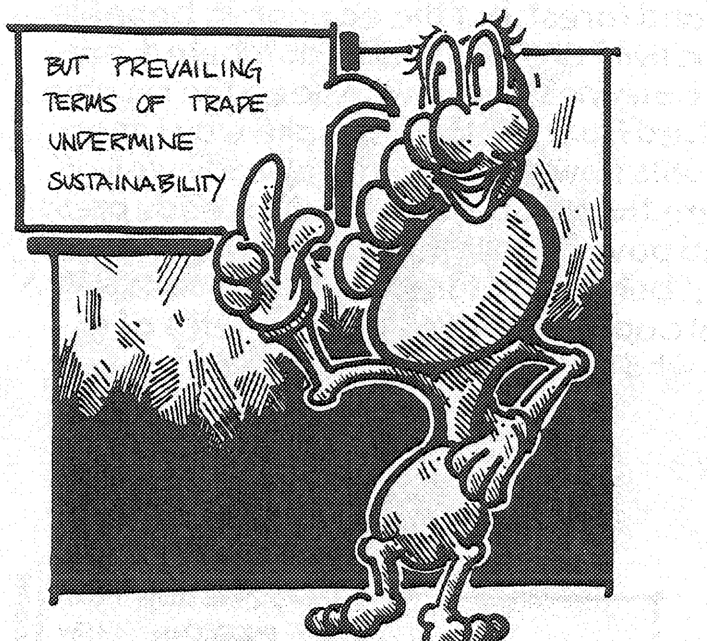


(What's the market price of a stable and predictable climate? How much ozone layer is enough?) The fact is that many decisions about people, resources and the ecosphere will continue to rely on partial scientific information and political judgment. Even such economic incentives as resource depletion taxes and tradable pollution rights require government intervention in the economy.

By the way, there is nothing inconsistent between your global economic trends and Ecological Footprint analysis. Higher incomes mean greater access to resources and bigger Ecological Footprints for the privileged minority. However, superabundance today does not guarantee even adequacy tomorrow. Much of our present "income" is derived from the liquidation of natural capital. Our Footprints are expanding even as the land upon which we stand shrinks beneath us.

THE DOCTRINE OF FREE TRADE:

Pilot: It seems to me that the Ecological Footprint questions the value of trade. I don't want to live in the Middle Ages! Trade is beneficial to everyone. For example, in North America, we cannot grow coffee and bananas, while coffee and banana exporters may not be able to build computers or grow wheat. Also, it is more economically efficient if we produce the products where it is ecologically most efficient. For example, is it not stupid to grow winter tomatoes in heated greenhouses in Canada rather than import them from California or Mexico?



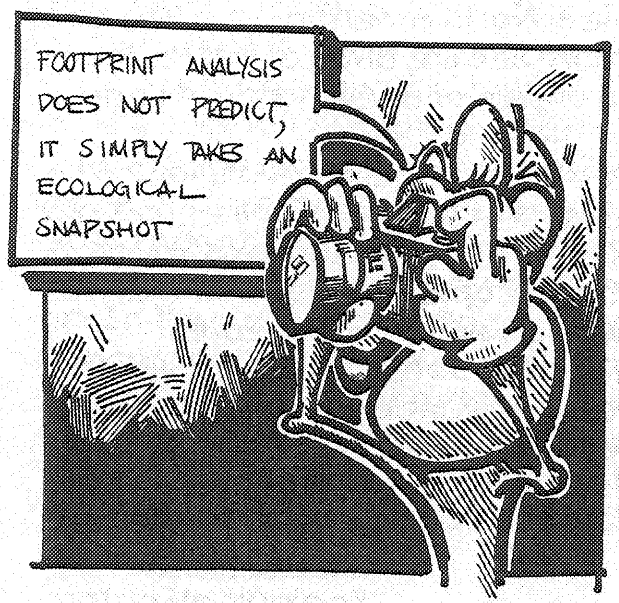
Dr. Footnote: Ecological Footprint analysis is not against trade per se. However, it examines trade through an ecological lens and reveals its environmental consequences. When economists talk about trade balances they refer only to money flows, not ecological flows. The fact is that some areas constantly give up ecological productivity, while others continuously draw on it. For example, Hong Kong, Switzerland and Japan, which have positive dollar trade balances, provide little ecological productivity to the world, while importing a great deal from other places to maintain their high levels of consumption. Unfortunately, not everybody can be a net importer of ecological goods and services. On the global scale, for every importer there must be an exporter. This means that even though most developing nations are trying to follow the development of places like Japan, Hong Kong or Switzerland, it is physically impossible for all of them to succeed.

Expanding world trade leads to increased global resource flows, which stimulates total economic production and accelerates the depletion of the planet's natural assets — and there are other problems. People who live on ecological goods imported from afar (and on "common-pool" ecological functions such as climate control, which are shared by everyone) are spatially and psychologically disconnected from the resources that sustain them. They lose any direct incentive to conserve their own local resources and have no hand in the management of the distant sources of supply. In fact, they may remain blissfully unaware of both the ecological and social effects of prevailing terms of trade. Modern intensive production methods not only accelerate the depletion and contamination of field and forest, but the economic benefits of the increased productivity are inequitably distributed, particularly in low-income countries. Those who need the income may actually be displaced from the land to make way for export crops while the profits flow mainly to the already well-off. In short, in a world where the global economy is already pressing ecological limits and poverty still stalks a billion people, we don't need "free trade," but terms of trade that encourage the rehabilitation of natural capital and direct the benefits of export activities to those who need them most.

THE UNCERTAIN FUTURE:

Fortune Teller:
Ecological Footprint analysts claim to see the future. But predictions and extrapolations are always way off. The only thing we know about the future is that it is likely to be different from what we think it will be. Even I have difficulty seeing into the future with my crystal ball...

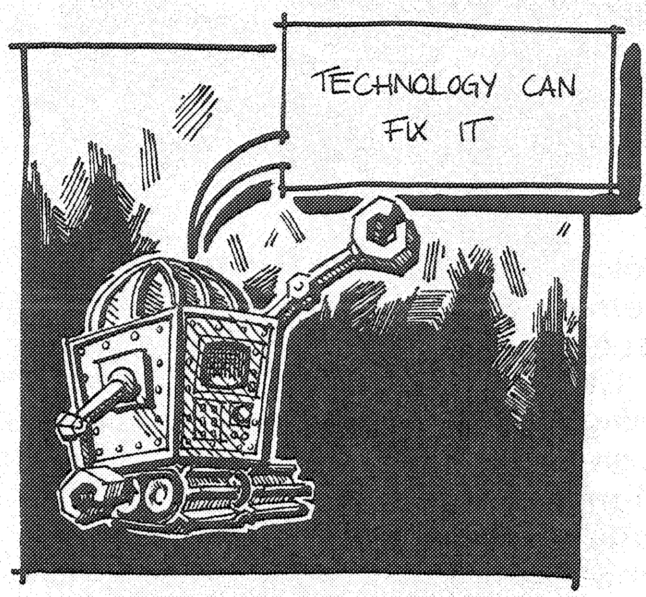
Dr. Footnote:
Ecological Footprint analysis is not a predictive tool. It is an "ecological camera" that takes a snapshot of our current demands on nature. Extrapolation to the anticipated human population and resource flows in 2040 does suggest there are serious biophysical barriers on our current development path, but the numbers do not predict how things will turn out. Rather, they measure the "sustainability" gap that society must somehow close to ensure a stable future. In short, Ecological Footprint analysis can show how much we have to reduce our consumption, improve our technology, or change our behavior



to achieve sustainability. It can also reveal with graphic clarity the chronic material inequity that persists between affluent and low-income countries today. Most important, Ecological Footprint analysis suggests some of the ways society can begin the shift toward sustainability and which of these measures provide the greatest leverage. To reiterate, this tool is not a telescope into the future, but a way to visualize the consequences of current trends and to assess alternative "what if" scenarios on the road to sustainability.

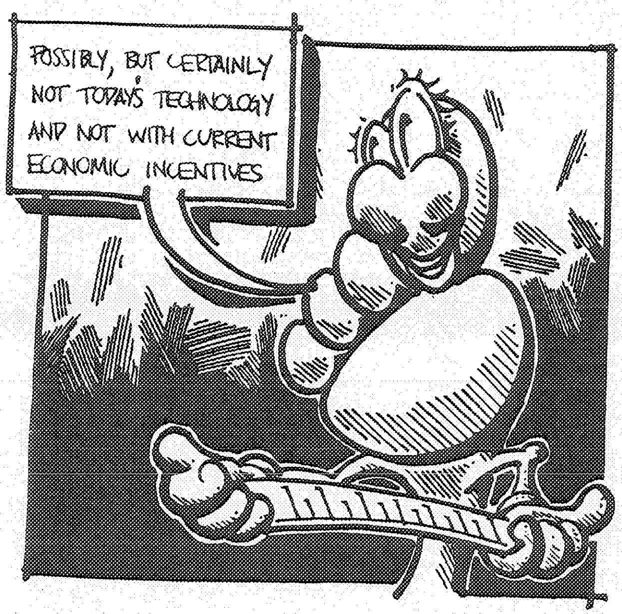
THE TECHNOLOGICAL FIX:

<u>Robot</u>: For hundreds of years people have worried that we would run out of land or resources. But no: the technological revolution has increased the abundance and lowered the prices of goods and services. Thanks to technology, a single farmer produces more than 200 farmers did 200 years ago. Thanks to



technology, millions of people in North America live more comfortably, are healthier, feel more secure and eat better than even kings and queens could dream of a few hundred years ago.

Who could have anticipated the computer revolution? Who can anticipate the future benefits of genetic engineering? For the last two hundred years, technology has successfully met the challenges of growth. Once people are faced with a problem, they will come up with a solution. Our greatest resource is the human mind, and the potential for innovation is unlimited. Just think about recent advances in medicine, transportation and communications. Why shouldn't we be able to fix any problem in the future?

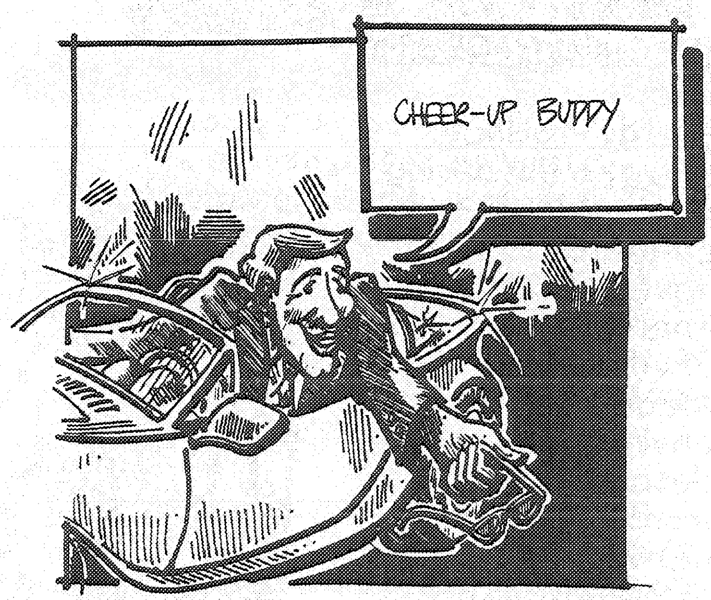


Dr. Footnote: Ecological Footprint analysis does not question the importance of technological innovation. In fact, technology will play a major role in making society more sustainable. If we really want to build a global economy five to 10 times the size of today's (as suggested by the Brundtland report), then we need technology that makes us five to 10 times more resource-efficient. Some analysts already refer to this as the "factor-10" economy (see chapter 4).

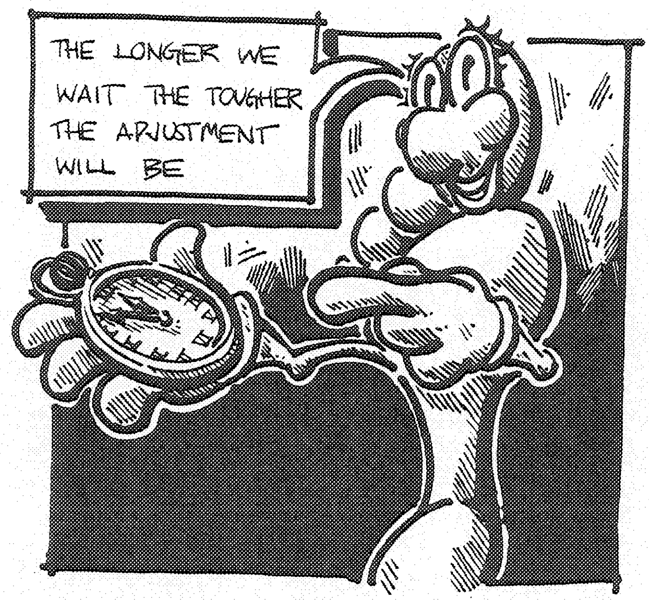
Clearly, improved technologies are essential. Even simple things like solar water heaters or better insulation in our houses can reduce our Footprint without compromising our material standards of living. However, keep in mind that many technological innovations have not reduced our use of resources, but only substituted capital — resources and machines — for labor. For example, while modern agriculture produces more output per farmer than traditional agriculture, it requires much more energy, materials and water per unit of crop produced (as the tomato example shows in Chapter 3). Also, in present circumstances, gains in technological efficiency often encourage increased consumption — more efficient cars are more economical and are consequently used more frequently by more people. Indeed, in spite of efficiency gains, most industrial countries' total energy consumption has increased in recent years. In this context, the Ecological Footprint can be an important measuring rod of progress toward sustainability. Can new technology increase or reduce society's demand on nature? It depends; if new technology is to reduce our Ecological Footprint, it must be accompanied by policy measures to ensure that efficiency gains are not redirected to alternative forms of consumption.

THE MANTRA OF OPTIMISM:

Optimist: Ecological Footprint analysis is depressing. It paints a bleak picture of the future. People like you seem to have an affinity for apocalyptic visions. Such visions have existed all through human history, but they have never come true. Why do you not look on the bright side of life? Stop to smell the roses — let's have a good time!



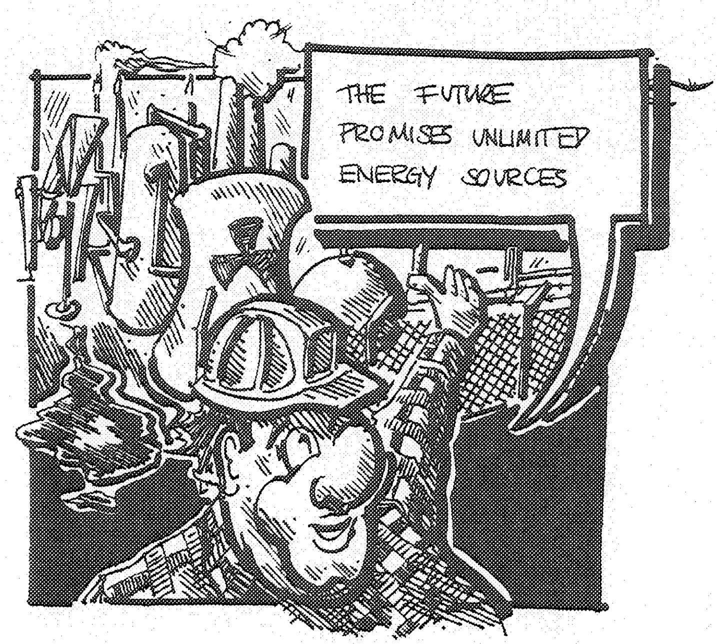
Dr. Footnote: Acknowledging that nature has a finite capacity is not pessimistic, just realistic. It makes room for wise decisions. To ignore these basic constraints would jeopardize future well-being. Ecological Footprint analysis starts from the premise that humanity must live within global



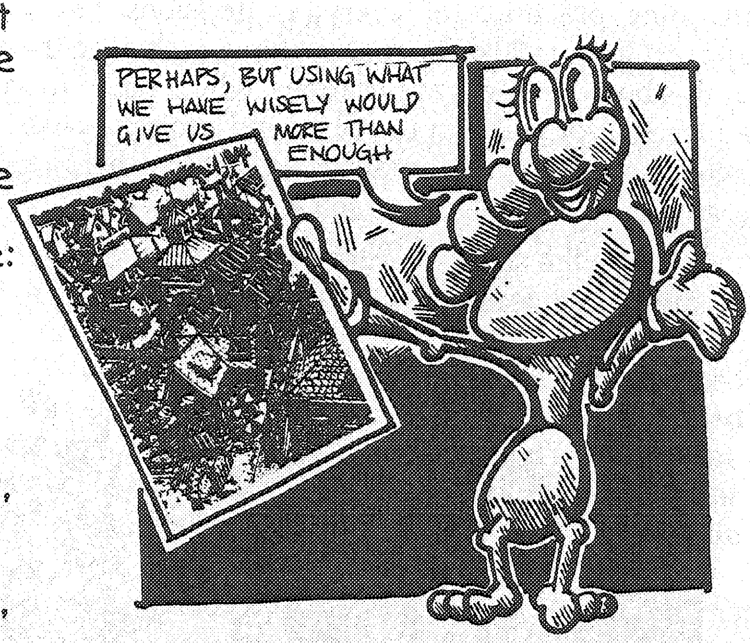
carrying capacity. It also maintains that if we choose wisely it might even be possible to increase our quality of life. Our concern is that the way we now live on the planet is self-destructive. The Footprint is a tool that facilitates learning about ecological constraints and developing a sustainable lifestyle. The earlier humanity starts to act upon the new challenges, the easier it will be.

THE GROWTH OF LIMITS:

Energy Producer:
Energy is the driving force of the human enterprise. If we have enough energy, we can do anything we like: clean up the environment, irrigate deserts, build fast transport-ation networks, power highly productive greenhouses — you name it! Today's ecological scarcity is only temporary. It won't be long before we develop



unlimited energy sources. Fusion energy is promising and we have hardly tapped into the potential for conventional fission power. And, imagine the potential if we could use all the tidal wave or solar energy that goes to waste today!



Dr. Footnote: Some people do hope that humanity will be able to harness unlimited energy supplies. In fact, we already are endowed with a huge energy source: the sun beams 175,000 terawatts to our planet, compared to just 10 terawatts of commercial energy, mainly fossil fuel, used by the human economy. However, imagine the impact of an unlimited energy supply, if not used wisely or with restraint. We've run down much of the planet with just 10 terawatts! Unlimited cheap energy could simply expand human activities further, depleting other natural capital stocks until we run into some new — and probably more severe — limiting factor. It may not be energy resources, but the waste assimilation capacity of our planet, that becomes most limiting. For example, while we used to be concerned about running out of fossil fuel, scientists now realize that CO_2 sinks are even scarcer (they're already filled to overflowing).

Of course, used with due caution, technology can help to overcome ecological scarcity. Indeed, moving toward a solar economy may be the most promising strategy for reducing our Ecological Footprint. Solar energy, with all its necessary equipment, will be more expensive, and we will use it more wisely. However, with a solar economy we should be able to secure a higher future quality of life.

Planning for a Sustainable Future

The Ecological Footprint is a tool to help us plan for sustainability. It not only addresses such global concerns as ecological deterioration and material inequity, it also links these concerns to individual and institutional decision-making. Further refinement is necessary to develop the tool's full potential for planning practitioners' everyday decisions. However, it has already been applied in over 20 different situations, including those presented as examples in this book. In these applications, which range from environmental outdoor education for children to policy and project assessments for municipalities, Ecological Footprint analysis is already helping to frame sustainability issues and solutions in Canada and several other countries.

Ecological deterioration and social injustice can be reversed — there are

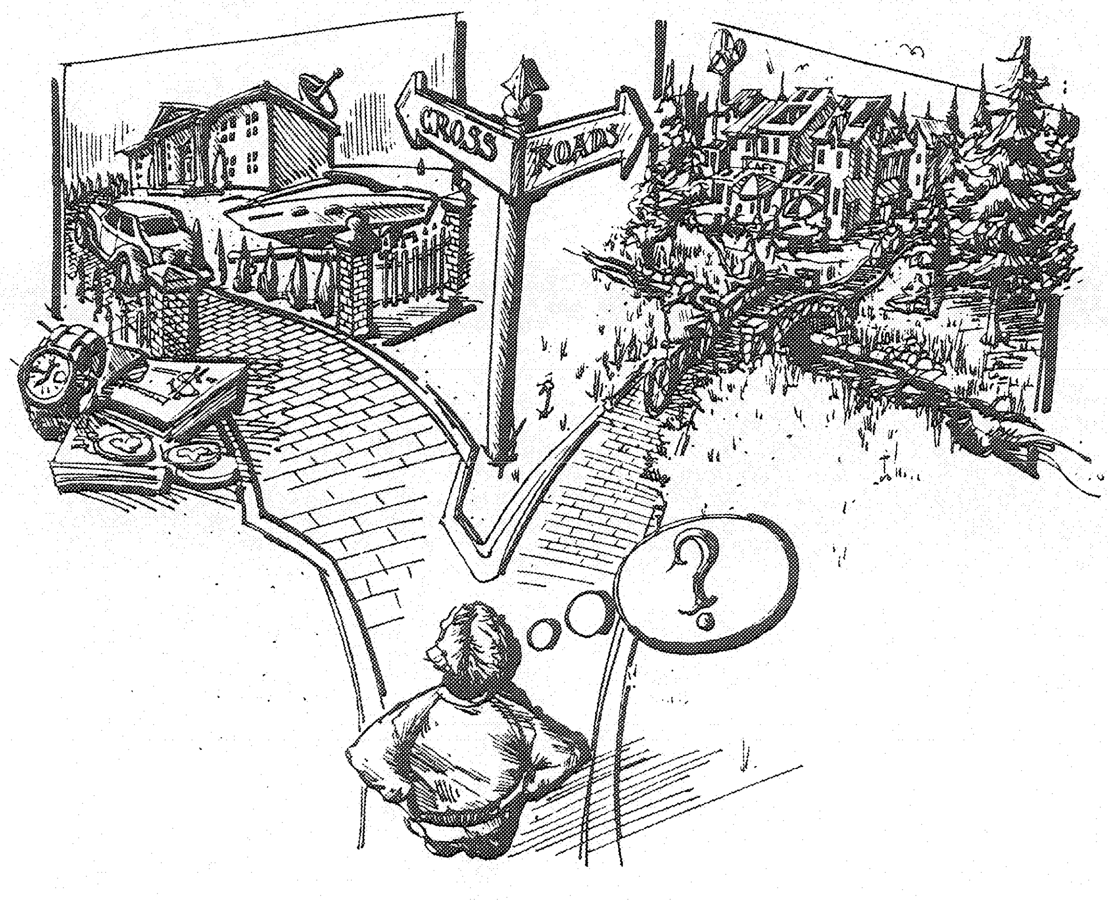


Figure 1.7: Paths We Can Choose.
What kind of future would you like and how can we get there?

thousands of conceptual tools and inspiring ideas about how to plan for a safer and more secure world. The Ecological Footprint is one of these tools. It helps us to understand both our present situation and the implications of policy choices.

Ecological Footprint analysis helps to put things in the larger perspective. To return to a previous image, we interpreted the Footprint of a city as the total area that would have to be enclosed with the city under a glass capsule to sustain the consumption patterns of the people in that city. Even without actual data, this mental image illustrates an important reality: as a result of high population densities, the rapid rise in *per capita* energy and material consumption, and the growing dependence on trade (all of which are facilitated by technology), *the ecological locations of human settlements no longer coincide with their geographic locations.* Modern cities and industrial regions are dependent for survival and growth on a vast and increasingly global hinterland of ecologically productive landscapes.

There is a small irony here — many science fiction writers have also evoked the image of a domed city, but in science fiction the device is usually needed to isolate and protect the human habitat from a hostile external environment. By contrast, our capsule experiment emphasizes that, without free access to the "environment," it is the isolated human habitat that becomes hostile to human life!

Thinking about such an encapsulated city forces us to consider not only all the ways in which we remain dependent on nature, but also on all the ways we can reduce humankind's negative impact on the systems that sustain us. For example, assume for a moment that *your* city or community is confined within a human terrarium as described above. That is, the hemisphere containing your city is just adequate to sustain the present population at prevailing material standards. Now ask yourself what the planning process and land-use bylaws might look like in the urban capsule. What sort of decision-making process would there be and who would be involved? What "trade-offs" and development costs that we currently ignore suddenly become very important? What criteria might be used to decide between private interests and the common good? To make this really interesting and more concrete, compare the desired planning process and legal regime with those currently in use in your community. Why are they different? Do these differences really make sense when we consider that the ecosphere is nothing but one big capsule containing the entire human family? The following chapters take off from here to explain how the Ecological Footprint concept contributes to building a sustainable society.

Notes

1. Michael Jacobs, *The Green Economy: Environment, Sustainable Development and the Politics of the Future* (Vancouver: U.B.C. Press, 1993) — originally published by Pluto Press in 1991.

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

finds a balance between complexity and simplicity — to be effective in guiding policy, models must be good enough to capture the essence of reality but simple enough to be understood and applied. For example, the human body temperature is a good indicator of human health. The theory that says "temperatures much over 37° Celsius are bad" is an enormous simplification, but a highly operational one — i.e., the theory is in most cases "good enough" to indicate illness. Similarly, EF analyses need not include all consumption items, waste categories and ecosphere functions to have diagnostic value.

Consistent with this approach, models concerned with the biophysical dimensions of sustainability should concentrate on understanding potentially limiting factors. Current trends suggest that the factors most likely to impose limits on human activity are certain forms of natural capital and the life-support functions they perform. In the 1970s, the limits-to-growth debate was largely concerned about the depletion of non-renewable resources such as metal ores and fossil fuel. In contrast (and ironically), a more likely bottleneck today seems to be the declining stocks of *renewable* natural capital such as fish, forests, soil and clean water. EF analysis therefore focuses on the renewable natural capital requirements of the economy and recognizes nature's capacity for self-renewal as a major limiting factor. Non-renewable resources are presently included in the Footprint only through the impacts of extraction and processing energy use and the direct occupation of land by mining infrastructure. More detailed analyses would also account for pollution effects. How we translate fossil fuel use into land equivalents is discussed below.

A *second* reason for keeping things simple is that certain ecosystem functions are analytically intractable. For example, it is difficult to quantify the connection between such generalized life-support services as global heat distribution, biodiversity and climate stability and either *per capita* demand for these services or associated ecosystem area. While these life-support services are essential for well-being and we all "consume" them, they cannot as yet be incorporated directly into the Ecological Footprint.

Calculation Procedure

As previously explained, the EF concept is based on the idea that for every item of material or energy consumption, a certain amount of land in one or more ecosystem categories is required to provide the consumption-related resource flows and waste sinks. Thus, to determine the total land area required to support a particular pattern of consumption, the land-use implications of each significant consumption category must be estimated. Since it is not feasible to assess land requirements for the provision, maintenance and disposal of each of the tens of thousands of consumer goods, the calculations are confined to select major categories and individual items.

(or ecosystem) categories.

- Are only beginning to include marine areas. Although humans already use critical marine ecosystems as intensely as the land, the sea provides a small fraction of human consumption and is less subject to policy and management manipulation than are terrestrial ecosystems (see Box 3.1).

Because of the first and second of these simplifications, our results present a conservative picture of humanity's demands on land. For example, assuming that present land uses are sustainable greatly underestimates the area of land required for truly sustainable production. High-input production agriculture typically depletes cropland soils in North America 10 to 20 times faster than they can regenerate. In other words, to compensate for soil loss, land in crop production should be left fallow for a decade or more for each year of cultivation. If we accounted for this regeneration period in our analyses, it would increase the area appropriated for crops by a factor of at least 10. Similarly, current forestry practices may not be sustainable: it is questionable whether, with current harvest practices, planned 70-year rotation periods can be sustained for more than two to three harvests. In addition, assumed yields can be maintained only if productivity is not reduced by pests or fires.[1]

We call the ratio of the land area that would be required under sustainable land-use and harvest practices to the land area that is actually required using prevailing production methods the "sustainability factor." (The sustainability factor is 10 to 20 in the agriculture example.) The magnitude of this factor is proportional to the rate of natural capital depletion and indicative of our present reliance on, and confidence in, technology (often itself based on nonrenewable resources) to maintain long-term productivity. In this sense, our Footprint estimates could be challenged as excessively optimistic. They grossly underestimate the land requirement of the economy as it would be, unsubsidized by natural capital depletion and technological inputs. Indeed, a technological pessimist would be justified in multiplying components of our EF calculations by their corresponding sustainability factors, greatly increasing the aggregate area.

Our simplified approach might also be criticized for not considering a larger variety of biophysical life-support services, particularly those that are not directly associated with land-based renewable resource production. While the scope of the present analyses is restricted, we do not think this limitation weakens the conceptual or consciousness-raising value of EF analysis for several reasons. *First*, there is virtue in accurate simplicity. However complete a theory or model purports to be, it cannot include all aspects of reality. By definition, every model is necessarily an abstraction from, and interpretation of, a more complex reality. To capture the essence of the thing it represents, a model must incorporate those key variables and limiting factors which determine and explain the behavior of that real-world entity. In short, good theory

Estimating the Ecological Footprint of a defined population is a multi-stage process. The basic structure of our approach is as follows. While the description refers to resource consumption, the same logic would apply to many categories of waste production and assimilation:

First we estimate the average person's annual consumption of particular items from aggregate regional or national data by dividing total consumption by population size. This is much simpler than attempting to estimate individual or household consumption by direct measurement! Much of the data

BOX 3.1: The Human Footprint in the Sea [2]

We have so far not included the marine area appropriated for human use in present Footprint estimates for several reasons. First, despite their vast area, the world's oceans provide only a small fraction of human direct consumption; second, despite this small contribution, the seas are already over-exploited by humans; third, there seems to be less scope for management manipulation of the seascape than of the landscape; forth, and most important, inclusion of the sea is generally not necessary for Footprint analysis to "make the case" that the total human load exceeds global carrying capacity. That said, ongoing work does include the marine area associated with seafood consumption to facilitate international comparisons and for possible incorporation into extended Footprint analysis. These studies support the findings of terrestrial Footprint analyses. Some of the factors we are taking into account are as follows:

Wild fish stocks, the dominant renewable resource from freshwater and marine ecosystems, provide less than two-and-a-half percent of the human food requirements as measured by nutritional energy content. This corresponds to about 16 percent of world consumption of animal protein. At the same time, it is unlikely that the resource yield from oceans, lakes and rivers can be much expanded economically; most fisheries are already over-harvested as humankind has become the dominant top carnivore in the sea. Indeed, the United Nations Food and Agriculture Organization (FAO) estimates that the global harvest of marine food approaches 90 percent of the theoretical maximum yield of the desirable species, if it has not reached it already. In fact, "...the *per capita* seafood supply, which peaked at 19 kilograms in 1989 and has since fallen, will be back down to 11 kilograms..." by 2030, according to Lester Brown from the Worldwatch Institute.

Some might argue that this scarcity could be overcome through fish-farming. However, fish-farming only shifts the ecological demand to other ecosystems such as the terrestrial cropland necessary to produce the feedstock for the fish farms or the water area to produce the algae that is fed to fish in the form of pellets. In fact, according to Carl Folke from the Beijer Institute in Stockholm, intensive salmon farming requires solar fixation by plankton from a sea surface area that is about 50,000 larger than the surface area covered by the farm cages.

needed for preliminary assessments is readily available from national statistical tables on, for example, energy, food, or forest products production and consumption. For many categories, national statistics provide both production and trade figures from which trade-corrected consumption can be assessed:

trade-corrected consumption = production + imports - exports

The next step is to estimate the land area appropriated *per capita* (aa) for the production of each major consumption item 'i.' We do this by dividing average annual consumption of that item as calculated above ['c,' in kg/capita] by its

It could also be argued, of course, that the oceans are used extensively as a dumping ground for waste and should be included in Footprint analysis on this basis. However, because ocean currents and upwellings produce significant material and heat exchange among all the seas of the world, the large and unknown dilution factor makes it difficult to translate waste discharges at sea into a well-defined appropriated area. In any event, bioaccumulation of toxic contaminants in food chains often renders measurements of ambient concentrations ecologically meaningless. On the other hand, because non-degradable toxic organic wastes (such as DDT and PCBs) and non-organic waste (such as heavy metals or radioactive substances) do accumulate in ecosystems, this can be reflected in EF analysis to the extent that heavily contaminated areas become unavailable for human consumption. Such contamination reduces the local "carrying capacity" available to human beings and expands the Footprint into alternative productive areas on land or sea.

For those interested in that part of the human marine Footprint associated with seafood consumption, a generalized first approximation can be calculated as follows. We start by dividing the fish catch by total productive ocean area. The maximum sustainable yield of the oceans is about 100 million tonnes of fish per year. While the seas occupy about 71 percent of the Earth's total surface (about 362 million square kilometres), less than 8.2 percent of this (or about 29.7 million square kilometres) is responsible for about 96 percent of the global fish-catch. In other words, average annual production is about 33.1 kg of fish per productive hectare or 0.03 hectares per kilogram of fish. An equal "seashare" of ocean (productive area divided by total human population) would therefore be about 0.51 hectares *per capita*, which corresponds to about 16.6 kilograms of fish per year. For comparison, Japan, one of the great fishing nations, accounts for about 12 percent of the global catch and her people consume 92 kg of fish *per capita* annually. This is about 5.4 times the estimated global maximum sustainable yield *per capita*, giving the average Japanese a marine EF approaching 2.8 ha. Clearly the whole world cannot aspire to Japan's level of seafood consumption.

Similar calculations could also be performed for freshwater fisheries.

average annual productivity or yield ['p,' in kg/ha]:

$$aa_i = c_i / p_i$$

Of course, many consumption items (e.g., clothing and furniture) "embody" several inputs and we have found it useful to estimate the areas appropriated by each significant input separately. Ecological footprint calculations are therefore both more complicated and more interesting than appears from the basic concept.

We then compute the total ecological footprint of the average person ('ef') — i.e., the *per capita* footprint — by summing all the ecosystem areas appropriated (aa_i) by all purchased items (n) in his or her annual shopping basket of consumption goods and services:

$$ef = \sum_{i=1 \text{ to } n} aa_i$$

Finally we obtain the ecological footprint (EF_P) of the study population by multiplying the average *per capita* footprint by population size (N):

$$EF_P = N(ef)$$

In some cases where the total area used is available from national statistics, we compute the *per capita* footprint by dividing by population.

Most of our footprint estimates are based on average national consumption and world average land yields. This is a standardization procedure that facilitates "general case" comparisons among regions or countries. (It is also fairly realistic for many countries given the increasing reliance on multi-lateral trade flows and appropriations from the global commons.) However, for more sophisticated or detailed analyses, it may be necessary or desirable to base the Footprint estimate on regional or local consumption and productivity statistics. With sufficient data, locally accurate EFs of consumer units as small as specific municipalities, households, and even individuals can be estimated. For example, we have sometimes found it interesting to compare the Ecological Footprint estimated from locally specific data to the "first approximation" based on national average consumption and global productivities. Such comparisons reveal the effects of regional variation in consumption patterns, productivities, and management approaches on the size of the local Footprint. They can also help identify and eliminate data gaps, errors, and apparent contradictions in the calculations.

Consumption categories

To simplify data collection, we have generally adopted data classifications used for official statistics. On this basis, we have found it useful to separate

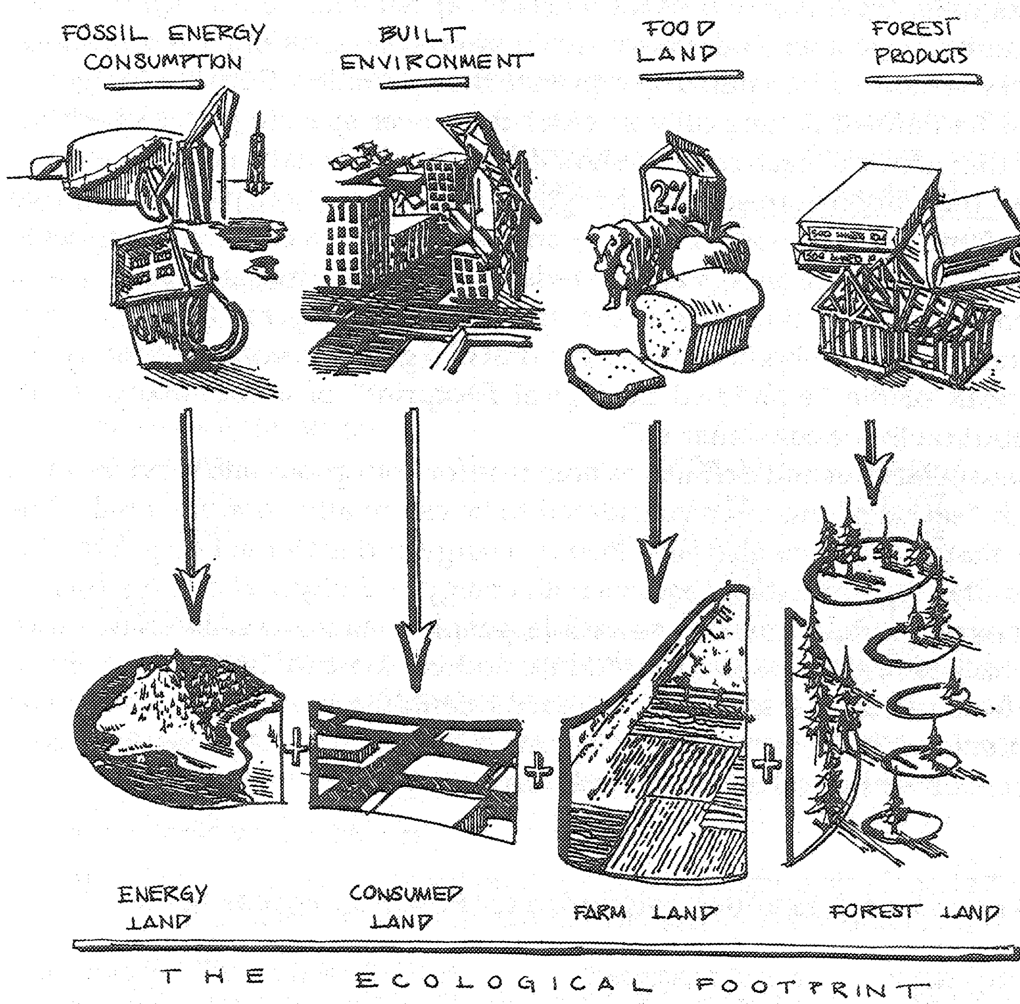


Figure 3.1: Converting Consumption into Land Area.
The production and use of any good and service depends on various types of ecological productivity. These ecological productivities can be converted to land-area equivalents. Summing the land requirements for all significant categories of consumption and waste estimates the EF for the reference population.

consumption into five major categories:

1. food
2. housing
3. transportation
4. consumer goods
5. services.

For more refined analyses, these categories can be subdivided as required. For example, the food component of the Footprint could be "assembled" by considering vegetable- and animal-based products separately. Transportation could be separated into public and private transportation. Such subcategories should be defined strategically in order to answer specific policy questions about that item. For each consumption item, a detailed analysis would encompass all the embodied resources that go into the production, use and disposal of that item. The "embodied" energy and resources of a commodity refers to the total quantities of energy and material that are used during the life cycle of that commodity for its manufacture, transport and disposal. "Energy intensity" refers to the embodied energy per unit of a good or service. Similarly, we can speak of the "embodied Ecological Footprint" of a commodity as its contribution to the consumer's EF.

These principles and definitions hold true for both goods and services, even though "services" are often considered to be essentially "non-material." The fact is that services are also sustained by energy and material flows. Even the transmittal of information requires both energy and physical carriers such as paper or wires and, to make it accessible, people need material interfaces such as screens or radios. Banks may produce nothing material but all their operations from money transactions, through the computerized generation of bank statements, to the construction and operation of bank buildings and infrastructure consume physical energy and resources.

Table 3.1:
The 8 main land & land-use categories for Footprint assessments

I) energy land:	a. land "appropriated" by fossil energy use	(ENERGY OR CO_2 LAND) **Note:** If we opt for fuel crops,this would remove some land from categories *c*, *d*, *e* or *f*.
II) consumed land:	b. built environment	(DEGRADED LAND)
III) currently used land:	c. gardens	(REVERSIBLY BUILT ENVIRONMENT)
	d. crop land	(CULTIVATED SYSTEMS)
	e. pasture f. managed forest	(MODIFIED SYSTEMS)
IV) land of limited availability:	g. untouched forests	(PRODUCTIVE NATURAL ECOSYSTEMS)
	h. non-productive areas	(DESERTS, ICECAPS)

Table 3.2: Productivity of various energy sources.
The energy Footprint varies inversely as the productivity of an energy source: the higher the productivity, the smaller the Footprint.

Energy Source	Productivity [in Gigajoules per hectare per year].	Footprint for 100 Gigajoules per year [in hectares]
Fossil fuel		
ethanol approach	80	1.25
CO_2 absorption approach	100	1.0
biomass replacement approach	80	1.25
Hydro-electricity (average)	1,000	0.1
lower course	150-500	0.2-0.67
high altitude	15,000	0.0067
Solar hot-water	up to 40,000	0.0025
Photovoltaics	1,000	0.1
Wind energy	12,500	0.008

Numerous sources can be used to quantify direct consumption and associated embodied resources. Statistics on waste streams, household and national expenditure, metabolic rates, diets, trade and resource flows can be consulted — and checked, one against the other (see Box 3.2).

Land and land-use categories

Our EF calculations are based on the following eight major land categories (Table 3.1). This classification is similar to that used by The World Conservation Union (IUCN).[3]

The "energy land" component of the EF can be computed in several ways (see below). Some methods estimate the area that would be required to grow fuel crops to replace our depleting stocks of fossil energy. If this notion seems far-fetched, keep in mind that fossil fuels are the product of ancient photosynthesis and the accumulation of biomass in forests and swamps that grew over much of the Earth's surface millions of years ago. William Catton therefore refers to these lands as "phantom land." The ecosystems are long gone but, in effect, we are still using them — or at least their productivity — today.[4] Catton points out that humanity is using this former productivity thousands of times faster than it accumulated and that nature is not able to replace it. In the absence of contemporary managed terrestrial carbon sink reserves, we are imposing a burden on future generations: less carbon-based energy stocks and elevated levels of atmospheric CO_2. In other words, we are using two kinds of natural income and liquidating critical natural capital without replacement or compensation.

Not all categories of ecologically productive land are equally accessible or directly harvestable by humans. Certainly, given growing concerns about climate change, we should approach category *'g'* with great caution. This category represents virgin forest ecosystems whose harvest would lead to a massive net CO_2 release that would be recovered only after 200 years of subsequent ecological production on this land.[5] Some of these forest lands are still accumulating carbon and also serve as biodiversity refuges that should not be disturbed. Land in category *'h'* includes deserts and ice-fields such as the Sahara and Antarctica and is regarded as ecologically unproductive for human purposes.

The remaining land categories provide a variety of goods and services (natural income) in support of human activities, from the provision of commercial energy, through space for cities and the absorption of waste, to the preservation of biodiversity. Here is how we convert these services to their land area equivalents for EF analysis.

BOX 3.2: Data Sources for Ecological Footprint Analyses

There are many sources of data for Footprint analyses. For approximate comparisons, a compendium such as the biannual report of the World Resources Institute may be sufficient. However, international statistics often focus mainly on production and trade, omitting consumption, and are often in dollars (rather than biophysical units), which decreases their usefulness. The list below maps the diversity of possible data sources that can be used for Footprint calculations. Please let us know if you come across good additional sources!

Global and National Statistics

- » Food and Agriculture Organization of the United Nations or FAO (*The State of Food and Agriculture; FAO Yearbook: Trade; FAO Yearbook: Production*, all annual)
- » International Road Transportation Union or IRTU (*World Transportation Data*, annual)
- » United Nations Development Program or UNDP (*Human Development Report*, annual)
- » The World Bank (*World Development Report*, annual)
- » World Resources Institute or WRI (*World Resources*, biannual, also available on computer disk)
- » Worldwatch Institute (*State of the World*, *Vital Signs*, both annual, the latter also available on computer disk)
- » United Nations statistics
- » Government publications with national statistics on:
  - Consumption, Economic Production and Trade
  - State of the Environment

i) Land requirements for commercial energy. This section discusses the land "use" implications of consuming fossil fuel, hydroelectricity and other renewable energy sources (Table 3.2).

Most of the energy on which human life depends comes from the sun. In fact, life on Earth is powered by a solar flux of about 175,000 terawatts. One terawatt is one trillion (or 1,000,000,000,000) watts or joules per second. This is the same energy required to lift one million tonnes 100 metres every second. In comparison, a standard light bulb radiates 60 watts of heat and light.

The commercial energy flow through the human economy amounts to "only" 10 terawatts. However, if we had to produce these 10 terawatts of commercial energy using contemporary photosynthesis we would need an enormous area of land: of the 175,000 solar terawatts, fewer than 150 are transformed into plant biomass by photosynthesis ("Net Primary Productivity"). Only a small fraction of this can be harvested and still a smaller fraction converted to useful fuel.

In the following discussion, the *energy-to-land* ratio describes how much

- Transportation
- Land-use
- Housing
- Energy
- Agriculture and Forestry

Reference and Handbooks:

» Engineering, ecology, resource management and agricultural handbooks
» Professional handbooks on topics such as agriculture, biological resources, energetics, chemistry, etc.
» Handbooks on energetics and life cycle analysis
» Handbooks on ecological cycles and biological productivity (e.g., carbon cycle, Net Primary Productivity)
» Transportation handbooks
» Engineering handbooks on the energy aspects of housing, transportation, chemical processes, technological efficiency, etc.
» Household ecology guides
» Encyclopedias, yearbooks and almanacs
» Cookbooks (for nutritional value of food, cooking energy, etc.)

Research Papers

» Reports in the popular and scientific press on consumption, energy efficiency, ecological productivity, etc.
» Special issues reports by Non-government Organizations (NGOs), government agencies, institutes (e.g., Greenpeace reports on cars, paper consumption).

commercial energy per year could be provided by one hectare of ecologically productive land. The units used are gigajoules per hectare per year, or GJ/ha/yr. One gigajoule stands for one billion joules; 1,000 gigajoules per second is equal to one terawatt.

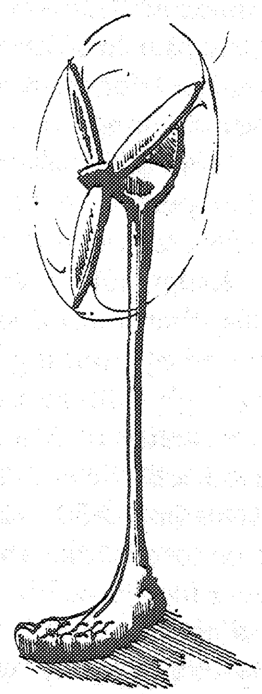
We have used three approaches to converting **fossil energy** consumption into a corresponding land area. Each is based on a different rationale, but all produce approximately the same results — the consumption of 80 to 100 gigajoules of fossil fuel per year corresponds to the use of one hectare of ecologically productive land.

The *first method* calculates the land required to produce a contemporary biologically-produced substitute for liquid fossil fuel. In effect, this is the area of land needed to bring Catton's "phantom land" back to life. This approach reasons that a sustainable economy requires a sustainable energy supply, i.e., it should not be dependent on depletable fossil capital. Moreover, if the fuel is carbon-based it is preferable to use carbon that is already cycling actively in the ecosphere rather than carbon that has been stored for millennia in an inactive pool. This approach avoids further CO_2 accumulation in the atmosphere.

Ethanol is one such potentially renewable energy carrier that is technically and qualitatively equivalent to fossil fuel. It is a homogeneous, concentrated fuel that can easily be stored and transported, and can power human processes the same way fossil hydrocarbons do. For these reasons it is already being used in some places as a supplement to gasoline. The land area corresponding to fossil fuel consumption can therefore be represented as the productive land necessary to produce the equivalent amount of ethanol. This area comprises land needed to grow the plant material (biomass) for both the ethanol fuel and the necessary processing energy. The most optimistic estimates for ethanol productivity suggest a net productivity of 80 gigajoules per year per hectare of ecologically productive land. [6]

Methanol is another possible substitute for fossil fuel. Calculations suggest that each kilogram of wood distilled would yield 10.5 to 13.5 megajoules of methanol. (One megajoule corresponds to one million joules or one thousandth of a gigajoule.) New Zealand tree plantations, at 12 tonnes of wood per hectare per year, are among the world's most productive "forests" and would yield a land-for-energy ratio of 120 to 150 gigajoules per hectare per year. However, the productivities typical of Canadian, Russian or Scandinavian, forests would yield only 17–30 gigajoules per hectare per year (approximately 55–68 in the U.S.).[7]

The *second method* estimates the land area needed today to sequester the CO_2 emitted from burning fossil fuel. The argument for this approach is that fossil carbon (in the form of CO_2) cannot be allowed to accumulate in the atmosphere if we wish to avoid possible climate change. If we continue to consume excessive quantities of fossil fuel we have a responsibility to manage its waste



products. This approach requires that we calculate the amount of "carbon sink" land required to assimilate the fossil CO_2 that we are injecting into the atmosphere.

Forest ecosystems and peat bogs are among those natural systems that can be significant net assimilators of CO_2. Young to middle-aged forests accumulate CO_2 at the highest rate over a 50- to 80-year time span. Data on typical forest productivities of temperate, boreal and tropical forests show that average forests can accumulate approximately 1.8 tonnes of carbon per hectare per year.[8] This means that one hectare of average forest can sequester annually the CO_2 emission generated by the consumption of 100 gigajoules of fossil fuel.

The *third method* of converting fossil energy use into a corresponding land area estimates the land area required to rebuild natural capital at the same rate as fossil fuel is being consumed. This builds on an argument put forward by World Bank economist Salah El Serafy.[9] If we accept that a society is not sustainable if its economy depends on the depletion of real wealth (natural capital), then any society using non-renewable resources should invest a portion of the revenues so generated in building up an equivalent value of manufactured capital or renewable resource assets. This approach — replacing what is consumed — addresses directly the constant capital stocks criterion for sustainability, which recognizes that equity between generations is a precondition for sustainability. Calculations show that one hectare of average forest could accumulate about 80 gigajoules of recoverable biomass energy per year in the standing timber. In other words, if we assume that depleted natural capital must be replaced, the land-for-energy ratio amounts to 80 gigajoules of biomass energy per hectare per year. (Once economic reserves of fossil fuels are used up and we start cropping the energy land, this method converges with the first.)

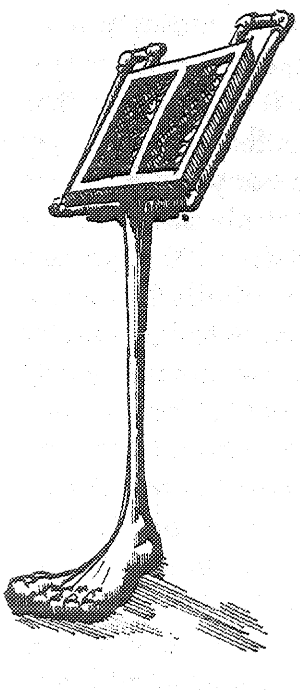


Figure 3.2: The Use of Renewable Energy sources can make a major contribution to reducing our Ecological Footprints.

The CO_2 assimilation method results in the smallest EF attributable to fossil fuel consumption. Many reviewers felt that this approach would enjoy the highest public acceptance. It implies no radical shift from fossil fuels yet accepts the need to stop greenhouse gas accumulation. Therefore, we chose **one hectare per 1.8 tonnes of carbon emitted each year (one hectare per 100 gigajoules per year)** from the CO_2 method as the land-for-energy ratio for fossil fuel. We use this ratio in all current EF assessments.

Note that if electricity is generated from fossil fuel with a typical efficiency of 30 percent, the EF per unit of end-use energy is over three times larger than if the fossil fuel were used directly.

Renewable energy sources provide much higher productivities (smaller EFs) than fossil fuel. For **hydroelectricity**, the area requirements can be estimated by dividing the flooded land behind dams, plus the land area occupied by high voltage power line corridors, by its annual electricity production. University of Manitoba Geographer Vaclav Smil suggests hydroelectricity productivities of 160 to 480 gigajoules per hectare per year for lower-course dams (in the 50 to 200 megawatt size), 1,500 to 5,000 gigajoules per hectare per year for middle- and upper-course dams, and 15,000 gigajoules per hectare per year for alpine high-altitude dams. Similarly, Michael Narodoslawsky and his colleagues at the Technical University of Graz, Austria estimate the productivity of typical hydro-power stations at about 1,500 gigajoules per hectare per year (not including the space requirements of power lines). Including powerlines would reduce this ratio to approximately 1,000 gigajoules per hectare per year. In contrast, David Pimentel and his team from Cornell University calculate an average hydroelectric productivity of only 47 gigajoules per hectare per year for the U.S., ranging from 4.5 gigajoules per hectare per year for lower-course systems up to 7,300 gigajoules/ha/yr. for high-altitude dams. (These latter data suggest that hydro plants that would yield less than 100 gigajoules per hectare per year — typical for biofuel — might be ecologically inefficient, particularly as dams in the lowlands flood areas of high ecological productivity.)[10] All these data indicate that a land-for-energy ratio of one hectare for each 1,000 gigajoules of continuous generating capacity would not be unreasonable for general EF calculations. (Note that this still does not account for other negative ecological effects such as impact on fisheries.) These Footprint areas would fall into the built environment category. However, when corridor land is made available for pasture, care should be taken to avoid double counting.

To date we have not included hydroelectricity consumption in our EF calculations. However, a preliminary estimate for Canada yields the following: according to the World Resources Institute, in 1991 Canada produced 1,111 petajoules (or 1,111 million gigajoules) of hydroelectricity.[11] At a land-for-energy ratio of one hectare per 1,000 gigajoules per year, this would add another 0.04 hectares to the average Canadian's Footprint for flooded land and transmission lines.[12]

Other forms of renewable energy reach quite impressive yields. Preliminary analysis suggests that large-scale **photovoltaic electricity** might produce

100 to 1,000 gigajoules per hectare per year, confirmed by the experience of a 2 hectare photovoltaic plant in the Swiss Alps, which delivered in its first year of operation about 1,000 gigajoules of electricity per hectare to the power grid.[13] Other examples of renewable energy production include wind generation in America's windiest places, which might score between 250 and 500 gigajoules per hectare per year. If we consider that the physical footprints of windmills occupy only two percent of the wind-farm area, allowing some other functions on the land, the productivity of the windmill rises to 12,500 to 25,000 gigajoules per hectare per year. Well-designed low-temperature solar collectors (for domestic hot water applications) can achieve 10,000 to 40,000 gigajoules per hectare per year.

It is important to recognize not only that in many areas the use of renewable energy sources such as photovoltaic cells, windmills and hot water solar collectors would significantly reduce the fossil fuel components of our present EFs, but also that these sources do not themselves require any direct use of ecologically productive land.

We do not incorporate **nuclear energy** in current EF assessments. On the surface, nuclear energy needs little space. In fact, including the complete fuel cycle of mining, processing of uranium ores, uranium enrichment, production of fuel elements, reprocessing of spent fuel, and storage of radioactive wastes, and *assuming no accidents*, each hectare occupied produces over 50,000 gigajoules per year. In other words, the productivity of well-functioning nuclear power plants seems to exceed that of the most efficient ethanol technology by two to three orders of magnitude. However, if we consider the impact of accidents — lost bioproductivity and contaminated land — the tables turn. In the case of Chernobyl, we estimate that energy productivity decreased to less than 20 gigajoules per hectare for the years immediately following the accident. In any event, the shattered popular trust in nuclear safety, the fact that peaceful use and military applications are interwoven, and the seemingly unsolvable problem of radioactive waste — which becomes an irresponsible burden for future generations — suggest that nuclear power is not a viable energy option today.

ii) Accounting for built-up land. Paved-over, built upon, badly eroded or otherwise degraded land is considered to have been "consumed" since it is no longer biologically productive. This means that total future bioproductivity has been reduced. As demand increases, it may become necessary to upgrade inferior land elsewhere to compensate for this lost productivity.[14] An additional debit would then be charged against the degraded land account for the energy, material and time expended to restore its productivity. (Economists generally overlook the fact that the substitution of human-made capital and labor for depleted natural capital and its functions carries an opportunity cost in the form of reduced economic productivity — the necessary expenditures are not available for other forms of investment or consumption.)

iii) Provision of water. In many regions of the world, the consumption of fresh water for human use compromises other possible use of this water or of the land required to "collect" it. In addition, energy and material is consumed in transporting the water. Thus, depending on the source of the water, EF analysis should account for the opportunity cost of water withdrawal and the energy costs of transporting the water. (The additional land needed to compensate for lost ecological productivity at the source may show up in the agricultural [crop- and pastureland] accounts, for example.) Catchment areas for water should also be included to the extent that water collection can be separated from other bioeconomic functions of the catchment area (otherwise, it would lead to double counting). In drier areas, these catchment areas can be of substantial size. For example, in Australia, for every city dweller about 0.27 to 0.37 hectares of land are set aside for water collection.[15]

iv) Absorption of waste products. Nature's capacity to absorb human-made waste is finite. However, substantial flows of nutrients and domestic organic wastes, if adequately distributed, can be broken down and the by-products recycled by local ecosystems with little exclusive addition to the EF. (Only the land required for pre-release sewage treatment facilities need be included. Nature's final processing of the residuals takes place in waters or on lands used and counted in the EF for other purposes.) On the other hand, what cannot be degraded and assimilated accumulates locally, or is carried away by water and air only to accumulate elsewhere, in the sea, or in global food chains. Contamination of soil, water, and airsheds may reduce productivity or contaminate the products of nature to the extent that they become unfit for human consumption. Where significant, these land and productivity losses should become part of the waste disposal Footprint. Similarly, to the extent that depletion of the atmospheric ozone layer eventually reduces bioproductivity (through damage to photosynthesis by increased UV_B radiation), this loss should be added to the EF area. In our EF examples to date, we have not accounted for waste absorption and pollution damage with the exception of the major contribution from CO_2 sequestering.

v) Protecting biodiversity. Biodiversity is threatened by the irreversible loss and fragmentation of wilderness areas on all continents. There is an ongoing debate about how much wilderness should be set aside, and in what configuration, to secure both adequate biodiversity and global ecological stability. Ecologist Eugene Odum has suggested that a third of every ecosystem type should be preserved to secure biodiversity. The Brundtland Commission proposed, seemingly arbitrarily, that at least 12 percent of the Earth's land area (or about 2 billion hectares) should be set aside for this task. The fact is, we have little idea how much natural habitat is required for the survival of other species, let alone to ensure our own ecological security. To what extent do modified and heavily exploited ecosystems such as well-managed forests conserve biodiversity and provide basic life-support functions? As noted, land category *h* refers to the about 1.5 billion hectares of nearly untouched forest ecosystems that both serve as a substantial carbon pool and provide habitat to the bulk of the Earth's species.[16] These 1.5 billion hectares correspond to just 9 percent of the Earth's terrestrial area, only one third of which is under protection; given current uncertainties and the scale of the potential hazard, ordinary prudence and the precautionary principle argue that this area should be left intact for the sake of global security.

The consumption — land-use matrix

Once the main consumption and land-use categories are defined, the connection between each consumption category and its land requirements must be established using the calculation procedure described above. The data are then assembled in a matrix that links consumption (rows) with land-uses (columns) (Table 3.3). Each of the data cells in the matrix represents a particular consumption item in terms of its corresponding "appropriated" land area.

The rows are divided into our five categories of consumption: food, housing, transportation, consumer goods and miscellaneous services. Note that the data for each category reflect not only the space directly occupied by individual consumption items (where relevant) but also the land "consumed" in producing and maintaining them. In effect, this becomes a life cycle analysis of the land implications of consumption. The housing category, for example, encompasses the land on which the house stands (including a proportionate share of urban land occupied by infrastructure), the land necessary to grow lumber for the house (or, alternatively, the energy land associated with producing bricks), and the energy land appropriated for space heating.

As in Table 3.1, the columns of the matrix are identified with the letters A to F, each representing one type of land-use. Column A represents the fossil energy land-equivalent for each consumption item using a land-for-energy ratio of one hectare per 100 gigajoules per year. Column B indicates the amount of built-over and degraded land. Column C shows garden-land, the area used mainly for vegetable and fruit production. (Typically, this land has the highest ecological productivity.) Column D contains other cropland, and column E the pastureland used for dairy, meat and wool production. Finally, column F includes the land committed to providing forest products. The TOTAL column shows aggregate land "occupancy" by each consumption category.

The Footprint data in Table 3.3 are based on global average ecological productivities. As noted above, this provides a reasonable approximation for several reasons. *First*, it reflects the increasingly diffuse real-world relationship between local consumption and corresponding global production. Many industrial urban communities depend little on local ecological productivity —

the ingredients of most of their consumption items typically originate in distant regions all over the world. *Second*, having a globally-adjusted measurement unit enables easy international comparisons of consumption impacts. *Third*, it facilitates accounting while not distorting the aggregates. Thus, if for some reason we wished to compare a given population's EF computed on the basis of global average productivity with the EF it might have based on the quality of locally available land, productivity adjustments to land area must be made. For example, if agricultural land in a particular region is twice as productive as the world average, a hectare of the local land would correspond to two hectares of average land and the EF based on local productivity would shrink accordingly. Of course, the sum of all such regionally-adjusted land areas would be equivalent to the globally available productive land area.

To reiterate, the calculation procedure described is conceptually simple and easy to perform. While an Ecological Footprint analysis could be done from scratch with detailed data on an individual's or a community's consumption patterns, we generally begin with aggregate (e.g., national or provincial/state) data. The analysis can later be elaborated with more detailed data on specific communities, regions, or even individual technologies, as necessary or useful.

The strength of the EF analysis is its ability to communicate simply and graphically the general nature and magnitude of the biophysical "connectedness" between humankind and the ecosphere. In a single index, the Ecological Footprint captures the essence of humankind-nature relationships as manifested through consumption. As explained in the preceding chapter, EF calculations are static. They provide an ecological snapshot of economy-land relationships at a particular point in time. However, historical trends can be captured by reconstructing the EF for a series of such points. It thus provides a starting point either for more detailed analysis of specific problem areas or for discussion of the broad policy implications for sustainable development.

The Ecological Footprint approach is sometimes wrongly criticized for disregarding the effects of technological improvements. The argument is that the EF of a population could be reduced if technology is able to substitute for certain resources or if efficiency gains enable us to enjoy equivalent or higher material standards with fewer resources. Either improvement could potentially decrease aggregate material consumption. Indeed, it is sometimes argued that massive efficiency gains could effectively "decouple" growth in *per capita* GDP from nature. (There is a growing literature on "eco-efficiency." However, see Box 4.1 for some of the counter-intuitive effects of efficiency strategies.)

It is true that EF analysis does not produce a dynamic picture of changing conditions. However, far from ignoring technology, EF analysis allows us to compare current ecological requirements and constraints with those that would result if specified technological improvements were widely implemented. For example, it would graphically reveal the effects on carrying capacity of a significant shift from fossil fuels to solar energy. And, through the use of time series, EF analysis can even provide a dynamic picture of changing conditions. Indeed, by showing the dependence of the economy on natural capital/income under any specified set of conditions, EF analysis provides an incentive to improve, an estimate of how far we have to go to achieve sustainability (the "sustainability gap"), and a yardstick to monitor the economy's progress toward reducing its load on nature. The latter could be achieved through technological decoupling *or* changing values — either would result in decreased material consumption.

The Footprint in Action: Adapting the Calculation Procedure to Specific Applications

After theory comes action. This section shows how the EF concept is applied using real data: we derive a detailed estimate of the average Canadian's Footprint and describe 16 other applications more briefly. In order not to overload the reader with numbers and statistics, we provide only summary results of these applications.

Since EF analysis can be applied at various scales (individual, household, region, nation, world), the first task is to define the population or economy whose appropriated carrying capacity we wish to estimate. We should keep in

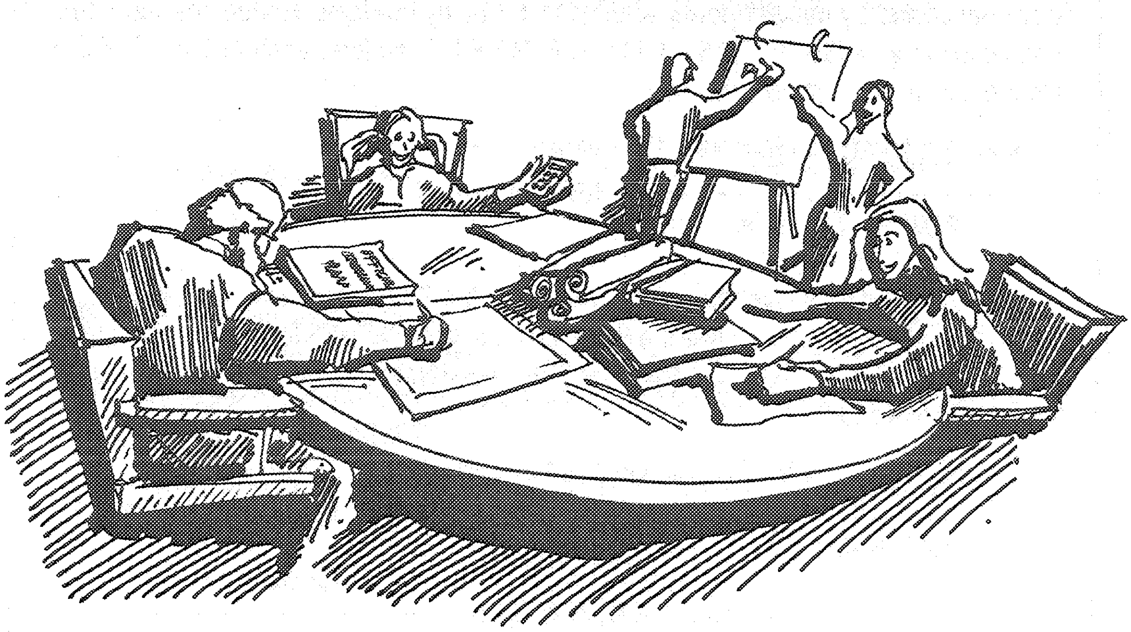


Figure 3.3: Figuring Out Footprints is Fun. With a pocket calculator and a few statistical books such as *World Resources* we are ready to calculate some simple Footprint examples.

mind, however, that the basic EF results are most interesting and useful in comparative analyses. For example, we might wish to contrast a given population's Ecological Footprint with the land area that is actually available in that population's home region, or with the hypothetical Ecological Footprints that might result from changes in the population's lifestyle. How we intend to use the analysis will affect our data requirements. Let's get started.

1) How big is the Ecological Footprint of the average North American?

"So, how big *are* people's Footprints?" This is one of the first questions people ask when introduced to the EF concept. As noted in Chapter 1, the answer depends on such factors as income, personal values and behavior,

BOX 3.3: Some Examples: Translating Consumption into Land Areas

Example 1: fossil energy consumption and carbon sinks

Question: How much ecologically productive land (i.e., carbon sink forest) would be required to sequester all the CO_2 released by the average Canadian's consumption of fossil energy? (See "total" in Column A of the consumption – land-use matrix [Table 3.3].)

The World Resources Institute reports that Canada's total commercial energy consumption was 8,779 petajoules (PJ or million gigajoules) in 1991. Of this amount, 926 PJ were generated by nuclear power and 1,111 PJ by hydro-dams. Hence, the fossil fuel consumption was (8,779 - 926 - 1,111 =) 6,742 PJ. Therefore, each of the 27 million Canadians in 1991 would consume...

$$\frac{6{,}742{,}000{,}000\ [\text{GJ/yr.}]}{27{,}000{,}000\ [\text{Canadians}]} = 250\ [\text{GJ/year}]\text{ of fossil fuel.}$$

However, Statistics Canada reports a figure of 234 GJ *per capita* per year. Wishing to err on the side of caution we use the Statscan data. With the land-for-energy conversion ratio for fossil fuel of 100 GJ/ha/yr., the land requirement for the average Canadian therefore comes to...

$$\frac{234\ [\text{GJ/cap./yr.}]}{100\ [\text{GJ/ha/yr.}]} = 2.34\ [\text{ha/cap.}]\text{ for sequestering the } CO_2 \text{ released by this fossil fuel.}$$

Key: PJ = petajoules; GJ = gigajoules; /cap. = *per capita*; ha = hectares; t = tonne consumption patterns, and the technologies used to produce consumer goods. There is, therefore, wide variation in Footprint size both among countries and individuals around the world. We can illustrate these points by summarizing our detailed calculations for the average Canadian's Ecological Footprint (Table 3.3) and contrasting the result with those for several other countries (Table 3.4). Note that while U.S. consumption patterns are roughly similar to Canada's *per capita* totals, their average Ecological Footprints are larger.

As noted, estimating the area of ecologically productive land needed to produce the natural resources and services used by an average Canadian involves several major steps: first we compile annualized statistics on five major categories of consumption and waste production and divide the totals

Example 2: productive forest area for paper

Question: How much forest area is dedicated to providing pulp-wood for the paper used by the average Canadian? (This corresponds to the cells "**f1**" (food wrappings), "**f40**" (packaging), "**f43**" (reading material) and the paper component of some of "**f2**" (household and construction paper) in the matrix of Table 3.3.)

Each Canadian consumes about 244 kilograms of paper every 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...

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

Example 3: urban environment

Question: How large is the average Canadian's share of the nation's "built environment" (includes roads, residences, commercial and industrial areas, and parks — see "total" in Column '**b**,' Table 3.3)?

The World Resources Institute reports 5,500,000 hectares of built-up land in Canada. Therefore, Canadians occupy...

$$\frac{5{,}500{,}000\ [\text{ha}]}{27{,}000{,}000\ [\text{Canadians}]} = 0.20\ [\text{ha/capita}] \text{ of built-up land.}$$

Table 3.3: The consumption — land-use matrix for the average Canadian (1991 data)

Cell entries = ecologically productive land in [ha/capita]	A ENERGY	B DEGR.	C GARDEN	D CROP	E PASTURE	F FOREST	TOTAL
1 FOOD	**0.33**		**0.02**	**0.60**	**0.33**	**0.02**	**1.30**
11 fruit, vegs., grain	*0.14*		*0.02*	*0.18*		*0.01?*	
12 animal products	*0.19*			*0.42*	*0.33*	*0.01?*	
2 HOUSING	**0.41**	**0.08**	**0.002?**			**0.40**	**0.89**
21 constn./maint.	*0.06*					*0.35*	
22 operation	*0.35*					*0.05*	
3 TRANSPORTATION	**0.79**	**0.10**					**0.89**
31 motorized private	*0.60*						
32 motorized public	*0.07*						
33 transp'n of goods	*0.12*						
4 CONSUMER GOODS	**0.52**	**0.01**		**0.06**	**0.13**	**0.17**	**0.89**
40 packaging	*0.10*					*0.04*	
41 clothing	*0.11*			*0.02*	*0.13*		
42 furniture & appli.	*0.06*					*0.03?*	
43 books/magazines	*0.06*					*0.10*	
44 tobacco & alcohol	*0.06*			*0.04*			
45 personal care	*0.03*						
46 recreation equip.	*0.10*						
47 other goods	*0.00*						

5 SERVICES	**0.29**	**0.01**					**0.30**
51 gov't (+ military)	*0.06*						
52 education	*0.08*						
53 health care	*0.08*						
54 social services	*0.00*						
55 tourism	*0.01*						
56 entertainment	*0.01*						
57 bank/insurance	*0.00*						
58 other services	*0.05*						
TOTAL	**2.34**	**0.20**	**0.02**	**0.66**	**0.46**	**0.59**	**4.27**

(0.00 = less than 0.005 [ha] or 50 [m^2]; blank = probably insignificant; ? = lacking data)

ABBREVIATIONS

a) ENERGY = **fossil energy consumed** expressed in the land area necessary to sequester the corresponding CO_2.
b) DEGR. = **degraded land** or built-up environment.
c) GARDEN = **gardens** for vegetable and fruit production.
d) CROP = **crop land.**
e) PASTURE = **pastures** for dairy, meat and wool production.
f) FOREST = prime **forest** area. An average roundwood harvest of 163 [m^3/ha] every 70 years is assumed.

for items in these categories by total population to determine average levels. (Consumption includes: direct household consumption; indirect consumption such as the energy "embodied" in consumer goods; and consumption by businesses and government, which ultimately benefits the households. Services refers to schooling, policing, governance or health care.) Second, we convert these data on average consumption ("ecological load") into their corresponding land areas based on the ecological productivity of relevant ecosystem types. The average Canadian's Ecological Footprint is then obtained by summing the land requirements for the various consumption/waste categories. Since this area represents that portion of planetary productivity needed to support a single individual we sometimes refer to it as the average "personal planetoid." The results of these calculations are summarized in the consumption – land-use matrix shown in Table 3.3.

It seems that Canadians are formidable consumers! For example, on average, each Canadian eats about 3,450 kilocalories worth of food each day, 1,125 in the form of animal products. Most of this food is produced by energy-intensive agriculture and is highly processed before it reaches the dinner table. According to the World Resources Institute, Canadian settlements cover about 55,000 square kilometres — 0.2 ha *per capita* — and have been built mainly on agricultural land. On average, Canadians drive a car 18,000 kilometres per year, use approximately 200 kilograms of packaging, spend about $2,700 on consumer goods and another $2,000 on services. Energy and material consumption in Canada is typically four to five times the world average and, in most categories, the average American's consumption is even higher (see Table 3.4).[17]

Every year approximately 320 gigajoules of commercial energy are needed to power the average North American's activities, including the energy embodied in consumer goods and services. This is equivalent to the energy in 10 cubic metres of gasoline and, indeed, most of this energy is from fossil sources. The World Resources Institute reports that Americans use 287 gigajoules and Canadians 250 gigajoules of fossil energy *per capita* per year.[18] (Canada uses a larger percentage of hydroelectricity.) In Table 3.3 we account for only the fossil fuel part of the commercial energy consumption.

Government statistics provide a breakdown of energy consumption by economic sector. However, using these statistics directly for Footprint calculations may distort our picture of energy consumption at the household level because of the energy content of trade goods. The embodied energy in exports should not be included as domestic consumption while that in imports should be added in. Using this correction shows Canada, for example, to be a net exporter of embodied CO_2 emissions — and therefore of embodied energy — as a result of its international trade.[19] The Ecological Footprint applications described here are corrected for import-export balances only for the primary products of the forestry, agriculture and commercial energy sectors. For all

Table 3.4: Comparing people's average consumption in the US, Canada, India and the world[17]

Consumption per person in 1991	Canada	USA	India	World
CO_2 emission [in tonnes per yr]	15.2	19.5	0.81	4.2
Purchasing Power [in $ US]	19,320	22,130	1,150	3,800
Vehicles per 100 persons	46	57	0.2	10
Paper consumption [in kilograms/yr]	247	317	2	44
Fossil energy use [in Gigajoules/yr]	250 (234)	287	5	56
Fresh water withdrawal [in m^3 /yr]	1,688	1,868	612	644
Ecological Footprint [ha./person]	**4.3**	**5.1**	**0.4**	**1.8**

other sectors, such as manufacturing and service industries, ecologically balanced trade is assumed: the embodied energy and resources in exports is assumed to be equal to that in imports. A more in-depth analysis, however, would be fully corrected for any ecological trade imbalance (Footprint of imports minus Footprint of exports), data permitting.

The second step in Ecological Footprint analysis involves converting consumption to a corresponding land area for each consumption category. This requires that we know the ecological productivity for each land-use category. We use trade and productivity figures compiled by the UN Food and Agriculture Organization (FAO) to determine global average productivity for croplands. The productivity and carrying capacity of pasturelands was estimated from agricultural handbooks. Average forest productivity was set at 2.3 cubic metres of usable wood fibre per hectare per year. This corresponds to the average productivity of temperate Canadian forests,[20] and is also close to the 2 cubic metres per hectare per year used by the Dutch *Friends of the Earth* for analyzing global carrying capacity constraints.[21] As discussed above, we account for CO_2 sequestration from the burning of fossil fuel at a land-for-energy ratio of one hectare per 100 gigajoules. (To date we do not include the absorption land requirements of other forms of waste and pollution. Our EF calculations therefore underestimate the actual land demand of the consumption cycle.) Sample estimates of land "consumption" by Canadians are provided in Box 3.3.

As noted, the figures in Table 3.3 show the land areas required to provide the current lifestyle of an average Canadian. Thus, if we read across row *"43-books/magazines"* to the *"F-FOREST"* column, we find that 0.1 hectare of forest land are required to produce his/her reading materials. In addition, the embodied energy land associated with books and magazines is 0.06 hectare. This means that on average 0.16 hectare of land is required continuously to produce the fibre for each Canadian's newsprint consumption. The bottom